Cardiorespiratory fitness in contemporary dance training and performance.

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Declaration

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Abstract

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This PhD thesis presents a thorough investigation of the relevance and importance of cardiorespiratory fitness in contemporary dance training and performance. Through an initial introduction and literature review, gaps in the current understanding of, and challenges presented by, dance training and performance practices are highlighted, as are five commonly presented conclusions of previous research. Firstly, it is often stated that dance activity predominantly consists of intermittent work periods of varying intensities, secondly that significant differences exist in the cardiorespiratory demands of class, rehearsal, and performance, thirdly that class and rehearsal intensity is insufficient to elicit an aerobic training response, fourth that the aerobic capacity of dancers is relatively low, and, lastly that high injury rates in dancers are often attributed to fatigue and overwork. However methodological limitations of previous research put into question the accuracy and validity of these statements. In order to develop understanding and overcome some of these limitations, five research studies were designed as extensions and enhancements of previous studies in this area. Three aims of the PhD were stated: 1) to investigate cardiorespiratory demands of contemporary dance performance repertoire, 2) to investigate cardiorespiratory adaptation to contemporary dance training and performance, and 3) to critically appraise methods commonly used in physiological investigation into dance and propose recommendations for future research. The main findings are that cardiorespiratory adaptation in relation to dance training and performance is highly specific and only detected through relative change in the demand of dance activity itself. Findings suggest that measures of cardiorespiratory fitness related to aerobic capacity (VO_{2peak}) and anaerobic threshold do not change over time and are not correlated to dance performance competence. It is emphasised throughout that current methodological limitations restrict our ability to accurately document the relative cardiorespiratory demands of dance performance and change in these across a period of extended training and/or performance. The highly varied nature of contemporary dance performance is discussed throughout, including fluctuations in demand experienced by individuals, and it is emphasised that this needs to be taken into consideration in future research. Potential implications of findings from the perspective of both the researcher and the dance educator are postulated as are the contributions made to the knowledge base.

1. Introduction

This thesis presents an examination of cardiorespiratory fitness in contemporary dance and, through a series of five studies, addresses aspects such as the fitness levels of vocational students, the demands of varied performance repertoire, and adaptation to training and performance.

The purpose of this initial chapter is to outline the theoretical and contextual basis for the thesis. The specific dance context examined throughout this thesis is vocational contemporary dance training in the United Kingdom, with the majority of participants in the presented studies being recruited from one specialist training institution. Therefore, this chapter begins with a brief historical account of the development of contemporary dance, leading to an outline of present day training, choreographic, and performance practices. The emergence of dance science as a field of academic study is also discussed before then introducing key physiological concepts and ideas, which form the basis for examining the body's response to movement. Relevant literature is cited and discussed throughout; however, an in-depth critical literature review of studies specifically examining the cardiorespiratory demands of dance activity is included in chapter 2. The purpose of literature included in this chapter is to illustrate the key themes for further discussion and examination throughout the thesis.

1.1. History and Development of Contemporary Dance

Through examination of the historical roots and development of contemporary dance it is possible to explain diverse features of techniques, styles, and choreography as seen today and, therefore, provide important context for the thesis.

Contemporary dance, interchangeably referred to as modern dance, is often explained in terms of its difference to the specific stylistic principles, movement approach, and narrative of classical ballet. Balletic movement developed over 300 years of work by teachers and dancers, where the attitude of the ballet dancer's body is one of formal correctness.

"Ballet is a formal classical style of dance, and modern dance is expressionistic in its thrust. Where ballet movement begins and ends in one of the five positions of the feet which have become the basis of ballet dancing, modern dance does not recognize the convention of only five positions. It asserts that there are as many positions as are needed by the artist to create his effects. In this sense modern dance is revolutionary by definition… Modern dance is more

receptive to the possibilities of unorthodox movement because of this basic attitude" (McDonagh, 1970, p.1-2).

Early origins of contemporary dance can be traced back to teachings of 19th century European cognitive and movement theorists. For example, Francois Delsarte's concerns with "concepts of tension-relaxation, form, force, design, and concentric (towards centre) and eccentric (from centre) movements provided a unique and still serviceable focus for creating and studying movement outside of the ballet vocabulary" (Strauss & Nadel, 2012, p.1). Further theoretical work by Rudolf Laban in the early 1900's regarding conceptual analysis of movement in space and time, laid the foundations of the characteristics of modern and contemporary dance we still see today, inspiring dance artists and choreographers to expand their notions of motion and space (Strauss & Nadel, 2012).

Notable early dance artists such as Isadora Duncan and Loie Fuller began to perform work that fell outside of the expected conventions of dance at the time. Isadora Duncan (1877-1927), noted as a revolutionary, created and performed work on the basis of valuing expression more than technique and form (Strauss & Nadel, 2012), rejecting the codified classical forms of dance. At a similar time Les Ballet Russes, formed by Serge Diaghilev in 1909, was noted for its move from purely classical ballet, urging a more complete theatrical art form incorporating music, design and choreography in new and ground-breaking ways (Strauss & Nadel, 2012). The continued growth of modern dance within the United States in the early twentieth century is often linked to individuals including Ruth St. Denis and Ted Shawn and their formation of the Denishawn School and Company in 1915, which attracted students such as Martha Graham, Doris Humphrey, and Charles Weidman (McDonagh, 1970). These students became recognised as the next generation of modern dance pioneers. This second generation developed new techniques, which are taught today in conservatoire and university settings, and are referred to by McDonagh (1970) as "The Founders".

"Each of the choreographers of the modern dance family strove to find the logical basis for developing a vocabulary of dance movement that was based on some natural body rhythm… all agreed that the fundamental process of dance movement had to be examined in order to find a logical and honest base so that each choreographer could create meaningful dancer works… so each set out to create the style that most perfectly suited individual creative needs." (McDonagh, 1970, p.48-49).

These basic principles varied between choreographers, for example Martha Graham focused on the basic breathing of the body and its contraction and release, while Doris Humphrey investigated the transitional state of human movement between disequilibrium and equilibrium. Given that the early origins of contemporary dance were grounded in a rejection of codified dance techniques, the development of these choreographer-specific techniques presents an interesting paradox. However, this practice continued to inspire the work of future noted choreographers in the creation of further contemporary dance techniques. This included the work of Merce Cunningham, who is often considered the father of postmodern dance (Strauss & Nadel, 2012). Cunningham's approach to movement creation incorporated chance and randomness taking away from the idea of set structure and atmosphere (Strauss & Nadel, 2012), although the development of his technique since initial explorations has also become codified into a recognised set of exercises.

Contemporary dance within the United Kingdom did not really find its roots until the 1960's, when individuals such as Steve Paxton, who had been to the United States to train under the noted choreographers mentioned above, returned home. The establishment of the London School of Contemporary Dance and transformation of Ballet Rambert from a classical company to a contemporary dance company in the late 1960's paved the way for contemporary dance to be viewed as an established and professional alternative to ballet (Jordan, 1992). As a result of this recognition, British contemporary dance began to develop its own leaders, such as Richard Alston, Siobhan Davies, Rosemary Butcher, and Michael Clark, who all made their impression on the development of the art form in the United Kingdom.

It is of note that, as a style or genre of dance, the history and development of contemporary dance is anchored in the works of individual artists and choreographers, such as those cited above. McDonagh (1970) notes that "the technique did not exist completely formed before the dance designer began to create a dance" (p.2), highlighting that each of the most commonly noted choreographers explored movement in a deeply personal way relevant to the expression of their individual creative ideas. Strauss and Nadel (2012) somewhat agree with this statement noting that, irrespective of the techniques used, the similarity amongst modern and post-modern works lies in the notion of an individual's right to create whatever she or he wishes. Contemporary dance could, therefore, be suggested to be less of a dance technique and more of a means of individual expression, allowing freedom, inspired by, but not necessarily following, previous stylised movement examples. Early 'modern' dancers were rebelling against more codified and classical art forms, and post-modern dancers found their own rebellion against that of the early modern practices (Strauss & Nadel, 2012). This analysis of contemporary dance speaks to its ever-evolving nature.

“Perhaps by the very definition of terms, “modern” and “contemporary” are supposed to keep transforming themselves, continually evolving as we move further and further into the 21st century though endless experimentations, rejections, and groundbreakings.” (Strauss & Nadel, 2012, xiv)

In relation to this described ‘nature’ of contemporary dance, there exists a huge variety within the contemporary dance repertoire performed today. A range of physical, emotional, and artistic skills are required for a virtuosic contemporary dancer to have a successful career, which presents a challenge in delivering effective training.

1.1.1. Current training practices

Current training in contemporary dance, in the United Kingdom, benefits from a formal structure, guiding individuals from pre-vocational, through vocational, and into professional settings.

Training for school age children has typically taken place in either specialist (often boarding) schools or as recreational training in local, grassroots dance schools. The specialist boarding dance schools tend to focus on classical ballet advocating the importance of early intensive training for a professional career in ballet. However, the formation of a pre-vocational, elite level, professional dance training scheme - Centres for Advanced Training (CAT), in 2004, provided an opportunity for young people to study contemporary dance at a high level on a part-time basis. Training on the CAT scheme is delivered predominantly at weekends and during school holidays, allowing normal schooling to take place alongside.

The UK benefits from multiple high level vocational contemporary dance training institutions with notable history and influence over the continued development of the art form. For example, London Contemporary Dance School, Northern School of Contemporary Dance, Rambert School of Ballet and Contemporary Dance, and Trinity Laban Conservatoire of Music and Dance. Typically, these institutions offer three-year Undergraduate degree programmes, which focus on the development of technical, choreographic, and performance skills alongside academic study. As is common within all dance training, teaching methods are steeped in tradition and often most heavily influenced by the personal experiences and prior training of the teaching and/or management staff. Ballet remains a fundamental technique taught across contemporary training institutions viewed as essentially useful as a foundation upon which the technique of contemporary dance, in all its styles, can be built (Strauss & Nadel, 2012). Most typically, training also centres on establishing technical proficiency in Release-based, Cunningham, and Graham techniques, and additionally other styles such as Limon. Throughout this technical training there remains a heavy emphasis on student autonomy and creativity, embracing the principles of contemporary dance as outlined above.

In more recent years training has been influenced by movement and exercise sciences, with education for student dancers on how to look after their bodies and minds, in training and their future careers delivered as a core part of degree programmes. Typically, this is delivered in an academic format giving students a basic understanding of anatomy and injury reduction and care. An anecdotal concern does, however, still exist that an overemphasis on technical proficiency, means that there remains a lack provision to develop an appropriate baseline fitness level, which would enable students to cope with the physiological demands being placed upon their bodies during training. This potential gap in provision will be discussed in more depth throughout this chapter and the thesis as a whole.

Vocational schools, as well as some university-based dance programmes, also offer Postgraduate one-year Masters degrees in a range of specialisms, for example choreography and performance. These programmes have led to the development of Postgraduate pre-professional touring companies, embedded within a Masters degree in Performance, the first of which was Transitions Dance Company, founded in 1982 by Bonnie Bird at Trinity Laban (then the Laban Centre). These companies aim to provide students with a platform for experience of professional work, including working with a range of commissioned choreographers and touring work, in order to aid their transition into the wider professional dance sector.

1.1.2. Current professional practices

Training can often continue into a contemporary dancer’s professional career. With very few established, company-based, full-time contracts available, the majority of work in the professional contemporary dance sector continues to be through independent, project-based opportunities. This format of professional work requires constantly evolving virtuosic dance skills. The parameters of contemporary dance performance are constantly expanding and increasingly incorporate other physical practices, including other dance styles and wider practices such as acrobatics and voice work. This requires professional dancers to continue to seek further (and increasingly diverse) training throughout their careers as well as remain physically and mentally robust to cope with these continually developing demands. In addition, the development of new repertoire for performance is often created in collaboration with the dancers throughout a rehearsal period and it is not uncommon for material to be continually developing and changing up to opening night, or even in some cases once a performance run has commenced. This process makes appropriate physiological preparation of the dancers, for the specific physical demands of the piece, extremely difficult.

1.1.3. Workload

Throughout all levels of dance training and performance, concerns are often raised regarding the high volume of work undertaken. Available research documenting typical working hours and the specific activities undertaken in both student and professional dancer populations enables an overview of the typical workload experienced.

Over the course of 3-4 years of training, student dancers typically engage in training for around eight hours per day, five days per week. Training days typically include around three hours of technique class, additional choreography and academic classes, and, at certain times of the year, concentrated periods of rehearsals in preparation for performances and exams. Bronner, Codman, Hash-Campbell, and Ojofeitimi (2016) reported students on a university dance programme spending between 16.5 and 21 hours per week in technique class and 3-6 hours per week towards the end of the semester in rehearsal and performance. Professional dancers on the other hand are documented as dancing for 6-10 hours per day 5-7 days per week (Wyon, 2010) and spending much more time in rehearsal and performance, often completing just one technique class in the morning. Bronner et al. (2016) reported professional contemporary dancers spending 7.5 hours per week in class and around 30 hours per week in rehearsal or performance. Similarly, the working day of professional ballet dancers has been documented as beginning with a 90 minute class followed by spending the rest of the day in rehearsals (Twitchett, Angioi, Koutedakis, & Wyon, 2010). Performance frequency across a range of dance genres can be as high as eight shows per week for continuous periods of four to eight weeks (Wyon, 2010). Ojofeitimi and Bronner (2011) reported that over an eight-year period, a professional contemporary dance company spent 24 ±6 weeks per year undertaking national and international touring and performances.

High workloads such as these, documented across student and professional dance in a variety of genres, raises concern around the limited rest time afforded. A study by Twitchett et al. (2010)

documented daily rest time in a professional ballet company and noted that 90% of dancers had less than 60 minutes consecutive rest in a work day, with 33.3% of the dancers having less than 20 minutes. Examination of the workload and intensity of work in these ballet dancers revealed significant differences between ranks (principles, soloists, first artists, corps de ballet), with a significantly greater mean exercise intensity in soloists compared to other ranks (Twitchett et al., 2010). However, all were noted to have insufficient rest time throughout the day (Twitchett et al., 2010).

High training volumes, such as those suggested in the studies outlined above, with limited rest and recovery time built in to schedules can have negative outcomes such as symptoms of overtraining and burnout in the long term (Koutedakis, 2000). Limited research has examined this within dance; however, one study by Koutedakis et al., (1999) found improved fitness levels (maximal oxygen uptake and peak anaerobic power) after six weeks of rest compared to pre-break data collected in professional ballet dancers at the end of a performance season. This study, therefore, suggested that a degree of burnout was experienced at the end of the season.

As briefly outlined above, there are many challenges presented by current contemporary dance training and performance practices to the continued health and wellbeing of dancers. In particular, the ability of a dancer to be physically prepared to cope with the varied physical demands they will likely face from diverse repertoire in their professional careers. Primary challenges to this preparation lie not only in the adequacy of vocational training programmes, but also in rehearsal and performance practices as stated above. The potential for integration of dance science into these practices in order to address some of these challenges and aid in keeping dancers fit and healthy has gained increasing traction over the past 30 years, as will now be discussed.

1.2. History and Development of Dance Science

Scientific enquiry into physical activity has long been undertaken and has grown into a broad and multidisciplinary field of academic study, research, and enterprise. Current day elite sports performance, in particular, benefits from a fundamental integration of sports science in many aspects of training and performance development. Sir Alex Ferguson previously stated, "*Sports science, without question, is the biggest & most important change in my lifetime*" (Ingle, 2014).

Dance science in contrast is a younger field and has not yet reached the same level of recognition from the wider dance industry. Dance science typically focuses on the application of three main disciplines: physiology, biomechanics, and psychology. A review by Krasnow and Kabbani (1999), highlighted nine classifications of research topic examined by previous dance specific literature, namely, injury incidence, conditioning testing, nutrition, body composition and menstrual dysfunction, psychological and psychosocial factors, biomechanical mechanisms, training enhancement, measurement tools, collections, and other areas of study. McCabe, Wyon, Ambegaonkar, and Redding (2013) similarly classified research undertaken specifically in DanceSport as focusing on participation motives, psychology, exercise physiology, fitness testing, injury and injury prevention, biomechanics, menstrual dysfunction, and substance use. These classifications demonstrate the continued multidisciplinary nature of dance science research that has been conducted over the past 30 years. It is also important to highlight that dance itself is a broad term relating to different dance genres as well as between different levels of dance practice (broadly separated into student and professional levels), as is the case with sport.

Dance science dates back to the 1970's, where individuals largely working within sports and exercise medicine and science were noted as also working with dancers, long before the recognition of dance science as an established field of academic pursuit. For example, in the case of medical professionals providing injury care to elite professional dancers, William G. Hamilton, MD, recognised as one of the founders of dance medicine and science, was invited by George Balanchine in 1972 to become the orthopaedist for the New York City Ballet and School of American Ballet. Also during the 1970's, the first peer-reviewed research studies with a focus on dance specific populations were published, initially with a focus on flexibility and physiology and later in mid-1980's expanding to include examination of psychology and injury concerns for dancers (Cohen, Gupta, Lichstein, & Chadda, 1980; Grahame & Jenkins, 1972; Novak, Magill, & Schutte, 1978). The incorporation of the International Association for Dance Medicine & Science (IADMS) in 1990 marked a notable point in the development of dance science as a serious field in its own right. IADMS aimed to bring together individuals working with dancers throughout the world, and today has a membership of over 1,000 members from over 35 countries working in different disciplines (clinicians, medical practitioners, dance educators, dancers, academics, researchers) and at different levels of dance engagement. The mission statement of IADMS, echoing the broader aims of dance medicine and science, states that, "IADMS enhances the health, well-being, training and performance of dancers by cultivating educational, medical, and scientific excellence." (www.iadms.org).

Parallel to these international developments, in 1990, the first Healthier Dancer Conference was hosted by Dance UK[1] in the United Kingdom. This lead to the establishment of Dance UK's Healthier Dancer Programme, which has continued to the present day, with the aim of bringing health and wellbeing concerns of dancers to the forefront of the dance industry in the UK. This early advocacy work led to a 1993 UK-wide national enquiry into dancer health, *Fit to Dance*, published in 1996 (Brinson & Dick, 1996). The survey provided a picture of the health and wellbeing status of dancers in the UK, highlighting key concerns for the sector. Participants who responded to this survey included 658 dancers, working in various genres of dance (contemporary, ballet, jazz, South-Asian, tap, etc.) at professional and student level. The commonly cited, key findings of this survey related to injury incidence, with over 80% of dancers self-reporting at least one injury in the prior 12-month period; only 37% of dancers seeking medical treatment for suspected injuries, and fatigue/ overwork being cited as the most commonly (<50%) perceived cause of injury (Brinson & Dick, 1996). Other key findings included a high prevalence of psychological problems and very few dancers reporting conducting an appropriate cool down following performance (range 11-23%) (Brinson & Dick, 1996). A follow up survey conducted in 2002, published in 2006 (*Fit to Dance 2*; Laws, 2006), demonstrated overall that limited progress had been made in the industry. A larger sample size of 1056 dancers was achieved in the 2002 survey; the result of a greater percentage of student respondents than in 1993. Injury rates remained above 80%, with fatigue and overwork still cited as the most commonly perceived cause; however, a greater proportion of respondents did state that they would seek medical treatment if they suspected an injury (60% compared to 37% in 1993) (Laws, 2006). Psychological problems were still prevalent, with 92% of respondents reporting at least one psychological problem in the prior 12-month period. Improvements were reported in cool-down statistics, with a range of ~15-48% of respondents reporting cool-down following performance, and in smoking prevalence, with a percentage reduction of 15% in female and 12% in male smokers (Laws, 2006).

In summary, these early studies made it clear that there were concerns around dancers' health and wellbeing, which led to a number of initiatives attempting to address these concerns, including education in dance science, better healthcare provision for professional dancers, and the undertaking of further research.

[1] On April 1 2016 Dance UK merged with the Association of Dance of the African Diaspora, the National Dance Teachers Association, and Youth Dance England to form One Dance UK. The Healthier Dancer Programme remains a key part of the wider work of One Dance UK, as the industry body for dance, in supporting a stronger, more vibrant, more diverse future for dance.

1.2.1. Where we are today

Now, another decade on from the last national enquiry, it seems pertinent to once again assess the level of progress made. In the absence of directly comparable data, it is of interest to examine the developments in vocational and professional dance settings, where some progress in the integration of dance medicine and science has occurred. As an example of integration within vocational training, Trinity Laban Conservatoire of Music and Dance has an established dance science department, in existence since its development of the first Master's degree in dance science in 2001. The department, however, is still developing and exploring avenues for effective integration with the technical and performance aspects of the training of dance students at undergraduate and postgraduate level. This quest has seen developments such as an on-site conditioning studio, on-site injury care, health modules embedded within the undergraduate and one-year foundation programmes, a student screening programme, and encouragement to participate in dance science research. Many vocational training institutions worldwide mirror these developments. One particular example is the vocational school ArtEZ in The Netherlands, where a radical shift in training approach and schedule has been implemented as a response to common training practices in sports and developed around the principles of training and the concept of periodization (Wyon, Brown, & Vos, 2014). Within this training approach the focus is systematically placed upon quality of training rather than quantity, with important emphasis placed upon integration of rest and recovery and distributed practice specific to particular learning objectives (Bompa & Haff, 2009). Educational dance science programmes also now exist internationally, with four Masters degree programmes available in the UK at Trinity Laban, the University of Wolverhampton, the University of Bedfordshire, and Edinburgh University.

Within the professional dance industry, large national ballet companies have the most provision for the health and well being of their dancers. In the United Kingdom, English National Ballet first began integrating supplemental fitness training for its dancers in 1996 in response to research findings, which recommend supplementary conditioning. Birmingham Royal Ballet opened its Jerwood Centre for the prevention and treatment of dance injuries in 2002. Today, ballet companies have large in-house healthcare teams, for example 'Ballet Healthcare' at the Royal Ballet Company currently employs a clinical director, Pilates practitioners, Physiotherapists, massage therapists, strength and conditioning coaches, sports scientists (on a consultancy basis), nutritionists, and a psychologist. Screening, workload tracking, and injury tracking programmes also typically run alongside this provision. Internationally, companies such as The Australian Ballet, American Ballet Theatre, and New York City Ballet (to name a few) mirror these developments. However, outside of these large companies, health and injury care provision seems to have remained somewhat limited. Mid-sized contemporary dance companies do not typically hire medical practitioners or health support staff, although Company Wayne McGregor recently employed a director of dancer health. Instead these companies often have a referral network of private freelance practitioners who they send their dancers to in the event of an injury and occasionally, although rarely, offer health insurance schemes as part of a contract of employment.

The number and effectiveness of organisations dedicated to dance medicine and science existing internationally has also grown, with key examples (other than those mentioned above) being the British Association for Performing Arts Medicine (UK; est. 1984), Performing Arts Medicine Association (USA; est. 1989), Tanzmedizin Deutschland e. V (TaMed) (Germany; est. 1997), Australian Society for Performing Arts Healthcare (ASPAH) (Australia; est. 2006), National Institute of Dance Medicine and Science (UK; est. 2012), Healthy Dancer Canada (Canada; est. 2012), and National Centre Performing Arts (The Netherlands; est. 2014). Specialised academic journals such as the Journal of Dance Medicine and Science, and Medical Problems of Performing Artists, and annual international conferences reach out to an established, specialised dance medicine and science research community.

While dance science is undeniably developing as a field of research and study it is still striving for successful integration into all levels of dance practice and often faces resistance from the sector. The place of science within dance training and performance could be argued to sit outside of the artistic components of dance; however, it should not and does not aim to interfere in artistry or creativity, but rather aims to support and optimise the mind and body of the dancer to enable open artistic expression without barriers. Increased traction has been given to the open discussion of dancer health and wellbeing concerns in recent years through increased media coverage. For example, a recent article in the *Observer* featured an open call for "companies to nurture dancers, rather than pressing them to remain thin while pushing themselves to physically dangerous levels" from Russian Prima Ballerina Irina Kolesnikova (Alberge, 2016). Speaking at the 2015 Dance UK conference under the title 'The future: new ideas, new inspirations', Dr Christopher Bannerman spoke of *"seismic"* challenges presented to traditional dance training by dance science stating

"We are slightly afraid in dance perhaps about the application of science… it doesn't mean we are not an art from, quite we need to have the confidence to include science in our understanding… has the ability to really influence profoundly dance training and perhaps answer

some questions about how we are going to continue to respond to the challenges presented to us…" (Bannerman, 2015, 24 min 30 s to 25 mins 25 s)

A key area of dance science investigation and its application to dance practice is exercise physiology, primarily with regard for the examination of fitness levels of dancers and the physiological demands faced when undertaking various dance activities. Redding and Wyon (2003) stated that in order to understand the ideal physiological characteristics for dancers, we need to carefully examine the physiological demands of performance and suggested that this is perhaps just as important as skill development in order to continue the progression of the art form. As the central theme for research undertaken in this thesis, the following section will describe the cardiorespiratory response to exercise and draw links to the response to dance activity in particular.

1.3. Cardiorespiratory Response to Exercise

The aim of this section is to examine key aspects of the cardiorespiratory response, starting with the energy systems used in muscle metabolism and then further examining concepts relating to the complexity of these systems in the dynamic energy continuum. The onset of exercise of any type, intensity, or duration elicits a physiological response. Specific cardiac and respiratory elements of the body's response at the onset of exercise are often examined separately; however, the integration of these enables cardiovascular and ventilatory systems to couple their behaviours to support common function and meet the increased respiratory demands of contracting muscle (Wasserman et al., 2011). Features of this coupled response influence an individual's ability to complete exercise/ movement of a particular intensity and duration. Dance activity, in its varied forms, relies upon such responses to enable continued muscular contraction through what could be described as highly complex and dynamic movement. Powerful movements such as jumps and lifts are often interspersed with lower intensity transitional movement over a sustained period of time. Previous research has, therefore, classified dance as an intermittent exercise form, requiring use of aerobic and anaerobic energy systems interchangeably (Redding & Wyon, 2003). The various physiological mechanisms underlying the dynamic use of these systems are outlined throughout this section and the potential implications for the body's response to dance activity are specifically postulated throughout.

1.3.1. Skeletal muscle fibre types

Firstly, it is of interest to understand the contractile properties of human skeletal muscle, which is typically classified into two basic categories of fibre type based upon their contraction speed, slow-twitch (type I) and fast-twitch (type II). Slow-twitch, type I, fibres are characterised as such due to their slow contractile potential and largely oxidative biochemical composition. Fast-twitch fibres are further characterised as type IIa, IIb, and more recently, additionally, IIx, on the basis of their oxidative and/or glycolytic capacity. The key features of each muscle fibre type and differences between these are highlighted in Table 1.1.

Table 1.1. Key characteristics of muscle fibre types (adapted from McArdle, Katch, & Katch, 2010, p.371; Wasserman et al., 2011, p.10)

	Slow Oxidative (type I)	**Fast Oxidative (type IIa)**	**Fast Oxidative-Glycolytic (type IIx)**	**Fast Glycolytic (type IIb)**
Motor neuron/ Fibre size	Small	Intermediate	Large	Very Large
Myoglobin concentration	High	High	Intermediate	Low
Mitochondrial density	High	High	Intermediate	Low
Capillary density	High	Intermediate	Low	Low
Major storage fuel	Triacylglycerol	PCr, glycogen	PCr, glycogen	PCr, glycogen
Myosin ATPase activity	Low	Intermediate	High	High
Time to peak tension	~80msec	~30msec	~30msec	~30msec
Resistance to fatigue	High	Fairly high	Intermediate	Low

The ratio of type I to type II (a,b,x) muscle fibres in an individual body is largely genetically determined, although limited histochemical adaptations with training have been shown regarding alterations in enzyme activity (McArdle et al., 2010). Fibre type ratio can vary throughout different muscles/ muscle groups in the body and certain ratios have been linked to superior performance in specific physical pursuits. For example, elite endurance athletes have been found to demonstrate up to 90% type I fibres in the vastus lateralis muscle, compared to around 50% in untrained controls and 20-30% elite sprinters (Wasserman et al., 2011). As well as the ratio, the pattern of activation for various fibre types in areas of the body varies and is largely determined by specific characteristics of the exercise. For intermittent field (stop-and-go or change-of-pace) sports, such as soccer and field hockey, it is suggested that activation of fast-twitch fibres plays an important role (McArdle et al., 2010, p.371). One study by Dahlstrom, Esbjörnsson Liljedahl, Gierup, Kaijser, & Jansson (1997) did undertake vastus lateralis muscle biopsy on 10 year old and 20 year old male and female dancers and reported higher percentage type I fibres than measured in age-matched controls. However, overall very little previous research has considered the implications of fibre type composition and/or activation patterns on success in dance activity or considered what may be an optimal fibre type ratio for elite performance success in dance. It is perhaps more relevant to examine the function of muscle metabolism in providing energy for muscular contraction throughout activity, as outlined below, in order to understand the basis for the body's response to dance movement.

1.3.2. Muscle metabolism/ energy systems

Adenosine triphosphate (ATP) is a high-energy phosphate compound, which acts as the 'energy-transfer agent' for biologic and cellular work (McArdle et al., 2010). The hydrolysis of a phosphate bond within an ATP molecule, forming adenosine diphosphate (ADP), releases a phosphate ion and approximately 7.3 KCal of free energy, which subsequently stimulates the contractile potential of muscle fibres (McArdle et al., 2010). Human muscle contains limited stores of ATP, which are maintained through re-synthesis of ATP from ADP (or AMP) by anaerobic and aerobic energy systems on the basis of phosphocreatine (PCr) and/or glucose catabolism in the muscle cell's cytosol and mitochondria. The system predominantly used depends upon factors such as speed of ATP depletion and oxygen availability at the cellular level. ATP concentration has a large dynamic range (100-fold) in order to cope with a large spectrum of fluctuating demand dependent upon features of the activity being undertaken. As previously stated, dance has been classified by available literature as an intermittent exercise form, requiring use of aerobic and anaerobic energy systems interchangeably (Redding & Wyon, 2003). In reality, as is likely in dance, all energy systems work simultaneously, although in different proportions during activity, to maintain ATP homeostasis and meet energetic demands for muscular contraction. The characteristics of the exercise bout being undertaken will stress the systems differently at different times, with the efficiency of each system, as related to the individual's fitness level, determining the ability to successfully complete the work. The efficiency with which an individual is able to re-synthesise ATP is determined by a number of rate limiting steps within the biochemical processes of muscle metabolism. Factors such as enzyme concentration and activity, glucose metabolism, oxygen utilisation, and the transport (and, therefore, availability) of oxygen and glucose to the muscle cells (McArdle et al., 2010) are all suggested as important rate limiting steps. Sutton (1992) states that a reduction in oxygen delivery will result in a reduction in oxygen uptake and utilisation by muscle tissue; therefore, suggesting transport may be the most important step. However, Poole and Jones (2011) dispute this, stating that the dynamics of pulmonary and cardiovascular (including muscle microvascular) systems act as fast, or even faster, than the increase in uptake of oxygen by muscle cells can occur. Whether primarily limited by transport or uptake, oxygen availability at the muscle tissue level is an important determinant of the rate of ATP re-synthesis, which itself is the primary determinant of energy system usage. Each system of ATP replenishment is further outlined below.

1.3.2.1. Anaerobic systems

There are two pathways for re-synthesis of ATP under anaerobic conditions (i.e. in the absence of oxygen): the ATP-PCr system and the anaerobic glycolytic system. Both anaerobic systems are linked to fast depletion of ATP and high levels of ADP and AMP and, therefore, shorter duration movement/ exercise.

The ATP-PCr system serves as a quick reserve for immediate increase in energetic requirement and can sustain skeletal muscle contraction for around 10 seconds (McArdle et al., 2010). In this simple system, breakdown of a PCr molecule supplies a phosphate ion for resynthesis of ATP from ADP. In contrast, the anaerobic glycolytic system involves a series of chemical reactions enabling the catabolism of glucose to produce pyruvate, throughout which 2 ATP molecules are synthesised and hydrogen and NADH (nicotinamide adenine dinucleotide) are released. Following glycolysis, in anaerobic conditions, pyruvate binds temporarily with excess hydrogen released from NADH to form lactate. Lactate production was traditionally thought to result from tissue hypoxia; however, it is now believed to be linked to an imbalance in the NAD+/NADH ratio and the impact of this upon hydrogen concentration, where hydrogen concentration exceeds the cell's capacity for uptake to the electron transport chain (ETC) (McArdle et al., 2010). Other factors such as lactate dehydrogenase enzyme activity also influence the rate of lactate production, with higher levels found in fast twitch muscle fibres (McArdle et al., 2010). Lactate is frequently anecdotally linked to peripheral fatigue through an assumption of accumulation causing intracellular acidosis; however, this assumption has been questioned more recently (Westerblad, Allen, & Lännergren, 2002). Following its production, lactate can be fully oxidised in the muscle cells to reform pyruvate, which can be used for further metabolism, or in the liver to form glycogen via glyconeogenesis, which can then be made available at the mitochondrial level for further glycolysis (McArdle et al., 2010). At exercise intensities below 50% of maximal aerobic capacity the rate of lactate oxidation meets the rate of production (Spurway & Jones, 2006); however, at intensities above this production rates exceed oxidation rates and lactate concentration exponentially increases with increased workload. This point is often referred to as a threshold, which will be further examined later in this chapter.

1.3.2.2. Aerobic system

The aerobic energy system consists of a number of steps resulting in the full oxidation of glucose, glycogen or tiacylglycerol. The first step is glycolysis, as in anaerobic conditions; however, in aerobic conditions (i.e. in the presence of oxygen) pyruvate is converted to acetyl-CoA rather than lactate. Acetyl-CoA then enters the citric acid cycle, resulting in further catabolism, releasing of hydrogen and carbon dioxide (CO_2), and the synthesis of further ATP. Hydrogen released by prior processes then enters the ETC where it is transported by NADH and $FADH_2$, leading to further synthesis of ATP. Overall, aerobic metabolism results in a higher ATP yield of 36 ATP per glucose molecule undergoing full oxidation and 37 ATP per glycogen molecule (Wasserman et al., 2011). Due to this higher yield the aerobic energy system has greater capacity to fuel sustained muscular contraction over longer duration activity.

1.3.3. Cardiovascular response

The response of the cardiovascular system to the onset of exercise is primarily related to an increased drive for transport and delivery of oxygen and nutrients via blood to the muscle cells. At exercise onset energy demand in the muscle cells raises immediately but increased blood supply to the muscle takes several minutes and is dependent upon increased cardiac output and reduced blood flow (vasoconstriction) to other organs (Newsholme & Leech, 1984, p.216).

Cardiac output is defined as “the amount of blood pumped by the heart during a 1-minute period” (McArdle et al., 2010, p.314). The maximal value of cardiac output represents the upper limit of the cardiovascular system. Cardiac output is influenced by heart rate (rate of pumping) and stroke volume (quantity of blood ejected with each pump), both of which increase from neural stimulation of the sympathetic nervous system at the onset of exercise (McArdle et al., 2010). Simultaneously to this cardiac response, modulation of vascular dilation (widening) and constriction (narrowing) optimises blood flow to areas in need (i.e. active muscle tissue) while maintaining blood pressure throughout the arterial system in proportion to exercise severity (McArdle et al., 2010). At maximal exercise intensities muscle tissue can experience up to a 10-fold increase from resting blood flow levels. A combination of these two factors at cardiac and vascular levels results in a higher blood flow through the working muscle and, therefore, a higher concentration of available substrates for metabolism. This drive for increased blood flow is further explained through examination of pulmonary and ventilatory response to exercise and outlined below.

1.3.4. Pulmonary ventilation and respiratory response

The rate at which ATP can be generated by oxidative processes is limited by the availability of oxygen in the muscle fibres (Newsholme & Leech, 1984, p.217), beyond the small stores held within muscle myoglobin. Oxygen transport has traditionally been suggested as the main limiting factor to this process; however, more recently it has been proposed that oxygen uptake by the working muscle tissue is the main limiting factor, where the speed at onset is likely to be limited by intramuscular processes and mitochondria (Poole & Jones, 2011). Oxygen utilisation at the cellular level is effected by elements such as mitochondrial density and related capacity for oxygen extraction from blood haemoglobin (as represented by the difference in oxygen concentration between arterial and mixed-venous blood: a-vO_2 difference). At rest, approximately 75% of the blood's oxygen load remains bound to haemoglobin (McArdle et al., 2010, p.349). During exercise, a-vO_2 difference can expand to at least three times resting values (McArdle et al., 2010, p.350). Enzymes such as creatine kinase or any one of the enzymes involved in the oxidative metabolic pathway (e.g. pyruvate dehydrogenase) are also likely to have an impact on the inertia of muscle oxidative metabolism. During this shortfall in oxygen availability at the cellular level, anaerobic metabolism produces excess CO_2 and further drives increased oxygen uptake. Therefore, despite oxygen delivery by the cardiovascular system as explained above, increased pulmonary ventilation to inspire more oxygen and expire CO_2 and the mechanics of oxygen uptake are explained here.

Oxygen uptake response to physical activity has long been documented, with notable seminal works by A.V. Hill in the early 1900's. At the onset of exercise of any type, intensity, or duration there is a neural drive for increased ventilation to facilitate CO_2 removal at rates of rapid increase (Poole & Jones, 2011), as well as to increase oxygen uptake. It is important to note that multiple chemical and neurogenic mechanisms are, however, responsible for the increase in ventilation during exercise, such as partial pressure of oxygen (PO_2) and carbon dioxide (PCO_2) in the alveoli and plasma (peripheral (arterial) chemoreceptor stimulation), increased hydrogen concentrations (from anaerobic metabolism), cortical activation, sensory input from joints, tendons and ligaments (mechanoreceptor stimulation), and temperature changes (McArdle et al., 2010).

For any given activity at steady state, there is an associated oxygen cost, which is not met automatically, giving a transitory metabolic phase. Poole and Jones (2011) suggest that the speed of this transition to required steady state oxygen uptake values (i.e. speed of VO_2 kinetics) is a fundamental parameter of aerobic performance and may help to explain the broad range of physiological capabilities across populations.

1.3.4.1. Oxygen uptake kinetics and oxygen deficit

Oxygen uptake is thought to occur in three stages, as described by the concept of oxygen uptake kinetics (Poole & Jones, 2011). Phase I, termed the cardiodynamic component, consists of an initial increase in oxygen uptake with brief delay. Phase II, the fundamental/primary component, then demonstrates an exponential increase in oxygen uptake up to phase III: steady state (Poole & Jones, 2011). Additionally, at exercise intensities above the lactate threshold ('heavy' and 'severe' in figure 1.1), a developing secondary oxygen uptake elevation is observed (Poole & Jones, 2011).

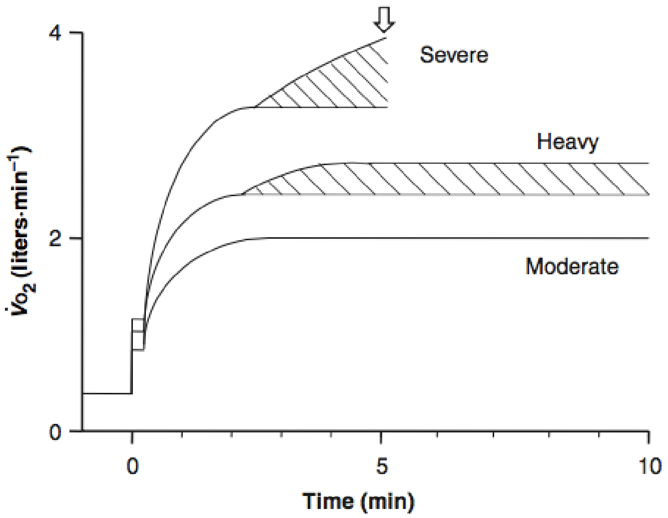

Figure 1.1. Schematic representation of the VO_2 response to constant-work-rate exercise at the moderate, heavy, and severe exercise intensities (taken from Poole & Jones, 2011, p.8).

Although the pattern of oxygen uptake kinetics observed is most crucially dependent upon the exercise-intensity at which the exercise is being performed, exercise modality has also been demonstrated to lead to some variability in oxygen uptake kinetics (Poole & Jones, 2011). Previous research examining this variability is largely confined to response demonstrated while exercising on different ergometers. When reviewed by Poole and Jones (2011) the key findings of this research were highlighted as a faster primary component in running compared to cycling (although research demonstrates mixed evidence), slower uptake kinetics in supine and prone exercise compared to upright exercise, and slower kinetics in arm versus leg exercise. It is also worth noting that the speed of oxygen uptake kinetics is affected by many determining factors such as fibre type recruitment and age of the individual (Poole & Jones, 2011). No previous research is available examining uptake kinetic parameters in dance activity, although given the complexity and variety of activity classed as dance there would be many challenges presented in accurately documenting patterns of uptake. Dance, of any genre, typically involves weight bearing, global whole body movement, with a range of levels and body positions explored (prone, supine, standing) in constant transition at varying exercise intensities. Therefore, in relation to antecedents of variation in oxygen uptake kinetics speed as highlighted by Poole and Jones (2011), a dynamic and highly varied pattern could be hypothesised.

This transient nature of oxygen uptake response results in a shortfall in initial oxygen supply to working muscles, termed the oxygen deficit. The magnitude of oxygen deficit "quantitatively expresses the difference between the total oxygen consumption during exercise and the total that would have been consumed had steady-rate oxygen consumption been achieved from the start" (McArdle et al., 2010, p.165). A larger oxygen deficit for a given activity has been associated with premature fatigue (Poole & Jones, 2011), due to the accompanying increase in lactate and hydrogen, and decrease in PCr from the dominance of immediate anaerobic energy transfer. Therefore, the speed at which the oxygen demand for a given movement task can be met is an important factor in determination of energy pathways used and an individual's ability to efficiently meet the required output, highlighting yet another important consideration for documenting the body's response to dance, and other, movement.

1.3.5. Metabolic threshold concepts

Metabolic threshold concepts are another key concept to address in the examination of the body's response to dynamic, intermittent activity. Many different terms are used to represent and describe a key threshold point in the exercise intensity continuum after which net increases in lactate are observed. A simple definition of this threshold point states that "above a certain exercise intensity muscle cells can neither meet additional energy demands aerobically nor oxidise lactate at its rate of formation" (McArdle et al., 2010, p.164). This represents a metabolic turn-point in the exercise intensity continuum; however, it is important to highlight that a dramatic shift to anaerobic metabolism does not occur after this point. Instead, a progressive increase in work intensity stresses both aerobic and anaerobic metabolism and results in lactate accumulation. Spurway and Jones (2006) stress that lactate production is related to increased NADH concentration in aerobic or anaerobic metabolism and not merely related to tissue hypoxia, as previously highlighted. Due to the complexity of this relationship between simultaneous aerobic and anaerobic metabolism, multiple terms have been used to describe and define markers of threshold points in previous literature and there appears to be no consensus regarding the most appropriate term to use and identifying markers to measure in defining this point in an exercising individual. Each of the most commonly used terms are outlined and discussed below.

Lactate threshold represents the first breakpoint on a blood lactate accumulation curve (Spurway & Jones, 2006), occurring at the highest intensity with less than a 1.0 mmol.L^{-1} increase above blood lactate resting levels (McArdle et al., 2010). Wasserman et al. (2011) defines lactate threshold as the exercise oxygen uptake value (VO_2) above which net increases in lactate production are observed to result in a sustained increase in blood lactate concentration. Lactate threshold is typically determined by capillary blood sampling techniques taken systematically throughout graded exercise. Lactate threshold definition and measurement is recommended by Spurway and Jones (2006) as it semantically represents observable substrate concentration increases instead of assumptions of anaerobic or aerobic production.

The term onset of blood lactate accumulation (OBLA) is intended to represent the minimum work rate at which a rise, rather than a fall, in blood lactate concentration occurs with sustained work at that work rate (Spurway & Jones, 2006). This point is difficult to define in practice and is, therefore, often estimated by the fixed point theory as occuring at a blood lactate concentration of 4 mmol.L^{-1} (McArdle et al., 2010). Maximal lactate steady state (MLSS), in contrast to OBLA, represents the highest work rate at which blood lactate is elevated but stable across time. Although crucial to exercise performance, MLSS is time consuming to establish and is, therefore, also rarely directly measured (Spurway & Jones, 2006).

In contrast to the concepts presented above, anaerobic threshold is typically solely measured via respiratory data. Wasserman et al. (2011) defines anaerobic threshold as the exercise VO_2 above which anaerobically produced high-energy phosphate supplements the aerobically produced phosphate, which is detected by carbon dioxide values (VCO_2) increasing above VO_2 concentrations. Anaerobic threshold appears to be an excellent discriminator of the highest work rate that can be endured for a sustained period (Wasserman et al., 2011). This term, however, was deemed misleading by Spurway and Jones (2006) due to the ability of fully aerobic muscles to produce lactate. However, if referring to a supplementation of aerobic metabolism rather than suggesting a full replacement, it could be argued to stand as a valid term which merely focuses on respiratory exchange parameters rather than lactate production.

Lastly, lactic acidosis threshold is defined by Wasserman et al. (2011) as the exercise VO_2 above which arterial lactic acid buffer (HCO-3) concentration decreases due to net increase in lactate production. Following a net increase in lactate accumulation an acidosis response is produced, whereby VCO_2 accelerates relative to VO_2. This point is, therefore, detected by similar methods to that of anaerobic threshold, using the point at which the VCO_2 versus VO_2 slope exceeds 1 (V.slope method) (Wasserman et al., 2011).

It is worth noting that the terms outlined above are not the only terms used within the literature. A 2009 review by Faude, Kindermann, and Meyer (2009) reported use of 25 different concepts and subsequently grouped these into three categories based upon methodology used to detect the threshold point. Firstly, they identified studies that used fixed blood lactate reference values to detect thresholds during incremental exercise, for example as occurring above 4 $mmol.L^{-1}$; secondly, those identifying the first rise in blood lactate levels above baseline/ resting values; thirdly, methods aiming to detect a distinct change in the inclination of the blood lactate curve (Faude et al., 2009). Definition of the most appropriate terminology to use based upon the method of detection appears to be a suitable means of distinction between the variety of terms presented. This approach was also suggested by Wasserman et al. (2011), who highlight that all concepts describe part of the same physiological phenomenon and that the distinction in terminology is more concerned with the method of measurement rather than the underlying cardiorespiratory and/or metabolic mechanisms.

Based on available data (as examined in depth in the chapter 2), it is likely that the intensity of dance activity, in particular that of dance performance, is similar too, or intermittently exceeds, that at which threshold markers occur (80-90% maximum heart rate), as has been previously documented in soccer match play (Stølen, Chamari, Castagna, & Wisløff, 2005). However, despite this hypothesis, little research has examined threshold concepts in dance, with only five studies available. Of these, three termed their focus as anaerobic threshold measurement (Guidetti, Emerenziani, Gallotta, Da Silva, & Baldari, 2008; Guidetti, Gallotta, Emerenziani, & Baldari, 2007; Wyon et al., 2016), one as lactate threshold (Oliveira et al., 2010), and one as metabolic acidosis (Maciejczyk & Feć, 2013). These studies are further examined throughout the thesis and the applicability of various measurement techniques to classify threshold points for dance populations is discussed.

1.3.6. Response to intermittent work

The response to steady state work is well explored and deemed relatively straightforward, as highlighted by the above sections. In constant work rate exercise below metabolic threshold points there is a gradual increase from onset to a steady-state plateau in physiological markers (e.g. heart rate) within two to three minutes (McArdle et al., 2010). However, dance activity is unanimously described in the literature as non-steady state, or intermittent in nature (Cohen, Segal, Witriol, & McArdle, 1982; Redding & Wyon, 2003; Schantz & Astrand, 1984; Twitchett, Koutedakis, & Wyon, 2009; Wyon, 2005; Wyon, Abt, Redding, Head, & Sharp, 2004) and non-steady state work exhibits a much more complicated response due to its constantly changing nature. Non-steady state, or intermittent, work simply refers to exercise of variable intensity and duration and, therefore, refers to a wide range of exercise tasks. Most commonly within sports literature, a wide range of stop-and-go or change-of-pace (non-steady state) sports, such as field-based team sports (e.g. soccer) or racquet sports (e.g. tennis) are frequently examined. In these exercise examples the physiological response is much less predictable and much more varied. Response mechanisms as described previously are less able to stabilise and, therefore, all three energy systems are typically used in a state of flux due to the characteristics of the exercise. For example, tennis match play is described by Kovacs (2007) as including repeated dynamic movements such as accelerations, decelerations, changes in direction and jumps, therefore, described as consisting of "intermittent anaerobic exercise bouts of varying intensities and a multitude of rest periods over a long duration, allowing the aerobic energy systems to aid in recovery" (Kovacs, 2007, p.189). Soccer is similarly described as including explosive bursts of activity including jumping, kicking, tackling, turning, sprinting, and changing pace, all within an endurance context throughout a 90 minute game (Stølen et al., 2005). Parallels may be drawn to dance activity of various genres which is known to include jumps, lifts, turns, pace transitions, level transitions, and moments of controlled holds sustained throughout performance repertoire pieces of varying lengths (Wyon et al., 2011). The percentage contribution of each energy system over the total course of such intermittent activities is largely determined by temporal and intensity characteristics on the specific measurement occasion. Temporal characteristics refer to the duration of work and rest periods, typically expressed as work to rest ratio (w:r). For example, tennis has been documented as having a w:r ranging from 1:3-1:5, with corresponding mean percentage play time ranging from 20-38% over the course of a match (Kovacs, 2007). Dance performance has been documented as having a mean percentage total time dancing of 62.76% and 61.65% in female and male ballet dancers respectively, and 71.28% and 66.56% in female and male contemporary dancers (Wyon et al., 2011). This suggests a w:r of around 2:1. There are implications of work time versus recovery time on sustained exercise performance, whereby a decrement in performance is typically seen if insufficient recovery time is given between exercise bouts. As well as documentation of w:r, quantification of discrete skill occurrence is also frequently undertaken by time motion analysis techniques, allowing insight into the frequency of explosive movements (as described from tennis, soccer, and dance) in particular.

Cardiorespiratory markers, such as, VO_2, VCO_2, and heart rate, are typically measured to express the intensity characteristics of exercise. There are, however, challenges to gathering accurate measurements of this nature. Real-time, in-situ match-play or performance measurements of respiratory data are often not possible due to restrictions imposed by gas analysis equipment. Heart rate measurement is, therefore, frequently resorted to, but has been suggested to not immediately reflect variations in exercise intensity during intermittent exercise. For example, Christmass, Richmond, Cable, Arthur, and Hartmann (1998) observed a relatively constant heart rate (<5% variation) across singles tennis match play, despite wide fluctuations in intensity between work and recovery periods. Other limitations exist surrounding the frequent reporting of mean metabolic response, which fails to document the high intensity, explosive elements while also being skewed by lower intensity extended rest periods, as also highlighted by Kovacs (2007) and Stølen et al. (2005). These methodological concerns and related implications for documenting the demands of dance activity are addressed in more detail in chapter 2.

The primary concern for sustained intermittent exercise is the decrement in performance over time (particularly power output) and the onset of fatigue in repeated bout interval exercise due to incomplete recovery between bouts. Decreased power output in particular has been suggested to relate to a continuous degradation of PCr stores, which may in turn place greater demand on glycogenolysis and glycolysis, contributing to increases in muscle and blood lactate concentrations (Kovacs, 2007, p.193). It is, therefore, also necessary to understand fatigue and examine aspects of recovery, in order to fully understand the body’s response to intermittent activity, as outlined by the following two sections.

1.3.7. Fatigue

In their review of muscular fatigue considerations for dance, Wyon and Koutedakis (2013) describe the complex interplay of central and peripheral causes leading to the decline in force production at the muscle cell level, commonly described as the fatigued state. They state that “muscular fatigue occurs when power output or exercise intensity cannot be maintained at a pre-set rate, and if exercise continues, it is at a lower intensity” (Wyon & Koutedakis, 2013, p.63). For exercise of set intensity and duration, such as a choreographed dance performance piece, it is, therefore, necessary to avoid muscular fatigue in order to be able to successfully complete the movement required at the intensity required.

The likelihood of reaching a fatigued state is heavily determined by the duration and intensity of the exercise being undertaken, although there is generally a lack of consensus regarding the primary cause of fatigue within available literature. The two main schools of thought sit between peripheral causes of fatigue, as related to energy system efficiency and metabolic limitations of the working muscle, and the central governor theory, as related to a neural response to increasing exercise intensity.

Examinations of the mechanisms of peripheral fatigue focuses upon the reduced contractile potential of muscle fibres, due to depletion of substrates, and accumulation of bi-products of energy metabolism. Simplistically this is explained in terms of the inability to resynthesise ATP at a fast enough rate during high intensity exercise and an increase in anaerobic metabolism to fill this shortfall in energy supply to the contracting muscle. This increase in anaerobic metabolism results in increased concentration of bi-products such as lactate from anaerobic glycolysis and inorganic phosphate (Pi) from the break-down of PCr (Allen & Westerblad, 2001). While lactate accumulation and resulting intracellular acidosis have historically been hypothesised as limiting contractile potential of the muscle, Allen and Westerblad (2001), in their review of the relevant literature, suggest that there is more support for the influence of increased concentration of inorganic phosphate (Pi) in the myoplasm on reduced release of unbound calcium (Ca2+) from the sarcoplasmic reticulum. They suggest that this mechanism may primarily explain peripheral fatigue experience in high to maximal intensity activities lasting 1-2 minutes but note that mechanisms such as glycogen depletion may have a greater influence on fatigue in lower intensity activities lasting over one hour (Allen & Westerblad, 2001). In line with these conclusions, Mohr, Krustrup, and Bangsbo (2005), in a review of fatigue in soccer, highlight the multifaceted nature of fatigue and state that different levels and mechanisms of fatigue operate at different points of a game. They distinguish between temporary fatigue that occurs following high intensity bouts during the game and the accumulated fatigue that occurs towards the end of the game. Temporary fatigue following high intensity bouts is suggested as primarily due to accumulated extracellular potassium, with previous research in soccer ruling out the impact of lactate accumulation and decreases in muscle creatine phosphate highlighted. Fatigue towards the end of the 90 minute game is suggested as primarily due to lowered muscle glycogen stores with hyperthermia and dehydration also perhaps playing a part. These multiple manifestations of peripheral fatigue throughout prolonged intermittent activity may perhaps highlight important considerations for dance performance, which has been shown to consist of high intensity bouts, interspersed with lower intensity periods, over a prolonged period of time (Cohen, Segal, & McArdle, 1982; Redding & Wyon, 2003; Schantz & Astrand, 1984; Wyon, 2005; Wyon et al., 2004), as previously highlighted.

In contrast to mechanisms presented above, the central governor theory presents an argument that feelings of fatigue and the resultant decrease in exercise intensity or cessation of exercise is part of a regulated, anticipatory response coordinated in the subconscious brain in order to preserve homeostasis in all physiological systems during exercise of any intensity or duration (Noakes & St Clair Gibson, 2004). In other words, monitoring of biochemical changes at the muscular level, such as those outlined above, by the central nervous system, allows an anticipatory response before catastrophic metabolic shifts occur. This theory does not, therefore, ignore the existence of metabolic shifts, such as those outlined by peripheral fatigue theories, but does suggest that the neural drive to maintain homeostasis reduces exercise intensity before such metabolic shifts, large enough to influence muscle contractile potential, can occur. It could, therefore, be argued that although peripheral factors may not be solely responsible for voluntary cessation of exercise, these can be suggested as a precursor to central factors. Debate continues within the literature; however, as Wyon and Koutedakis, (2013) conclude upon review “muscle fatigue is a multifaceted phenomenon that has biochemical and neuromuscular components” (p.66) and perhaps should, therefore, always be examined as such.

An understanding of the mechanisms causing fatigue, specifically in dance activity, may help to guide training structure to reduce the incidence of fatigue. For example, Wyon and Koutedakis (2013) suggest that high intensity impact dance classes and rehearsals should be of shorter duration (less than 60 minutes) and that work to rest ratio during these activities be around 1:3 to allow effective recovery of muscles between bouts.

1.3.8. Recovery

Recovery from muscular stress/ metabolic demand can occur during small periods of lower intensity exercise during an extended exercise bout as well as in end exercise recovery. The efficiency of recovery during intermittent/ non-steady state exercise, as discussed above, can have a large impact upon the successful continuation of that exercise.

Rate of recovery following an exercise bout is dependent upon many factors, such as duration and intensity of exercise, type of exercise (steady/ non-steady state), type of movement/ muscular contraction, metabolic factors, physiologic factors, individual fitness level and individual skill level, among others. Poole and Jones (2011) state the purpose of recovery is to restore homeostasis, which includes many physiological processes including dynamics of cardiac output, muscle blood flow, muscle VO_2, partial refilling of blood and muscle O_2 stores, as well as hormonal, thermal, and metabolic derangements. Recovery from depletion of substrates utilised in energy systems can take anything ranging from two to 24 hours and is additionally influenced by factors such as fibre-type utilisation and blood glucose levels (McArdle et al., 2010).

A decline in ventilation at the cessation of exercise reflects removal of the neural command drive and decreased sensory input from previously active muscles; however, to aid recovery, oxygen consumption following exercise always exists in excess of resting values (McArdle et al., 2010). This continued heightened oxygen uptake is termed excessive post-exercise oxygen consumption (EPOC) (McArdle et al., 2010). Traditionally, elevated oxygen consumption required in recovery, termed the oxygen debt, was thought to mirror oxygen deficit built up at the onset of exercise (as previously discussed); however, EPOC additionally takes into account the level of anaerobic metabolism in previous exercise (due to the need for oxidation of accumulated lactate) as well as respiratory, circulatory, hormonal, ionic, and thermal adjustments that elevate metabolism during recovery (McArdle et al., 2010, p.172).

Similar to oxygen consumption at the onset of exercise, there are observable fast and slow components of oxygen off-kinetics, with the slow component existing in addition to the fast component mainly following strenuous exercise. In line with this, the extent to which off-kinetics mirror those described in on-kinetics is most notably influenced by the exercise intensity. On- and off-kinetics are largely symmetrical for moderate intensity exercise, but at heavy exercise intensities and above, a secondary VO_2 elevation as seen during on-kinetics is sometimes absent from off-kinetics (Poole & Jones, 2011).

The intensity and duration of individual exercise bouts, as well as the intensity and duration of active rest or total rest periods, throughout a sustained period of activity, will largely influence the recovery possible between bouts and, therefore, determine the total amount of activity possible. As intensity experienced during execution of any set movement, such as pre-choreographed dance, is relative to the individual's ability to meet that demand, elements of cardiorespiratory fitness as related to exercise economy also need to be addressed.

1.3.9. Exercise economy

Exercise economy refers to the oxygen uptake required at a given absolute exercise intensity, with a more economical individual theoretically requiring less oxygen to complete the same task. Economy has been shown to be associated with anthropometric, biomechanical, technical factors, and other associated predictors, and not just previously outlined physiological and metabolic factors (Jones & Carter, 2000). Jones and Carter (2000) speculate that this concept goes some way to explaining the considerable inter-individual variation in oxygen cost often documented during submaximal exercise, even amongst individuals of similar fitness and/or performance levels. Good exercise economy is traditionally viewed as an advantage in endurance performance in particular due to the lower relative strain experienced for any given exercise intensity (Jones & Carter, 2000). However, this concept clearly also has many implications for other activities, including intermittent activities. Helgerud, Engen, Wisloff, and Hoff (2001) found significant improvements in running economy following an interval training intervention in soccer players, as well as performance improvements that found the players able to increase the intensity of their match-play and sustain this better into the second half of the match.

Exercise economy is potentially highly relevant to dance as a high skill and technique based activity. Given the low cardiorespiratory fitness levels often documented for dancers of varying levels across various dance genres, and the highly specific nature of dance training practices, it seems likely that dancers are highly economical in their movement, allowing them to complete required sequences at a lower relative intensity and with seeming ease. This concept has not been previously addressed in dance specific research, so at present this is merely speculation. Accurate measurement of economy requires recording of oxygen uptake at a constant power output or velocity during steady state (McArdle et al., 2010) in order to remove confounding factors and ensure a stable absolute intensity for comparison. Dance, as highly dynamic movement in nature, with frequent changes in direction and pace does not lend itself to accurate direct measurement of economy; however, this does seem a relevant concept for future research to explore.

This section (1.3) as a whole has provided a basic physiological, theoretical underpinning for the study of energy demand in, and the cardiorespiratory response to, physical activity. It is likely that dance activity elicits a complex response of systems described above; therefore, requiring dancers to have a good physiological base of aerobic and anaerobic fitness to support the demands placed upon them through efficient activation of energy systems (discussed in depth in chapter 2).

1.4. Cardiorespiratory Training Adaptation

Optimisation of, and improvements, in the systems and response mechanisms outlined above form the basis of increased cardiorespiratory fitness levels. The ability to train these systems and the specific adaptations they undergo in response to training are outlined in this section.

In order for training to cause positive adaptation within the body the stimulus applied must be sufficient to cause stress to existing functional capacity. In exercise prescription this is managed by adherence to the principles of training and careful manipulation of the frequency, intensity, timing, and type of exercise undertaken. Intensity, or level of strain, has a large influence upon resultant adaptation (McArdle et al., 2010). Exercise intensity can be expressed in many different ways, such as energy expenditure ($KCal.min^{-1}$), absolute power output (W), relative metabolic level (%VO_{2max}), exercise below, at, or above OBLA ($mmol.L^{-1}$ of lactate), exercise heart rate or %HR_{max} ($b.min^{-1}$), multiples of resting metabolic rate (METs), or ratings of perceived exertion (RPE) (McArdle et al., 2010, p.470). Prescription of appropriate intensities for specific training adaptation are, therefore, often made in terms of target relative intensity zones based upon these measures. With sufficient strain experienced systematically using these principles, global and peripheral fitness adaptations can occur in both biochemical and physical manifestations. Typical training adaptations to cardiorespiratory systems are outlined below, grouped into metabolic, cardiovascular and pulmonary adaptations.

Metabolic adaptations refer to substrate, enzyme, and bi-product concentrations as well as structural changes at the muscle cell level, and, therefore, directly related to the efficiency of aerobic and anaerobic energy systems. Anaerobic system adaptations include increased PCr and ATP concentrations in resting muscle, increased concentration and activity of glycolytic enzymes, and lower levels of blood lactate accumulation either due to a decreased rate of formation or an increased rate of oxidation (McArdle et al., 2010). Aerobic energy system adaptations include increased mitochondrial density, increased concentration and activity of enzymes, increased capacity of carbohydrate oxidation during maximal exercise, and increased capacity for fat metabolism (McArdle et al., 2010).

Adaptations in cardiac and vascular systems are related to increased heart mass and volume (cardiac hypertrophy) and/or blood flow parameters. Specific changes to the heart include myocardial cell enlargement, increased size of left ventricular cavity and thickening of its walls, increased sensitivity to Ca^{2+} increasing contractile potential, thickening of individual myofibrils, and an increase in the number of contractile filaments. These specific adaptations allow for greater left-ventricular and end-diastolic volumes during rest and exercise as well as higher contractile potential increasing both stroke volume and cardiac output and reducing heart rate (bradycardia) in rest and exercise. Endurance athletes have been reported to have, on average, a 25% larger heart volume than sedentary controls (McArdle et al., 2010). Differences have been noted in the cardiac adaptation in different types of athletes, for example between resistance and endurance-based athletes. One study with classical ballet dancers noted significant differences in echocardiographic data compared to sedentary control participants, indicating some level of left ventricular hypertrophy and increased left ventricular internal dimension (volume) in proportion to their training (Cohen et al., 1980).

Pulmonary adaptations include a speeding of primary VO_2 kinetics and a reduction in the VO_2 slow component via improved muscle oxygen delivery (Poole & Jones, 2011), increased oxygen extraction from circulating blood (a-VO_2 difference), and an increase in maximal exercise ventilation related to increased tidal volume and breathing rate (McArdle et al., 2010).

It is worth highlighting that different adaptations to same exercise exposure are shown between individuals, partly due to the influence of the individual's initial fitness level, where a lower fit individual gains greater adaptation from the same load than a high fit individual. Optimal training conditions rely on programmes focused on individual needs. In elite endurance athletes, improved performance through such training adaptations has mainly been related to improvement in four key parameters, maximal aerobic capacity (VO_{2max}), exercise economy, lactate/ ventilatory threshold, and oxygen uptake kinetics. These improvements allow athletes to exercise for longer at a given absolute exercise intensity, or to exercise at a higher exercise intensity for a given duration (Jones & Carter, 2000).

1.4.1. Continuous versus interval training

Debate surrounding the best training methodologies for improving cardiorespiratory fitness exists within the literature, primarily concerning the use of interval training, rather than continuous training, to elicit adaptation. Continuous training typically refers to steady pace, prolonged moderate or high intensity work (60-80% VO_{2max}) whereas interval training intersperses high intensity work with rest periods. Through this methodology, interval training can give the ability for more overall work at a higher intensity due to the systematic distribution of rest periods (Sloth, Sloth, Overgaard, & Dalgas, 2013). It also provides the ability to target specific energy systems on the basis of manipulation of intensity, duration of work and rest periods, and the number of repetitions of work periods completed overall. Therefore, while continuous training typically only targets aerobic system development, interval training can target both aerobic and anaerobic systems simultaneously. Numerous reviews exist examining the claimed benefits of interval training. For example, Sloth et al. (2013) reviewed 21 sprint interval training intervention studies and reported consistent improvements in VO_{2max}/VO_{2peak} in the range of 4-13.5% and increases in mean peak power during a Wingate anaerobic bike test of up to 17%. Further reported benefits include reduced heart rate during submaximal exercise, increased citrate synthase enzyme activity, increased resting glycogen availability, and increased oxygen availability (Sloth et al., 2013). Other studies have examined, more specifically, the elite performance effects of interval training interventions and the adaptations noted above. For example, Helgerud et al. (2001) noted significant improvements in VO_{2max} and absolute lactate threshold following an eight-week interval training intervention in soccer players that were accompanied by significant differences pre- to post-intervention in match-play related parameters such as distance covered, number of sprints, and overall playing intensity; highlighting greater performance related capacity.

1.4.2. Dance specific training adaptation

The cardiorespiratory adaptation possible through traditional dance training is documented as extremely limited by previous research. Adaptation has, however, only typically been measured through documenting changes in fitness test performance and measures such as VO_{2max}, rather than monitoring any metabolic adaptations as outlined above.

Although dance, as an intermittent activity, does reach high intensity, the limiting factor to positive adaptation is noted as the duration spent at these high intensities. For example, during ballet class it has been reported that heart rate is only elevated into an aerobic training zone for 1-6minutes at a time (Rimmer, Jay, & Plowman, 1994). Rehearsal has similarly been noted as providing limited training stimulus, with a previous study noting no significant changes in aerobic fitness measures throughout a rehearsal period (Wyon & Redding, 2005). The same study, did, however, report significant improvements in aerobic fitness following an eight week performance period, which was speculated as due to the higher intensity often documented in dance performance compared to class and rehearsal (Wyon & Redding, 2005). Available literature investigating the demands of class, rehearsal, and performance and the potential training adaptation afforded by these is examined in depth in chapter 2.

A number of studies have implemented supplementary training interventions with dancers and monitored the impact of these upon various fitness components, including aerobic and anaerobic capacity, strength, power, and flexibility, as well as markers of performance improvement (Angioi, Metsios, Twitchett, Koutedakis, & Wyon, 2012; Galanti et al., 1993; Koutedakis et al., 2007; Mistiaen et al., 2012; Ramel, Thorsson, & Wollmer, 1997). Findings are also discussed in greater depth in chapter 2, but overall supplementary training seems necessary to elicit improvement in fitness in dance populations.

Wyon (2005) makes recommendations for cardiorespiratory training for dancers in line with these discussion points, outlining a three-tier process of development. Firstly, development of an aerobic foundation through 20-40 minutes of continuous moderate intensity, specific or general movement conducted at an intensity of 70-90%HR_{max}. Secondly, development of VO_{2max} through interval training at a 1:1 exercise to rest ratio, with work periods of 3-6 minutes duration at near maximal intensity (90-96%HR_{max}) and low intensity exercise in rest periods. Lastly, development of the fast glycolytic system through interval training at a 1:3-1:5 work to rest ratio, with work periods of 15-30 seconds at supra-maximal intensity and low intensity exercise in rest periods to promote active recovery. These recommendations seem appropriate for dance specific needs; however, in order to provide further specificity in training, it could also be suggested that work to rest ratios and exercise intensities used within interval training sessions could be set based upon those documented in performance to systematically plan training within rehearsal periods to ensure specific preparation for performance demands. Regarding exercise mode, Wyon (2005) suggests that training should ideally utilise dance specific movement in order to maximise specific peripheral adaptations. Following any strenuous exercise there is arguably a degree of global adaptation, which benefits any exercise modality, such as to cardiac function as outlined above. However, adaptations to the muscle cell unit have previously been shown to occur peripherally, relevant to the training modality employed; therefore, it does seem valid to suggest that supplementary training should employ dance specific movement where possible. Wyon (2005) recommends substituting one or two dance classes per week with systematically planned supplementary training, due to the long working hours already imposed by dance training and performance schedules. This recommendation is often not well received within dance training and performance environments, due to the high importance currently given to development of technique and skill. Rafferty (2010) discusses the potential for the work to rest ratio and intensity of dance technique class to be modified to allow for a greater cardiorespiratory training stimulus, but highlights difficulties with this due to restrictions of space, the numbers of students per class, and time required for teaching and correcting technique, all of which impact upon the possible work rate. It is, therefore, concluded that there is limited scope for providing further training stimulus effectively through class and supplementary training outside of technique class is highlighted as a more appropriate approach

(Rafferty, 2010). Krasnow & Chatfield (1996) do, however, also highlight the importance of ensuring transfer of improvements made in training programmes into dance practice and argue that dance technique class is the most appropriate setting for this.

Wyon (2005) does highlight limitations of the recommendations made. These relate to the limited empirical data on which recommendations are based, highlighting a limited knowledge of the physiological demands of dance and the adaptations of the energy systems possible through dance training, as well as noting the variety of demands seemingly apparent across different dance performance pieces. Redding and Wyon (2003) further note that until research has indicated the extent to which improved aerobic fitness actually enhances dance performance, there is a need to ensure this is not developed to the detriment of other energy systems and/or components of fitness such as strength, power, and agility. It, therefore, seems that further research is necessary in order to determine the training stimulus afforded by dance activity (class, rehearsal, and performance) through more in-depth analysis of the cardiorespiratory demands of these activities and explore their relevance to performance enhancement.

1.5. Cardiorespiratory Fitness, Fatigue, and Injury in Dance

Previous sections have explored the context of the research within contemporary dance and dance science investigation, as well as the physiologic theoretical basis for the study of cardiorespiratory demand and fitness in elite performance. The next two sections aim to bring together all of this work and expand on its relevance. Initially, the potential implications of inadequate levels of cardiorespiratory fitness to cope with the demands of dance training, rehearsal, and performance are highlighted with regard to experience of fatigue and related injury risk.

1.5.1. Fatigue and injury

While definitions of injury used and methods of collecting incidence data do vary, high injury rates are reported across literature in various dance genres regardless of the methods adopted. For example, in addition to the earlier cited 80% of dancers injured within a year (Brinson & Dick, 1996; Laws, 2006), studies of professional ballet dancers have reported injury incidence ranging from 1.10 injuries per dancer per year or 0.91 per 1000 hours of dance exposure (Ramkumar, Farber, Arnouk, Varner, & Mcculloch, 2016) to seven injuries per dancer per year, 4.4 injuries per 1000 hours of dance exposure (Allen, Nevill, Brooks, Koutedakis, & Wyon, 2012). Injury incidence in professional modern dance companies has been reported at 65% of dancers sustaining an injury or 0.41 injuries per 1000 hours of exposure (Ojofeitimi & Bronner, 2011). It seems from this preliminary data that contemporary dancers are less at risk of sustaining injuries than ballet dancers (as was also supported by Laws, 2006); however, injury rates still remain high in all cited dance injury data. Therefore, it is important to stress the magnitude of dance injury as a persistent problem.

Many potential injury risk factors have been identified in dance; however, Brinson and Dick (1996) and Laws (2006) both found the highest perceived cause of injury by dancers to be fatigue/ overwork. Malkogeorgos, Mavrovouniotis, Zaggelidis, and Ciucurel (2011) discuss injury risk factors such as anatomic alignment, muscle strength imbalances, hypermobility, poor training, technical errors, unfamiliar choreography or style, environmental factors, amenorrhea, disordered eating, low bone density, age, tiredness, muscle fatigue, and loss of balance. Russell (2013) additionally speculates the potential influence of psychosocial factors, such as negative stressors and personality characteristics. All of these make determining the primary cause of an injury difficult, as any injury is likely to be caused by an interaction of many of these factors. Dance injuries are generally classified as either due to acute incidents or overuse (Malkogeorgos et al., 2011). Loss of technique or control, or merely faulty technique, is often cited as the primary risk factor for acute injury occurrence, although fatigue is often linked to these as a secondary factor perhaps leading to the loss of control (Malkogeorgos et al., 2011). Faulty technique is, however, also linked to occurrence of overuse injuries, whereby repeated malalignment over a period of time causes repetitive microtrauma to bone or soft tissue structures (Malkogeorgos et al., 2011). Overuse injuries represent the highest proportion of dance injuries reported at 64% of female and 68% of male injuries by Allen et al. (2012). Dancers have also been reported to be at greater risk of overuse injury towards the end of a season/ training year (Koutedakis et al., 1999). If hypothesising the link between fitness, fatigue, and injury, this is in line with findings that dancers exhibit their lowest fitness levels at end of performance season (Koutedakis et al., 1999), which was attributed to chronic fatigue related to overtraining and burnout. Data regarding the high work hours of dancers and limited rest time, as previously outlined, support this hypothesis of overtraining and/or chronic fatigue in dancers and may, therefore, go some way to explaining the high reported injury rates.

1.5.2. Cardiorespiratory fitness as prevention

Low levels of cardiorespiratory fitness for intermittent activity are related to higher experienced intensity during work periods and inadequate recovery during rest periods. These together are suggested to lead to an individual with lower cardiorespiratory fitness experiencing fatigue earlier than an individual with a higher cardiorespiratory fitness level (Wyon & Koutedakis, 2013). With fatigue experienced earlier, a limited number of exercise bouts are achievable. As previously stated, dance performance has been predominantly described as an intermittent activity with total dance time making up 60-70% of total performance time (Wyon et al., 2011) and, therefore, displaying a mean work to rest ratio of around 2:1. Dance class, while also intermittent, displays a work to rest ratio of around 1:2 with mean percentage dance time for contemporary dance reported as ranging between 33-49% for the centre phase (Wyon, Abt, Redding, Head, & Sharp, 2004; Wyon, Head, Sharp, & Redding, 2002). The previous literature documenting the demands of dance activity is thoroughly reviewed in chapter 2, although it is important to contextualise it here in relation to the apparent gap between the physiological demands placed upon dancers in training and performance and their cardiorespiratory fitness levels.

Wyon and Koutedakis (2013) suggest that supplemental cardiorespiratory training may have a significant effect in combating dance injury. The impact of improved cardiorespiratory fitness levels on injury rates in dance specific populations is yet to be longitudinally investigated, although limited literature is available which has examined correlations between existing fitness levels and injury rates. Fifteen-week injury monitoring in female ballet dancers showed a significant correlation between the number of injuries sustained by an individual and individual aerobic fitness levels (measured using the Dance Aerobic Fitness Test, DAFT; Wyon, Redding, Abt, Head, & Sharp, 2003) although not between aerobic fitness and the total time spent modifying dance activity due to the injury (Twitchett, Brodrick, et al., 2010). A 12-month retrospective survey of injury occurrence in female contemporary dancers, however, showed no significant correlation between the same measure of aerobic fitness and injury rate or time off due to injury (Angioi, Metsios, Koutedakis, Twitchett, & Wyon, 2009). Clearly further research is necessary here in order to provide evidence of a direct link between various measures of cardiorespiratory fitness, experience of fatigue, and injury occurrence, to support theoretical links as outlined in this section.

1.6. Cardiorespiratory Fitness and Performance Enhancement in Dance

The relationship between cardiorespiratory fitness and dance performance remains a topic of contention with questions often arising such as can dance performance be enhanced by improvements in cardiorespiratory fitness and is a fitter dancer a better dancer?

Performance enhancement in dance, broadly speaking, could incorporate the development of physiological components, which overall result in a reduction in the relative intensity of a set movement and, therefore, allow relative ease in performance; however, more often in dance, performance enhancement is used to describe the enhancement of a more complex notion of outwardly observable and perceived technical or artistic ability. Previous literature discussed throughout this introduction highlights benefits of the former; however, less consensus exists for the latter, the latter perhaps being more important in investigation of dance than it is in other physical activities and sports, where the observable aesthetics are less important in sports than winning. These characteristics of dance highlight difficulties of quantifying performance enhancement and, therefore, present experimental research in dance with a limited ability to judge the efficacy of training interventions and the overall impact of enhancing various elements. In relation to cardiorespiratory fitness levels as one of these elements, previous research has attempted to document the relationship between cardiorespiratory fitness and dance performance enhancement.

Firstly, studies have examined this relationship indirectly by comparing stages of training/ experience or company rank/position under the assumption that those with more training, professional dance experience, or given more prominent roles, are better performers. Fitness levels amongst different ranks within ballet (principals, soloists, first artists, and corps de ballet/ artists) are found to vary; however, findings do not display a linear increase in fitness with higher ranks. A study by Schantz and Astrand (1984) reported a 5% higher VO_{2max} in soloists than corps; however, more recent research has reported significantly higher VO_{2peak} values in corps and principals than first artists and soloists ($p < 0.05$) (Wyon et al., 2007). A further study also found principals and artists to have significantly higher VO_{2peak} than soloists ($p < 0.01$); however, also found soloists and principals to have a significantly higher anaerobic threshold than artists ($p < 0.01$) (Wyon et al., 2016). These variations between ranks are suggested as related to differences in the duration and intensity of performance work of the different ranks (Wyon et al., 2007, 2016). The same rank structure does not typically exist in contemporary dance to allow direct comparison between professional dancers of varying skill and performance level; however, previous research has made comparisons between student and professional contemporary dancers. A review by Angioi, Metsios, Koutedakis, and Wyon (2009) noted mean VO_{2max} values of 49.1 $ml.Kg^{-1}.min^{-1}$ in professional female contemporary dancers and 39.2 $ml.Kg^{-1}.min^{-1}$ in student female contemporary dancers across all available literature. A recent study also found significantly better aerobic fitness levels in large samples of professional contemporary dancers than pre-professional vocational students using an accelerated 3 minute step test (Bronner et al., 2016). Therefore, it is suggested that dancers with a higher level of training and professional performance experience have higher cardiorespiratory fitness levels.

A limited number of previous studies have also examined the relationship between cardiorespiratory fitness and performance enhancement directly through correlational and intervention studies. Angioi, Metsios, Twichett, Koutedakis, and Wyon (2009) assessed the relationship of performance, as measured by a developed aesthetic competence measure (ACM), to a battery of fitness assessments. Fitness assessments included measures of anthropometrics, flexibility, muscular power, muscular endurance, as well as employing the DAFT (Wyon et al., 2003) as an indicator of aerobic fitness levels. Significant correlations to ACM mean scores were only found for push up and jump height assessments. These two tests were also found to be the best predictors of aesthetic competence in a stepwise backward multiple regression analysis (Angioi, Metsios, Twitchett, et al., 2009). A lack of significant correlation with aerobic capacity was suggested as due to the predominantly intermittent nature of dance (Angioi, Metsios, Twitchett, et al., 2009). In a follow up study, Angioi et al. (2012) assessed changes following a supplementary training intervention in ACM scores and fitness measures including press-ups, standing vertical jump height, and heart rate during the last minute of the final stage of the DAFT. Similarly, Koutedakis et al. (2007) evaluated a supplementary training intervention through measures of hamstring flexibility, maximal oxygen uptake (VO_{2max}), knee extensor isometric strength, and a specifically designed dance test. Both of these studies noted significant increases in both measures of aerobic fitness and aesthetic competence/ dance test scores in the intervention group from pre- to post-testing. Neither correlational nor regression analyses were undertaken in these studies; however, it does seem that dance performance ability, as measured by these tools, is improved by the same programme of supplementary physical training that causes positive training adaptation of the aerobic energy system (Angioi et al., 2012; Koutedakis et al., 2007). A further study in classical ballet dancers demonstrated significant improvement in performance following a supplementary training intervention involving interval and circuit training (Twitchett, Angioi, Koutedakis, & Wyon, 2011). Although this study did not directly measure changes in aerobic fitness throughout the intervention, it does further confirm the ability of performance enhancement through fitness training.

The ability to train harder for longer as well perform at a lower relative intensity, as a result of increased cardiorespiratory fitness levels, should, in theory, lead to higher technical and artistic ability. Previous research, as outlined above, has begun to demonstrate this practically; however, there appears to still be a limited belief in the importance of this in dance. Therefore, researchers remain under pressure to demonstrate the direct benefits of any supplementary or intervention strategy on the output, performance quality, and/or skill of the dancer. It is, however, still important to highlight all of the other benefits of cardiorespiratory conditioning as outlined throughout this introduction and not ignore these purely for the pursuit of the aesthetic aspects of performance enhancement in dance. Previous research has also highlighted that without enhancement of 'the physiological dancer' the limiting factor in the development of 'the artistic dancer' will potentially be their physical conditioning (Koutedakis, 2005). Therefore, it is important to continue to develop our understanding of the physiological demands of dance and the fitness levels of dancers.

1.7. Summary

Throughout this introduction chapter, the theoretical basis of the body's physiological response to physical activity has been explored and specific elements of this have been highlighted with regard to the likely complex response of the body to high-intensity, intermittent dance activity. The context for the research contained within this thesis has been outlined, including the setting within a vocational contemporary dance training institution in the UK. Current practices of contemporary dance training and performance present many challenges to ensuring appropriate cardiorespiratory fitness levels to enable dancers to cope with the demands placed upon their bodies. Future research aiming to define and overcome these challenges seems warranted given the potential implications of inadequate fitness upon both injury incidence and performance ability.

The following literature review was published by the author during this PhD and outlines the available research investigating the cardiorespiratory demands of dance activity and the impact of training and/or performance on measures of cardiorespiratory fitness (i.e. training adaptation).

2. Methodological Considerations for Documenting the Energy Demand of Dance Activity: A Review

This systematic literature review is included as published on May 6 2015.

Beck, S., Redding, E., & Wyon, M.A. (2015). Methodological considerations for documenting the energy demand of dance activity: a review. *Frontiers in Psychology. 6:568*. doi: 10.3389/fpsyg.2015.00568

2.1. Abstract

Previous research has explored the intensity of dance class, rehearsal and performance, and attempted to document the body's physiological adaptation to these activities. Dance activity is frequently described as: complex, diverse, non-steady state, intermittent, of moderate to high intensity, and with notable differences between training and performance intensities and durations. Many limitations are noted in the methodologies of previous studies creating barriers to consensual conclusion. The present study therefore aims to examine the previous body of literature and in doing so, seeks to highlight important methodological considerations for future research in this area to strengthen our knowledge base. Four recommendations are made for future research. Firstly, research should continue to be dance genre specific, with detailed accounts of technical and stylistic elements of the movement vocabulary examined given wherever possible. Secondly, a greater breadth of performance repertoire, within and between genres, needs to be closely examined. Thirdly, a greater focus on threshold measurements is recommended due to the documented complex interplay between aerobic and anaerobic energy systems. Lastly, it is important for research to begin to combine temporal data relating to work and rest periods with real-time measurement of metabolic data in work and rest, in order to be able to quantify demand more accurately.

Keywords: Dance, energy demand, cardiorespiratory fitness, dance training, dance performance

2.2. Introduction

The importance of physical fitness in dance and the level of physical fitness required of dancers is a topic of much contention within both dance teaching and training settings, and in dance medicine and science literature. While physiological capacity is an important aspect of dance performance, it must also be acknowledged that dance is first and foremost an art form encompassing technical and expressive aspects. Therefore, solely examining the body's physiological adaptations to training cannot infer optimal performance. As stated by Koutedakis and Jamurtas (2004), "dance performance... is a rather complex phenomenon made up of many elements that have direct and indirect effect on outcome" (p.651-52). Therefore, it could be argued that the presence of an underlying physical fitness foundation is an important pre-requisite to successful and sustained dance performance. Previous literature has highlighted the relationship between fatigue and injury risk with regard to the considerable, and ever increasing, physical demand placed on dancers from choreography (Allen & Wyon, 2008; Koutedakis & Jamurtas, 2004), further emphasizing the role of appropriate physical preparation in dancers. In sports, training methodologies are based upon in-depth research, which seeks to understand the response of systems of energy utilization during activities and their links to performance capabilities. While dance shares several characteristics with sport there are also fundamental differences, for example, in the structure of training, approach to skill and physical development, and objective versus subjective means of performance evaluation. These features present challenges to the application of non-dance specific research to dance contexts. With the growth of dance science as a relatively new field of research and its increased dissemination into studio practice, there is a need for evidence to ensure the appropriate preparation of dancers within their training.

The concept of energy demand can be simplified as the energy, or oxygen, cost of completing an activity. Previous research has aimed to classify the energy demand of aspects of dance training (class and rehearsal) and performance, leading to the common description of dance activity as: complex, diverse, non-steady state, intermittent, of moderate to high intensity, and with notable differences between training and performance intensities and durations (Cohen, Segal, Witriol, & McArdle, 1982; Redding & Wyon, 2003; Schantz & Astrand, 1984; Twitchett, Koutedakis, & Wyon, 2009; Wyon, 2005; Wyon, Abt, Redding, Head, & Sharp, 2004; Wyon et al., 2011). The diversity of dance performance is particularly highlighted in relation to differences in movement vocabulary and execution both between and within dance genres. One study has noted this diversity as comparable to that of field sports such as soccer and rugby, for which extensive analyses of demand have been undertaken in the past (Wyon et al., 2011). The physiological response of the body to dance activity is noted as complicated and difficult to describe due to these characterizing features, along with a focus on technique and skill.

Only two systematic literature reviews are available in this topic area; one examining fitness components in relation to contemporary dance (Angioi, Metsios, Koutedakis, & Wyon, 2009), and one examining existing dance medicine and science literature in Dance Sport (McCabe, Wyon, Ambegaonkar, & Redding, 2013). Through both of these reviews it is clear that a) the weak methodologies of many studies do not provide a strong evidence base, b) studies do not differentiate between levels and styles of dance adequately, and c) inappropriate comparisons are often drawn between dance and other forms of activity - for example a generalized concept of sport. Other dance specific review articles available include: an early paper on the physiological aspects of dance (Kirkendall & Calabrese, 1983), a brief review examining classical ballet (Twitchett et al., 2009) and a review of eccentric muscular contraction in dance activity (Paschalis et al., 2012). Further comment and methodological analysis articles include: examining the dancer as an athlete (Allen & Wyon, 2008; Koutedakis & Jamurtas, 2004), reviewing aerobic and anaerobic aspects of dance (Cohen, 1984), considerations for dance fitness training (Rafferty, 2010; Wyon, 2005) and a methodological review (Redding & Wyon, 2003). While these articles are useful in framing our current understanding of the physiological demands of dance, comprehensive and consensus based conclusions currently do not seem possible largely due to the lack of consistency in methodological design, protocol and measurement instrumentation, making comparisons between different study findings difficult.

While the above-mentioned articles have examined various physiological data in dance populations, to date a comprehensive literature review has not been undertaken examining data available on the intensity and energy demand of various genres of dance. The present study aims to examine the previous body of literature and, in doing so, seeks to highlight important methodological considerations for future research in this area to strengthen our knowledge base.

2.3. Methods

Pub Med/ Medline, Cochrane, and SportDiscus research databases were searched between April and August 2013 with a limit to English language publications utilizing human participants only. Articles published from 1982 to August 2013 regarding the physiological demands and adaptations to dance training and performance were considered. The Medical Subject Heading (MeSH) terms “energy demand” “physiological intensity” “aerobic” “anaerobic” “movement economy” “efficiency” were employed in combination with “dance” “dancer” “ballet dance” “contemporary dance” “modern dance”.

Articles retrieved were assessed for relevance based on title, abstract, and full-text against the pre-determined inclusion and exclusion criteria. Inclusion criteria were: (I) examining energy demand of dance or the effects of training or performance on the cardiorespiratory fitness of dancers, (II) involving participants defined as professional and/or student dancers in pre-vocational, vocational and/or university settings, (III) examining any professionally recognized genre of dance (for the purpose of this review categorized as ballet, contemporary (incl. modern), or other), (IV) investigating any aspect of dance activity (single exercise, class, training, rehearsal, performance, or competition). Exclusion criteria were: (I) editorials, review or comment articles, and conference proceedings, (II) studies measuring physical fitness variables in a one off screen, (III) studies incorporating aerobic dance (including exercise classes), (IV) studies using dance as an intervention for general population health (i.e. elderly, youth, sedentary etc). Finally, reference lists of accepted articles were scanned for further appropriate publications, which were subsequently sourced and included in analysis.

An assessment of study quality of full-text articles deemed relevant was undertaken according to the grading system set out by the Academy of Nutrition and Dietetics Evidence Analysis Library (ADA EAL, 2013). The grading system, through pre-set criteria, assesses: quality, consistency, quantity, clinical impact, and generalisability. Allowing assigning of grade: I (good), II (fair), III (limited), IV (expert opinion only), or V (grade not assignable). For example, under the criteria ‘quantity’, grades are assigned based upon the following statements, “ grade I, one to several good quality studies, large number of subjects studies, studies with negative results have sufficiently large sample size for adequate statistical power, grade II, several studies by independent investigators, doubts about adequacy of sample size to avoid Type I and Type II error, grade III, limited number of studies, low number of subjects studied and/or inadequate sample size within studies, grade IV, unsubstantiated by published research studies, grade V, relevant studies have not been done” (ADA EAL, 2013). For the purpose of this review, articles graded as expert opinion only, or grade not assignable were omitted from analysis. A flow diagram of the studies identified and included in the review appears in Figure 2.1. A sample review was completed by an independent reviewer to demonstrate reliability of classification. Data analysis was conducted on accepted articles to extract relevant information for comparison and construction of evidence tables. These evidence tables form the basis of this review, allowing the summary of previous research findings and highlighting areas in need of further study.

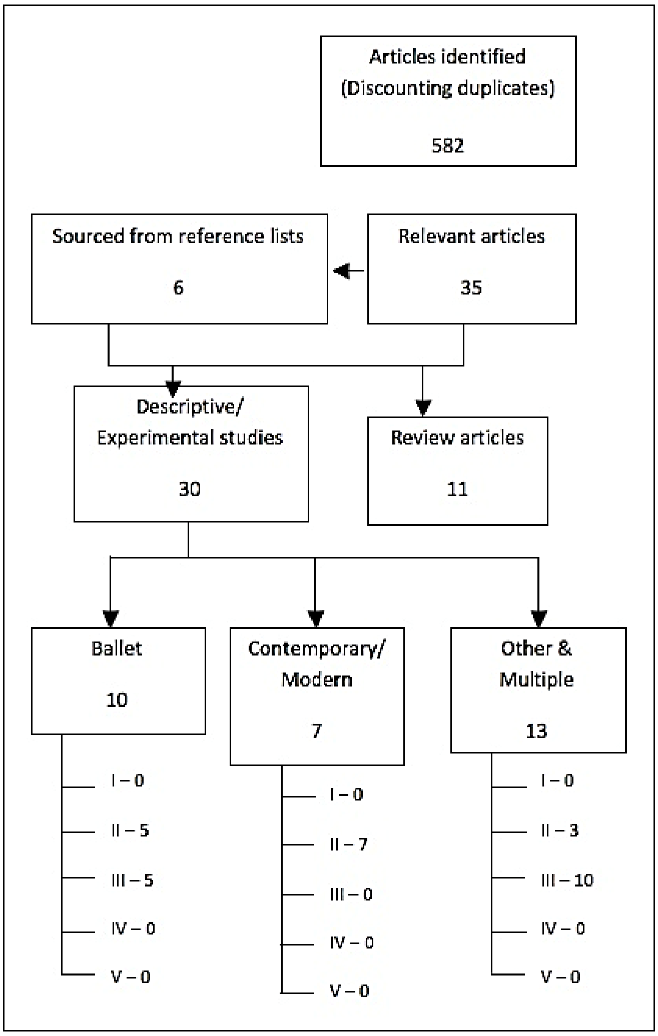

Figure 2.1. Article identification and grading process

2.4. Results

Based on the adopted methodology and search parameters, 30 articles sourced were included in this review; 24 were descriptive studies and six involved an intervention, of which only one was clearly defined as a randomized control trial. Of the 30 articles selected, 10 articles examined ballet; seven contemporary or modern dance; nine were categorized as 'other', which included highland dance, dance sport, folk dance, tap dance, and jazz dance; and four examined multiple genres within the same study, which included ballet, contemporary, and jazz, and additionally included character dance. Terminology used to describe the genre of dance examined varied in some cases. For the purpose of this review the term 'contemporary' also includes studies examining modern dance and the term 'dance sport-ballroom' also includes studies examining standard or modern ballroom dance. Three studies took their sample from groups of pre-vocational, adolescent dancers, 15 examined professional dancers, 10 examined student dancers, and two looked at both student and professional dancers. Although no universal definition for categorizing an individual as a professional dancer was provided in studies examined, for the purpose of this review the term professional dancer is adopted where participants were described as such within the source study.

Quality assessment undertaken revealed the quality of evidence available to be relatively poor, with 47% graded as ‘limited’ and the remaining 53% as ‘fair’. For the majority of cases, grading within the category ‘quantity’ was the main limiting factor, with a limited number of studies confirming single study findings and low or inadequate sample sizes within studies.

Results are organized by aspects of dance activity measured in order to accurately represent different elements of a dancer’s schedule. Five studies undertook measurements on more than one aspect of dance activity and therefore are included under multiple sub-headings (and appear twice or more in subsequent counts).

2.4.1. Energy demand of class

Literature examining dance class generally classifies the energy demand as moderate to high and intermittent in nature, although a greater intensity and shorter duration of exercise is noted in the centre phase compared to the warm-up.

Thirteen papers in total have investigated elements of dance class in various genres. Four measured only the execution of a single exercise within a class setting (Table 2.2) (Guidetti, Emerenziani, Gallotta, & Baldari, 2007; Guidetti, Emerenziani, Gallotta, Da Silva, & Baldari, 2008; Maciejczyk & Feć, 2013; Oliveira et al., 2010), with the remaining nine examining an entire class, often drawing comparisons between different sections; most-commonly the warm-up and centre phases (Table 2.1) (Baillie, Wyon, & Head, 2007; Cohen, Segal, Witriol, & McArdle, 1982; Dahlstrom, 1997; Dahlstrom, Inasio, Jansson, & Kaijser et al., 1996; Guidetti, Gallotta, Emerenziani, & Baldari, 2007; Rimmer, Jay, & Plowman, 1994; Schantz & Astrand, 1984; Wyon, Head, Sharp, & Redding, 2002; Wyon et al., 2004). Of the 13 papers examined, the majority of studies examined either ballet or contemporary dance with single, small scale studies additionally examining highland, tap, and folk dance. Groups of pre-vocational adolescents, undergraduate and graduate students, and professional dancers were examined. Data were reported on a variety of variables as displayed in Table 2.1 and Table 2.2. More detailed information relating to specific methodologies of each study are available in Supplementary Table 1 (appendices).

Reported work and rest temporal data suggest dance class is an intermittent form of activity. Differences are noted between the work to rest ratio of the warm-up/ barre phase of class and that of the centre/ execution phase, with the centre/ execution phase consisting of shorter work and longer rest periods (Dahlstrom, et al., 1996; Schantz & Astrand, 1984; Wyon, et al., 2002; Wyon, et al., 2004). Though methodologies and variables of focus vary, the magnitude of physiological strain is described throughout the breadth of literature as moderate to high, although this is also seen to differ between different sections of the class. Mean intensity (as represented by reported aspects of VO_2, HR and EE) of the warm-up/ barre phase is consistently reported as lower than that during the centre/ execution phase (Cohen, Segal, Witriol, & McArdle, 1982; Dahlstrom et al., 1996; Dahlstrom, 1997; Schantz & Astrand, 1984; Wyon et al., 2002; Wyon et al., 2004). This difference was reported as significant for both VO_2 and HR data in four of the studies presented (Cohen, Segal, Witriol, & McArdle, 1982; Schantz & Astrand, 1984; Wyon et al., 2002; Wyon et al., 2004).

Three studies have compared the intensity of single exercises within a class to individual lactate/ anaerobic/ metabolic acidosis threshold, and described demand as working close to (Maciejczyk & Feć, 2013), often above (Guidetti, Emerenziani, et al., 2007), 10% less than and non-significantly different to (Oliveira et al., 2010) threshold levels in folk, ballet, and tap dance respectively. Negligible differences in the intensity of class can be seen between dance genres, when visually comparing different studies. Only one study reported direct comparisons between classes of different dance genres and found no significant differences in the median HR values (Dahlstrom et al., 1996). One study reported no significant differences between classes in different techniques of the same genre (Wyon et al., 2004). Lastly, differences between participant characteristics such a gender and training status are reported. For example, significant differences have been reported between sexes in O_2 requirement for the whole class, warm-up, and centre phases (Wyon et al., 2004). One study noted significant differences between percentage of dance-time (work-time) and mean whole class HR values between undergraduate, graduate and professional dancers (Wyon et al., 2002). Another study found no significant difference in the overall energy requirements of a single ballet exercise between dancers ranked as high or low technical ability. However it did find significant differences in energy source contribution, with high technical ability dancers using significantly higher aerobic source contribution and significantly lower anaerobic lactic system contribution than the low technical ability dancers (Guidetti et al., 2008).

The data drawn from previous research and examined here provides basic information regarding the intensity of dance class and therefore alludes to the demand placed upon dancers during class. However, it should be noted that data are rarely presented relative to the individual dancer's fitness levels. Significant differences are noted between different phases of class, in the response of different sexes and in dancers of varying technical ability, this must be taken into account during the interpretation of data sets.

Table 2.1. Mean data of studies examining the energy demand of dance class

Variable	Reference	Genre	Level	Gender	Warm-up	Centre	Mean
Mean VO_2 ($ml.kg^{-1}.min^{-1}$)	Cohen, Segal, Witriol, & McArdle, 1982	**Ballet**	Pro	Female	16.49	20.06	
				Male	18.48	26.32	
	Wyon et al., 2002	**Contemporary**	Student	Mean	13.2	18.9	16.8
			Graduate		20.2	20.6	20.4
			Pro		15.1	21.2	18.3
	Wyon et al., 2004	**Contemporary**	Mixed	Female	14.67	19.39	17.42
				Male	18.65	24.78	22.06
Peak $\%VO_{2max}$	Cohen, Segal, Witriol, & McArdle, 1982	**Ballet**	Pro	Female		60	
				Male		71	
				Mean	51		
Mean $\%VO_{2max}$	Schantz & Astrand, 1984	**Ballet**	Pro	Mean	36	44.5	
Peak heart rate ($b.min^{-1}$)	Cohen, Segal, Witriol, & McArdle, 1982	**Ballet**	Pro	Female		158	
				Male		178	
Median heart rate ($b.min^{-1}$)	Dahlstrom et al., 1996	**Ballet**	Student	Mean	117	134	126
		Contemporary			118	137	124
		Jazz			126	153	144
		Character			133	146	140
Mean heart rate ($b.min^{-1}$)	Cohen, Segal, Witriol, & McArdle, 1982	**Ballet**	Pro	Female	117	137	
				Male	134	153	
	Wyon et al., 2002	**Contemporary**	Student	Mean	103	125	118
			Graduate		133	132	133
			Pro		98	121	111
	Wyon et al., 2004	**Contemporary**	Mixed	Female	107	122	117
				Male	108	126	118
	Baillie et al., 2007	**Highland**	Pro	Female			151.9
	Dahlstrom, 1997	**Multiple**	Student	Female	132	137	134
Mean % heart rate max	Dahlstrom, 1997	**Multiple**	Student	Female	69	72	71
Mean blood lactate ($mmol.L^{-1}$)	Dahlstrom et al., 1996	**Ballet**	Student	Mean			6.6
		Contemporary					3.8
		Jazz					2.6
		Character					4.9

	Schantz & Astrand, 1984	**Ballet**	Pro	Mean			3
	Dahlstrom 1997	**Multiple**	Student	Female			3
Mean energy expenditure ($Kcal.min^{-1}$)	Cohen, Segal, Witriol, & McArdle, 1982	**Ballet**	Pro	Female	3.96	4.86	
				Male	5.85	8.38	
	Wyon et al., 2002	**Contemporary**	Student	Mean	3.7	5.7	4.8
			Graduate		5.9	7.3	6.4
			Pro		4.4	6.3	5.3
Mean work time (sec)	Guidetti, Gallotta, et al., 2007	**Ballet**	Student	Female			68
	Schantz & Astrand, 1984			Mean	60	25	
Mean rest time (sec)	Guidetti, Gallotta, et al., 2007	**Ballet**	Student	Female			92
	Schantz & Astrand, 1984			Mean	30	80	
Mean % work time	Dahlstrom et al., 1996	**Ballet**	Student	Mean	60	46	55.3
		Contemporary			64	45	57.3
		Jazz			52	30	39.6
		Character			60	45	49.5
	Wyon et al., 2002	**Contemporary**	Student	Mean	69	33	
			Graduate		78	49	
			Pro		79	41	
	Wyon et al., 2004		Mixed	Female	74.83	41.85	
				Male	80.93	46.45	
Total time at 60-90% HR_{max} (min)	Rimmer et al., 1994	**Ballet**	Student	Mean			46.8

Table 2.2. Mean data of studies examining energy demand of a single exercise within dance class

Variable	References	Genre	Level	Gender	Mean
Mean VO_2 ($ml.kg^{-1}.min^{-1}$)	Oliveira et al., 2010	**Tap**	Student	Female	28.2
	Maciejczyk & Feć, 2013	**Folk**		Female	34.23
				Male	37.75
Mean overall O_2 cost ($ml.kg^{-1}$)	Guidetti, Emerenziani, et al., 2007	**Ballet**	Student	Female	37.5
	Guidetti et al., 2008				87.5
Mean $\%VO_{2max}$	Oliveira et al., 2010	**Tap**	Student	Female	68.9
	Maciejczyk & Feć, 2013	**Folk**		Female	81.1
				Male	74.3
Mean heart rate ($b.min^{-1}$)	Oliveira et al., 2010	**Tap**	Student	Female	171
	Maciejczyk & Feć, 2013	**Folk**	Student	Female	178.3
				Male	167.8
Mean % heart rate max	Oliveira et al., 2010	**Tap**	Student	Female	83.8
	Maciejczyk & Feć, 2013	**Folk**		Female	91
				Male	85

Mean blood lactate ($mmol.L^{-1}$)	Oliveira et al., 2010	**Tap**	Student	Female	1.7
Mean %VO_2 at lactate threshold	Oliveira et al., 2010	**Tap**	Student	Female	88.2
Mean aerobic system use ($ml.kg^{-1}$)	Guidetti, Emerenziani, et al., 2007	**Ballet**	Student	Female	12
	Guidetti et al., 2008			Female	63
Mean anaerobic alactic system use ($ml.kg^{-1}$)	Guidetti, Emerenziani, et al., 2007	**Ballet**	Student	Female	19.5
	Guidetti et al., 2008			Female	18
Mean anaerobic lactic system use ($ml.kg^{-1}$)	Guidetti, Emerenziani, et al., 2007	**Ballet**	Student	Female	5.5
	Guidetti et al., 2008			Female	7
Mean energy expenditure ($KCal.min^{-1}$)	Maciejczyk & Feć, 2013	**Folk**	Student	Female	10.08
				Male	14.52
Mean energy expenditure (METS)	Oliveira et al., 2010	**Tap**	Student	Female	8.1

2.4.2. Energy demand of rehearsal

Very few studies have presented data on the energy demands of rehearsal and high variation is reported between results of those that have. Therefore, an ambiguity regarding the demands of rehearsal prevails. Measurements during rehearsals have been undertaken in ballet (Rimmer et al., 1994; Schantz & Astrand, 1984), contemporary (Wyon et al., 2004), and highland dance (Baillie et al., 2007), with samples taken from student and/ or professional dancers. Two of the papers included in this section of the review claim to have also measured performance data, however Schantz and Astrand (1984) do not differentiate between measurements that took place in final rehearsals and those conducted during performance, and Wyon et al. (2004) used measurements undertaken within dress rehearsals as their performance data. Therefore, all data described above is included here as measuring the physiological demands of dance rehearsal. Data available from these studies is reported in Table 2.3, with more detailed information relating to specific methodologies available in Supplementary Table 2 (appendices).

Reported mean HR values for female participants range from 108-176.9b.min^{-1} across two studies (Baillie et al., 2007; Wyon et al., 2004), with the third reporting HR values “frequently close to max” (Schantz & Astrand, 1984), and the final study reporting that dancers spend 52% of the rehearsal time working at 60-90% HR_{max} (Rimmer et al., 1994). One study described the structure of rehearsals stating that segments of dance were performed at a high intensity level followed by a period of rest (Rimmer et al., 1994). One study reported significant differences for both mean O_2 requirement and mean HR between rehearsal and dress rehearsal measurements, with no significant differences between sexes (Wyon et al., 2004).

Table 2.3. Mean data of studies examining the demand of dance rehearsal

Variable	Reference	Genre	Level	Gender	Rehearsal	Dress Rehearsal
Mean VO_2 ($ml.kg^{-1}.min^{-1}$)	Wyon et al., 2004	**Contemporary**	Mixed	Female	10.17	23.34
				Male	17.19	24.85
Mean heart rate ($b.min^{-1}$)	Wyon et al., 2004	**Contemporary**	Mixed	Female	108	132
				Male	112	134
	Baillie et al., 2007	**Highland**	Pro	Female	172.6	
End-exercise blood lactate ($mmol.L^{-1}$)	Schantz & Astrand, 1984	**Ballet**	Pro	Mean	11	
Mean energy expenditure ($KCal.min^{-1}$)	Wyon et al., 2004	**Contemporary**	Mixed	Female	2.63	6.67
				Male	5.93	8.49
Total mean time at 60-90% HRmax (min)	Rimmer et al., 1994	**Ballet**	Student	Mean	45.1	

2.4.3. Energy demand of performance

The intensity of dance performance is almost unanimously described as high/ heavy, with an intermittent nature, utilizing both aerobic and anaerobic energy systems, by the available literature.

Eleven papers have measured aspects of performance or competition, although the conditions under which measurements were taken do vary (Table 2.4). Five studies involved simulated competition, mimicking temporal characteristics of typical competition format in Dance Sport (Latin American or Ballroom) (Blanksby & Reidy, 1988; Bria et al., 2011; Kļonova & Kļonovs, 2010; Liiv, Jurimae, Klonova, & Cicchella, 2013; Massidda, Cugusi, Ibba, Tradori, & Calo, 2011). Three studies have undertaken real-time heart rate measurements: one during a scheduled championship competition (Baillie et al., 2007), one during stage performance (Cohen, Segal, & McArdle, 1982), and one immediately post-performance (Galanti et al., 1993). Two studies undertook retrospective analysis from video recordings of performances (Twitchett, Angioi, Koutedakis, & Wyon, 2009; Wyon et al., 2011), and the remaining study does not specifically outline the conditions of the heart rate and blood lactate measures taken (Redding et al., 2009). The majority of these studies examined professional dancers, with only one study taking its sample from student dancers. Data were reported on a variety of variables as outlined in Table 2.4. More detailed information relating to specific methodologies of each study are available in Supplementary Table 3 (appendices).

The data available suggests a high mean intensity of dance performance/ competition across all genres, with participants frequently reported as reaching over 80% of their HR_{max} (Blanksby &

Reidy, 1988; Cohen, Segal, & McArdle, 1982; Galanti et al., 1993) and/or VO_{2max} (Blanksby & Reidy, 1988; Liiv et al., 2013). However, when looking more in-depth at the data available, there seems to be no agreement regarding the amount of variation both within and between performance repertoires examined. One study found significant variations in percentage time spent working at different intensities among different positions within a classical ballet company, with soloists spending a higher percentage of total time resting compared to principals and principals spending a higher percentage time working at moderate intensity than soloists and artists (Twitchett, Angioi, et al., 2009). The same study commented on little variation between the demands of different classical repertoire examined (Twitchett, Angioi, et al., 2009). Similarly, when comparing end-performance blood lactate levels in contemporary dancers, no significant difference was noted in values from four different pieces of repertoire, with all measurements noted as under $4mmol.L^{-1}$ (Redding et al., 2009). Conversely, one study found significant differences in blood lactate levels between the three dance techniques performed in highland dance ($p<0.01$) (Baillie et al., 2007). In a study comparing performance repertoire of two dance genres (ballet and contemporary/ modern), significant differences were found between genres for time ($s.min^{-1}$) spent at all subjectively categorized exercise intensities (excluding 'hard'). For example, significantly more time was spent at 'rest' and 'very hard intensities' during ballet than during contemporary performance ($p<0.001$) (Wyon et al., 2011). Based on the data presented, it is currently unclear whether any generality can be drawn in the intensity of performance between or within dance genres.

Table 2.4. Mean data of studies examining demand of dance performance and/or competition

Variable	Reference	Genre	Level	Gender	Mean
Peak VO_2 ($ml.kg^{-1}.min^{-1}$)	Liiv et al., 2013	**Dance Sport - Ballroom**	Pro	Female	43.8
				Male	50.5
Mean VO_2 ($ml.kg^{-1}.min^{-1}$)	Blanksby & Reidy, 1988	**Dance Sport - Ballroom**	Pro	Female	34.7
				Male	42.8
		Dance Sport - Latin		Female	36.1
				Male	42.8
Peak $\%VO_{2max}$	Liiv et al., 2013	**Dance Sport - Ballroom**	Pro	Female	88.1
				Male	75.8
Mean $\%VO_{2max}$	Blanksby & Reidy, 1988	**Dance Sport - Ballroom**	Pro	Female	82.8
				Male	82.3
		Dance Sport - Latin		Female	85.9
				Male	81.9
	Bria et al., 2011	**Dance Sport - Ballroom**		Female	72.5
				Male	75.7
		Dance Sport - Latin		Female	70.8
				Male	84.2

Peak heart rate (b.min^{-1})	Cohen, Segal, & McArdle, 1982	**Ballet**	Pro	Mean	178.2
	Redding et al., 2009	**Contemporary**	Pro	Mean	187
Mean heart rate (b.min^{-1})	Cohen, Segal, & McArdle, 1982	**Ballet**	Pro	Mean	160
	Redding et al., 2009	**Contemporary**		Mean	101
	Baillie et al., 2007	**Highland**		Female	195
	Klonova & Klonovs, 2010	**Dance Sport - Ballroom**		Female	173.05
				Male	168.8
	Blanksby & Reidy, 1988			Female	173
				Male	170
		Dance Sport - Latin		Female	177
				Male	168
Mean % heart rate max	Cohen, Segal, & McArdle, 1982	**Ballet**	Pro	Mean	81.5
	Galanti et al., 1993	**Jazz**	Student	Female	94.3
	Blanksby & Reidy, 1988	**Dance Sport - Ballroom**	Pro	Female	88
				Male	86
		Dance Sport - Latin		Female	91
				Male	85
Mean end blood lactate (mmol.L^{-1})	Redding et al., 2009	**Contemporary**	Pro	Mean	2.45
	Baillie et al., 2007	**Highland**		Female	6.2
	Liiv et al., 2013	**Dance Sport - Ballroom**		Female	8.7
				Male	8.0
	Bria et al., 2011			Female	6.91
				Male	6.50
		Dance Sport - Latin		Female	6.04
				Male	7.95
Mean energy expenditure (total KCal)	Massidda et al., 2011	**Dance Sport - Latin**	Pro	Female	159.9
				Male	251
% total time dancing	Wyon et al., 2011	**Ballet**	Pro	Female	62.76
				Male	61.65
		Contemporary		Female	71.28
				Male	66.56
Mean time at rest (s.min^{-1})	Wyon et al., 2011	**Ballet**	Pro	Female	37.22
				Male	38.5
		Contemporary		Female	18.64
				Male	20.06
Mean % total time at rest	Twitchett, Angioi, et al., 2009	**Ballet**	Pro	Mean	64.1
Mean time at very light intensity (s.min^{-1})	Wyon et al., 2011	**Ballet**	Pro	Female	4.88
				Male	6.21
		Contemporary		Female	8.33
				Male	8.95
Mean time at light intensity (s.min^{-1})	Wyon et al., 2011	**Ballet**	Pro	Female	3.55
				Male	2.85

		Contemporary		Female	16.41
				Male	13.74
Mean time at moderate intensity (s.min^{-1})	Wyon et al., 2011	**Ballet**	Pro	Female	8.34
				Male	5.59
		Contemporary		Female	13.77
				Male	9.99
Mean % total time at moderate intensity	Twitchett, Angioi, et al., 2009	**Ballet**	Pro	Mean	13
Mean time at hard intensity (s.min^{-1})	Wyon et al., 2011	**Ballet**	Pro	Female	7.68
				Male	4.61
		Contemporary		Female	4.28
				Male	6.59
Mean % total time at high intensity	Twitchett, Angioi et al., 2009	**Ballet**	Pro	Mean	11.3
Mean time at very hard intensity (s.min^{-1})	Wyon et al., 2011	**Ballet**	Pro	Female	2.06
				Male	3.34
		Contemporary		Female	0
				Male	0.589

2.4.4. Impact of training/ performance on cardiorespiratory fitness

Data presented suggests that a programme of dance activity alone is insufficient to elicit improvement in cardiorespiratory fitness, with the exception perhaps of a prolonged period of performance. This is suggested as causal of the low aerobic fitness levels often reported in dancers.

Nine studies examined adaptation of elements of cardiorespiratory fitness longitudinally over a range of training approaches. Four studies did not alter the training undertaken and simply measured at multiple time-points to see the effect of a typical training/ performance period (Dahlstrom et al., 1996; Koutedakis et al., 1999; Martyn-Stevens, Brown, Beam, & Wiersma, 2012; Wyon & Redding, 2005) (Table 2.5). However, five studies additionally involved intervention in the dancers' usual training schedule, by introducing fitness training programmes/ sessions, or extra classes/ rehearsals into the dancers' schedules (Angioi, Metsios, Twitchett, Koutedakis, & Wyon, 2012; Galanti et al., 1993; Koutedakis et al., 2007; Mistiaen et al., 2012; Ramel, Thorsson, & Wollmer, 1997) (Table 2.6). More detailed information relating to specific methodologies of each study are available in Supplementary Table 4 (appendices).

Of the four studies that did not implement an intervention to the schedules and/or training of the dancers', differences can be observed in available data related to the characteristics of the dancers' schedules at the time of testing, for instance between periods of rehearsal and periods of performance (Wyon & Redding, 2005). Over the course of a three year dance training programme, with aerobic fitness measured four times per year, a significant change in predicted VO_{2max} was only observed between the first and second half of the third year of study (Dahlstrom et al., 1996). A sub-set of participants who completed measurements at all time points, recorded a mean 20% increase over the three years (Dahlstrom et al., 1996). Two studies examined changes in cardiorespiratory fitness during a narrower time frame of a specific rehearsal and performance cycle/ season, with contrasting findings (Martyn-Stevens et al., 2012; Wyon & Redding, 2005). One study undertook a VO_{2max} test and the Wingate anaerobic bike test 10-12 weeks prior to a single performance and then again one-to-two weeks following the performance, reporting significant increases in absolute and relative peak power output and fatigue index, but no significant changes in VO_{2max} values (Martyn-Stevens et al., 2012). Whereas, significant decreases in HR, $\%HR_{max}$ and BLa values at stage 5 of the DAFT were observed following an eight week performance period (tour), indicating enhanced aerobic fitness (Wyon & Redding, 2005). In the same study, no significant differences were reported during a 12 week rehearsal period leading up to the performance period (Wyon & Redding, 2005). The fourth study measured changes in VO_{2max} and anaerobic power over the course of a six week rest/ holiday period and over the course of the subsequent two-to-three month training period. During the rest period significant increases were reported in peak anaerobic power ($p < 0.01$) and VO_{2max} ($p < 0.05$), with a further increase reported in VO_{2max} during the subsequent training period (Koutedakis et al., 1999).

Across all nine studies, mean VO_{2max} values reported ranged from 37.4(±4.1) to 56.6(±9.3) $ml.kg^{-1}.min^{-1}$, with the top end of the range representing data recorded immediately post-aerobic training intervention. Furthermore, all five studies that implemented an intervention into the typical training schedules of the dancers, reported significant increases in measures of aerobic fitness in participants exposed to the intervention (training/ exercise groups), despite differences in intervention design and length, and exercise protocol employed. One of these studies included only additional dance rehearsals, with no supplementary fitness intervention and noted improvements of 15% in a sub-maximal measure of VO_{2peak} (Galanti et al., 1993). Of the three studies that additionally undertook measurements with a control group, two also reported no significant changes in the mean VO_{2max} of control participants' (Koutedakis et al., 2007; Ramel, et al., 1997), with one reporting no increase in control participants' mean HR at DAFT stage 5 (Angioi et al., 2012). Finally, of note are the corresponding significant increases in measured aspects of dance ability/ competence found only in participants exposed to training intervention in two of the studies (Angioi et al., 2012; Koutedakis et al., 2007).

Table 2.5. Mean data of studies examining measures of cardiorespiratory fitness pre-, (mid-), and post- a schedule of dance training and/or performance without intervention

Variable	Reference	Genre	Level	Gender	1	2	3
VO_{2max} (ml.kg^{-1}.min^{-1})	Koutedakis et al., 1999	**Ballet**	Pro	Female	41.2	45.2	48.4
	Martyn-Stevens et al., 2012	**Contemporary**	Student	Female	42.66	42.55	
	Dahlstrom et al., 1996	**Multiple**	Student	Mean	48	49	52
Mean HR DAFT stage 5 (b.min^{-1})	Wyon & Redding 2005	**Contemporary**	Pro	Mean	178.5	177.5	167
Mean %HRmax DAFT stage 5	Wyon & Redding 2005	**Contemporary**	Pro	Mean	90.5	89.95	84.85
Mean BLa DAFT stage 5 (mmol.L^{-1})	Wyon & Redding 2005	**Contemporary**	Pro	Mean	2.8	2.75	2.15
Mean power output (W)	Koutedakis et al., 1999	**Ballet**	Pro	Female	285.9	292	299
Peak power output (W)	Koutedakis et al., 1999	**Ballet**	Pro	Female	350	400	405
	Martyn-Stevens et al., 2012	**Contemporary**	Student	Female	430.08	463.92	
Mean fatigue index (%)	Martyn-Stevens et al., 2012	**Contemporary**	Student	Female	33.38	38.91	

Table 2.6. Mean data of studies examining measures of cardiorespiratory fitness pre- and post-implementation of a training intervention

Variable	Reference	Genre	Level	Gender	Group	Pre	Post
VO_{2max} (ml.kg^{-1}.min^{-1})	Ramel et al., 1997	**Ballet**	Pro	Mean	Training	47.8	50.9
					Control	50.9	51.3
	Koutedakis et al., 2007	**Ballet**	Student	Mean	Training	50.7	56.6
					Control	49.2	48.5
	Galanti et al., 1993	**Jazz**	Student	Female		37.4	43
Mean VO_2 at 75% HR_{max} (ml.kg^{-1}.min^{-1})	Mistiaen et al., 2012	**Multiple**	Student	Mean	Training	27.62	29.67
Mean HR DAFT stage 5 (b.min^{-1})	Angioi et al., 2012	**Contemporary**	Mixed	Female	Training	196	177
					Control	196	185
Max BLa (mmol.L^{-1})	Ramel et al., 1997	**Ballet**	Pro	Mean	Training	9.1	9.5
					Control	9.1	8.9
Mean power output at 75% HR_{max} (W.kg^{-1})	Mistiaen et al., 2012	**Multiple**	Student	Mean	Training	2.28	2.44
Dance test score	Koutedakis et al., 2007	**Contemporary**	Student	Mean	Training	73.9	109.2
					Control	76	81.5
Aesthetic competence score	Angioi et al., 2012	**Contemporary**	Mixed	Female	Training	38	43
					Control	45	42

2.5. Discussion

Evidence presented in the current review pertains to either the physiological demand of dance activity (within class, rehearsal or performance) or the longitudinal tracking of measures of aerobic and/ or anaerobic fitness. Significant differences are noted in the results of multiple variables presented, which are further discussed herein.

2.5.1. Physiological demand of dance activity

As demonstrated by results of studies included in this review, the classification of the degree of physiological strain placed on the body during dance class involves a complex interaction of the intermittent work and rest periods, and the varying intensities of work depending on specific movement vocabulary executed at different stages of the class. With most studies noting differences between two distinct phases that exist within dance classes of multiple genres, it is suggested that mean data based on the entire length of a class should be discarded. Wyon, et al. (2002) recommended that classification as a high intensity intermittent activity should only be applied to the centre phase work of the dance class. Furthermore, this study highlighted important influences on the total time spent dancing, such as the amount of time spent by the teachers correcting technique and the size of each group (Wyon et al., 2002).

It is evident from the review of literature that very few studies have examined dance rehearsal and amongst the data available variation is too high to allow a generalized statement of the energetic demand. In a review, Wyon (2005) noted the diversity in physical stresses previously reported and suggested the presence of a build in intensity of rehearsal closer to performance. As previously noted, a study by Wyon et al. (2004) reported significant differences for both mean O_2 requirement and mean HR between rehearsal and dress rehearsal measurements. While the length of time between the two measurements was not stated in this instance, this nevertheless supports the suggestion that there is likely to be an influence of rehearsal status on values. It is recommended that future studies give a detailed account of the time frame in which measurements were taken (i.e. how far along the rehearsal process) and describe the temporal characteristics of the rehearsal, including time spent learning, marking, correcting, and completing a full-run through at maximum effort. Full-run through intensity is likely to closely mirror that of performance, based upon data presented by Wyon et al. (2004). Conversely, Schantz and Astrand (1984), while not differentiating full data sets, noted heart rate values 5-10 $b.min^{-1}$ lower and blood lactate concentrations 8% lower during measurements without audience in rehearsal compared to those recorded during performance of the same dance piece by the same dancers.

While the high intensity nature of performance across dance genres is evident from data sets presented, there remains disagreement as to the diversity of different dance repertoire within single dance genres. On the one hand, there is the suggestion that performance demands vary considerably (Baillie et al., 2007; Wyon, 2005) and on the other hand, there is the suggestion that physiological demands rarely change dramatically with different repertoire (Redding et al., 2009; Twitchett, Angioi, et al., 2009). Only one study has carried out direct comparison between a range of performance repertoire of different dance genres, namely ballet and contemporary, and, as previously stated, reported significant differences in time spent working at a range of exercise intensities (Wyon et al., 2011).

The main problem faced in dance training, as highlighted by the data presented, is the significant differences apparent between the energetic demands of class, rehearsal, and performance. This, along with the lack of documented positive physiological adaptation occurring through periods of dance training and rehearsal, has often led to the conclusion that dancers are not physically prepared for performance (Wyon & Redding, 2005; Wyon et al., 2004). It is also important to acknowledge the relative nature of intensity measurements, such as those undertaken by literature presented. Wyon (2005) highlighted that, while the absolute intensity of a movement sequence, be it executed as part of class, rehearsal, or performance, is set by the teacher/ choreographer, the relative intensity recorded is largely influenced by the fitness of the individual dancer. It stands to reason that an individual with greater cardiorespiratory fitness would have an increased capacity to cope with the demands being placed on them during movement, therefore resulting in a documented lower relative intensity. This could be particularly important to consider in the analysis of performance data in light of suggestions that dancers do not possess the adequate fitness to cope with performance demand. Furthermore, Allen and Wyon (2008) suggest that dancers of a high skill level are likely to possess a very good economy of movement, reducing the physiological stress dancing places on them.

2.5.2. Impact of training/ performance on cardiorespiratory fitness

While studies have commented on the possible cardiorespiratory training effect of dance class based on total length of time spent in an appropriate training zone throughout the class (suggested as 60-70% HR_{max}), later studies have criticized this conclusion due to the small continuous time spans during which these values are attained. For example, Rimmer, et al.,

(1994) noted that HR was not elevated into a training zone for longer than one to six minutes at any given time.

In terms of rehearsals being able to elicit positive physiological adaptation, Redding and Wyon (2003) speculated... “often rehearsal periods are short and do not allow enough time for the physiological adaptation to take place that would enable the dancer to cope with the increased demands of performance” (p.10). Two studies have tracked change in fitness variables throughout a rehearsal period and noted no significant differences in aerobic fitness measures of VO_{2max} or HR at stage 5 of the DAFT (Martyn-Stevens et al., 2012; Wyon & Redding, 2005), but a significant difference in measures of anaerobic power (Martyn-Stevens et al., 2012). A complex interplay between time and intensity is again perhaps a limiting factor in aerobic adaptation, with the emphasis of rehearsals remaining on skill acquisition and learning.

The high intensity nature of performance has prompted speculation from research as to the possible training effect of performing, with suggestions of eliciting an aerobic training response (Blanksby & Reidy, 1988; Twitchett, Koutedakis, & Wyon, 2009). Intensities and durations during ballet performance have been noted as bearing similarities to recommendations for interval training, with the frequency of performance instead suggested as potentially limiting factor to positive adaptation (Cohen, Segal, & McArdle, 1982). No studies to date have clearly documented performing frequency, although one study by Wyon and Redding (2005) stated an eight week performance period for two separate contemporary dance companies and a significant change in stage 5 DAFT HRs over this time.

Control groups of intervention studies have typically involved a sample of dancers who continue their typical training schedule, or in other words are subjected to a ‘dance only’ programme. Over a 12-week period Koutedakis et al. (2007) noted no increase in VO_{2max} under this training condition, compared to a significant increase in the sample undertaking additional supplementary fitness training. A further study included an additional contemporary dance technique class for those in the ‘dance only’ condition and reported a non-significant change in markers of aerobic fitness (Angioi et al., 2012). Moreover, all studies included in the present review that involved supplementary fitness training intervention noted positive cardiorespiratory adaptation in exercise groups regardless of design, length, and protocol (Angioi, et al., 2012; Koutedakis et al., 2007; Mistiaen et al., 2012; Ramel et al., 1997). From the literature currently available, it can subsequently be concluded that in order to elicit positive adaptation in markers of cardiorespiratory fitness, supplementary fitness training is required. Wyon and Redding (2005) further suggest that: “Cardiorespiratory training needs to be planned and managed to the same extent as the rehearsal schedule to allow the dancers to peak for each performance period as physically as they do technically” (p.74).

2.5.3. Methodological considerations

Methodological limitations of the examined literature fall under four main categories: use of mean data, prediction of VO_2 from previous steady-state work, validity and reliability of fitness test protocols, and variables of focus.

Firstly, with all modes of dance activity described as intermittent and non-steady state in nature, the reporting of mean data is deemed somewhat invalid. As early as 1983, a review highlighted the potential underestimating of caloric expenditure in dance due to the inclusion of rest periods reducing the energy expenditure when calculated per unit of time (Kirkendall & Calabrese, 1983). Redding and Wyon (2003) also stated that “dance research that has attempted to measure work output in class, rehearsal, and performance often appears not to have considered two factors: first, that dance is not a steady-state activity ... and second, that mean calculation of work output probably does not provide particularly useful information” (p.15). However, studies have continued to report data in this way, commenting on the potential influence on results in some cases. It is of interest to document the intensity of work periods and that of rest periods separately, as well as examine response to transitory periods, to allow an understanding not only of work intensity, but also of features of recovery as important markers of efficiency and cardiorespiratory fitness.

Secondly, the use of HR-VO_2 relationships established during previous steady-state treadmill work to enable prediction of VO_2 from HRs measured during dance activity, as adopted by some previous research, has been invalidated by data supplied by two studies. Schantz and Astrand (1984) found the prediction of VO_2 in ballet class to be under-estimated by 3% (range: -9 to 21) during barre exercise, by 7% (range: -9 to 21) during moderate centre work, and by 15% (-1 to 21) during severe centre work. The findings of a later paper by Redding, et al., (2004) further confirmed these results, reporting differences of up to 30b.min^{-1} between the treadmill and dance protocols at any given VO_2 value and an increase in variability with increasing intensity, up to differences of 49b.min^{-1} at a VO_2 of 60ml.kg^{-1}.min^{-1}.

Thirdly, the validity, reliability, and sensitivity of adopted protocols for assessing cardiorespiratory fitness are questioned. For instance, the importance of weight bearing and muscle group activation has been highlighted (Redding & Wyon, 2003), suggesting that tests undertaken on a cycle ergometer, for example, may be less valid than those undertaken on a treadmill. The validity of prediction of maximal fitness from sub-maximal testing protocols is also questioned. Redding and Wyon (2003), in a review of aerobic testing methods, highlighted a necessary trade-off between reliability and validity in field predictions with potentially greater error versus lab based controlled tests. There may also be an influence of the timing of testing, as demonstrated by significant differences in VO_{2max}, before and after a six weeks holiday and again after a preparatory training period (Koutedakis et al., 1999). Martyn-Stevens, et al. (2012) also highlighted a possible influence of familiarity with the test protocols in improvements recorded during post-testing.

The choice of variables reported largely influence the conclusions of the studies presented. Cohen, Segal, Witriol, and McArdle (1982) highlighted the challenge of measuring absolute intensity of dance activity, due to an inability to accurately measure work output, as well as difficulties in relative measurements due to variability in the level of the dancer (time spent training/ skill level) and the type and style of dance. Potential influences of muscular contraction type on metabolic data outputs have also been cited. Guidetti, Gollotta, et al., (2007) speculated that during a ballet class, heart rate may be more closely associated with skeletal muscle contraction than the level aerobic demand, with a potential influence of the combination of static and dynamic leg and arm movements. Paschalis et al. (2012) further cited potential influences of eccentric muscular contraction during dance movement on resting energy expenditure and movement economy. Lastly, an overreliance on reporting VO_{2max} as a marker of cardiorespiratory fitness is noted. Guidetti, Gollotta, et al. (2007) commented on the importance of relating measurements to individual dancers' ventilatory and anaerobic thresholds as these proved more sensitive to detect differences between groups of varying skill levels compared to $\%VO_{2max}$ or %HR reserve or absolute HR. Given the high intensity nature of dance, measures relating to ventilatory and/or anaerobic and/or lactate thresholds seem valid, however have been examined by very few studies to date.

In addition, it is important to account for the conditions under which data claiming to document the intensity of performance or competition are collected. One study utilizing dress rehearsal data to represent performance was previously highlighted as potentially invalid and therefore analysed within this review as rehearsal data (Wyon et al., 2004). The use of simulated competition rather than actual competitive conditions in the available Dance Sport research (Bria et al., 2011; Blanksby & Reidy, 1988; Kļonova & Kļonovs, 2010; Liiv et al., 2013; Massidda et al., 2011) also perhaps warrants the same scrutiny. It is important to note the restriction placed on performance measurements by equipment, whereby only equipment that can be hidden under costumes is typically utilized in live performance or competition. This has led to an over-reliance on HR data; the questionable validity and reliability of which has already been discussed. It may therefore be pertinent for future research to examine the ability of carefully designed simulated conditions, such as these, to represent performance and/ or competition demands with an adequate degree of accuracy.

2.6. Conclusions and future recommendations

Most individual studies examined within this review claim that dance can be classified as high intensity, intermittent exercise. Based on the temporal data examined within this review, it can be agreed that dance is an intermittent activity; however, data are highlighted as inconsistent in terms of intensity, with large variability reported between study results. Furthermore, without a clearer conclusion regarding the intensity of dance training and performance, the levels of cardiorespiratory fitness required by dancers remain relatively unknown.

Previous reviews have commented on barriers to a consensual conclusion and suggest further research is necessary. Specific recommendations to guide future research, based upon the findings of this review, are as follows. Firstly, research should continue to be genre specific, with detailed accounts of technical and stylistic elements of the movement vocabulary being examined. Secondly, a greater breadth of performance repertoire, within and between genres, needs to be closely examined to gain a fuller understanding of demand, as well as similarities and/ or differences of measurements. This is necessary to determine appropriate cardiorespiratory fitness levels for dancers. Thirdly, a greater focus on threshold measurements is recommended due to the documented complex interplay between aerobic and anaerobic energy systems. Lastly, it is important for research to begin to combine temporal data relating to work and rest periods with real-time measurement of metabolic data in work and rest, in order to be able to quantify demand more accurately.

3. Reasons for the Research

3.1. Summary of Previous Research

The previous two chapters have outlined previous research examining the cardiorespiratory fitness and demands of contemporary dance within the wider context of the dance science research field and of applied physiological investigation. Early studies examining the physiological basis of dance in the 1980's laid the foundation for this work, which was then extended by a body of research published between 2003-2010, primarily by the same authors (Angioi, Koutedakis, Redding, Twitchett, and Wyon). However, since then the recommendations made by this body of research have not been followed up on, findings have not been corroborated through study replication, nor have new but related questions been adequately explored. In reality our understanding has not greatly developed in the past six years.

Based upon the examination of the body's physiological response to physical activity presented in chapter 1, it is likely that the response to dance activity is complex; particularly in relation to elements such as speed of oxygen uptake kinetics, metabolic thresholds, recovery during intermittent activity, and exercise economy. In order to summarise the current understanding of this response to dance activity, as available in the previous literature, five commonly presented conclusions are noted.

Firstly, that **dance activity predominantly consists of intermittent work periods of varying intensities**. As outlined in chapter 2, previous research has examined class, rehearsal, and performance of various genres. Class is described as an intermittent activity, with notable differences in intensity and temporal characteristics between the warm-up/ barre phase and the centre/ execution phase (Cohen, Segal, Witriol, & McArdle, 1982; Dahlstroem, 1997; Dahlstrom, Inasio, Jansson, & Kaijser, 1996; Schantz & Astrand, 1984; Wyon, Abt, Redding, Head, & Sharp, 2004; Wyon, Head, Sharp, & Redding, 2002). Significant differences between intensity characteristics of class are additionally noted for different sexes and levels of training/ technical ability (Wyon et al., 2002), although not between genres (Dahlstrom et al., 1996) or between techniques within the contemporary dance genre (Wyon et al., 2004). High variation in overall demand is noted in the limited research available on dance rehearsal, with a suggested influence of the stage of the rehearsal process measured on the cardiorespiratory demand experienced (Wyon et al., 2004). Performance data have primarily been collected on professional dancers and, although performance is frequently described as high intensity intermittent exercise, the amount of variability in the demands of different performance repertoire, both within and between genres, is unclear.

Secondly, that **significant differences exist in the cardiorespiratory demands of class, rehearsal, and performance**. Cardiorespiratory demand in dance could possibly be thought of as existing on a spectrum from low intensity class warm-up/ barre phase, early stages of rehearsals, to class execution/ centre phase, later stages of rehearsals, and higher intensity performance as demonstrated by data presented in chapter 2. Repeated measures have not been undertaken on the same individuals in all of these stages of training and performance; however, Wyon (2005) did note a build in the intensity of rehearsals closer to performance time.

Thirdly, previous research has often stated that **class and rehearsal intensity is insufficient to elicit an aerobic training response**. There is a general lack of documented positive cardiorespiratory adaptation to current training practices, which often leads to the conclusion that dancers are not physically prepared for the physical demands of performance (Wyon et al., 2004; Wyon & Redding, 2005). This documented higher intensity of performance is speculated to provide some positive training stimulus, with one study noting significant reductions in exercise heart rate following an 8 week performance period (Wyon & Redding, 2005).

Fourth, that **the aerobic capacity of dancers is relatively low**. This is often attributed to the limited training stimulus provided by class and rehearsal practices as outlined above, as well as the anecdotally reported lack of appropriate supplementary training integrated within these practices across different levels of dance. It is, however, also worth highlighting that limitations of current understanding of the demands faced in dance training and performance make it difficult to accurately determine what optimal cardiorespiratory fitness levels are for dancers. Furthermore, without substantial evidence of the impact that improved fitness levels can have on performance ability, the importance of high cardiorespiratory fitness levels for this population remains somewhat questionable.

Finally, that **high injury rates in dancers are often attributed to fatigue and overwork**. Dancers of all levels are suggested to often be working in a state of overtraining, burnout, or chronic fatigue due to the documented lack of rest time included in their schedules. Wyon and Koutedakis (2013) suggest that supplemental cardiorespiratory training may have a significant effect in combating dance injury due to the link between improved fitness levels and delayed on-set of fatigue.

There are several limitations associated with the previous research outlined above. The validity of these conclusions must, therefore, be considered. Dance science research in general suffers from single-study findings, meaning the overall evidence base is somewhat weak. Sample sizes are often small and differences have been found between genres and different levels of engagement and/or training. The generalisabilty of these single-study findings to dance activity as a whole is, therefore, poor. While there is a fair basis for the examination of cardiorespiratory demands and fitness in dance, with a prior grounding in ballet and contemporary dance in particular, the current evidence base available does not provide conclusive answers to the many research questions. This was further confirmed by the literature review within this thesis (chapter 2), which established that 47% of articles reviewed as part of the search, were returned as “limited” and 53% as “fair” upon quality assessment.

Five key limitations of previous dance investigations into cardiorespiratory physiology were highlighted and summarised in chapter 2, namely, reporting of mean data, indirect measurement of VO_2, protocols for assessing cardiorespiratory fitness, the choice of variables reported, and performance measurement settings. As an additional sixth concern, issues of generalisabillity continue to be raised, due to the variety of techniques and expressions within the contemporary dance genre in particular, as explored in chapter 1. Further considerations when appraising the previous literature include, limited longitudinal data available, data rarely presented relative to individual fitness levels, and difficulties in quantifying ‘good’ performance in dance due to its subjective assessment nature.

3.2. Aims and Outline of Studies

In light of aforementioned limitations to the existing knowledge base it is of interest to examine, critique, and attempt to address some of these concerns. Therefore, the overall aims of this PhD are:

1) To investigate the cardiorespiratory demands of contemporary dance performance repertoire
2) To investigate cardiorespiratory adaptation to contemporary dance training and performance
3) To critically appraise methods commonly used in physiological investigation into dance and propose recommendations for future research

The five studies presented within this thesis are extensions and enhancements of previous studies. They thoroughly appraise the conclusions drawn in previous studies as well as scrutinise the methodologies used.

Study 1 (chapter 4) utilises a large sample size to compare documented cardiorespiratory fitness levels of dancers from previous studies to those measured in vocational contemporary dance students. Both anaerobic threshold and VO_{2peak} are measured due to the paucity of data available in previous literature. Considerations for maximal testing in this population are discussed and protocols typically used in measurement critiqued.

Studies 2 and 3 (chapters 5 and 6) are longitudinal in nature and document dance specific cardiorespiratory adaptations across one training year in study 2 and one performance period in study 3. Previous literature has noted no change in fitness measures through dance training; however, has suggested improvement during performance periods. The two studies contribute to the limited available longitudinal data and report on a range of cardiorespiratory variables across time as well as commenting on important considerations regarding movement economy.

Study 4 (chapter 7) is a detailed descriptive study, which further investigates the demands of contemporary dance repertoire and examines both metabolic and temporal data, where previous studies have examined just one or the other. Study 4, therefore, gives a more detailed account of cardiorespiratory demand. Due to the variety of contemporary dance performance repertoire, this study adds to the available data and reports on a wide range of descriptive variables. Methodologies and variables reported are critiqued with the view of developing recommendations for future research.

Study 5 (chapter 8) is an exploratory study intended to acknowledge the role of cardiorespiratory conditioning in the overall performance enhancement of dancers and therefore its relationship to the enhancement of aesthetic and performance aspects of dance, as well as to overall health and fitness. Therefore, this study provides context to the importance of the prior four studies and addresses a vital, outstanding, question in the overall premise of this thesis.

3.3. Contributions

An overall discussion is presented in chapter 9, which integrates and compares the five studies; their findings, limitations, and overall applications to both dance training and performance practices and future research. A final chapter offers conclusions and highlights two broad contributions made by the thesis to the existing knowledge base. Firstly, original data presented contribute to that currently available in previous literature and extend the knowledge base regarding cardiorespiratory fitness levels of vocational contemporary dance students, longitudinal tracking of cardiorespiratory adaptation to vocational dance training, interrogation of the intensity of contemporary dance performance, and examination of the relevance of cardiorespiratory fitness to perceived performance ability. Data presented are highlighted as highly specific to the current structure of vocational contemporary dance training and therefore provide an in-depth insight into this setting. Secondly, a detailed account and interrogation of the methodologies used in previous dance science research is presented and critically evaluated, leading to the proposal of recommendations for future research outlining factors such as the need for future research design and appraisal to acknowledge the complexity of dance in its many forms.

4. Study 1: Cardiorespiratory Fitness in Female Vocational Contemporary Dance Students

4.1. Abstract

Within vocational training, the proportion of time spent in class, rehearsal, and performance shifts throughout a programme, from more focus on technique development through class in the first year, to more focus on performance by the third year. Therefore, we may be able to hypothesise differences in the fitness levels of individuals at various stages of vocational training**.** The aim of the present study is to assess cardiorespiratory fitness levels of students at various levels of vocational contemporary dance training and provide a large data set for future literature comparisons. A total of 72 female participants took part in testing: 12 first year (UG yr1) and 54 third year (UG yr3) undergraduate student dancers and 6 pre-professional postgraduate dancers (PG). All participants were recruited from one vocational dance conservatoire in the UK. The primary finding of the present study is that, between levels of experience, limited difference exists across mean VO_{2peak} and anaerobic threshold ($ml.kg^{-1}.min^{-1}$ and $\%VO_{2peak}$) values in vocational contemporary dance students. UG yr3 participants displayed significantly lower VO_{2peak} values than UG yr1 participants, however a clear reason for this difference is not apparent due to limitations of study design. Further research on appropriate protocols to use and variables to report in assessing the cardiorespiratory fitness of contemporary dancers is recommended as well as longitudinal tracking of cardiorespiratory fitness development in individuals through vocational contemporary dance training.

Key words: anaerobic threshold, aerobic capacity, VO_{2peak}, dance, vocational training, students, fitness testing

4.2. Introduction

As highlighted in chapter 1, the basis of cardiorespiratory fitness centres on the ability of cardiovascular and respiratory systems to support the resynthesis of ATP in working muscles to supply energy for muscular contraction. Dance activity requires the ability to perform high intensity, powerful, short-duration movement and more moderate intensity, sustained work throughout a class, rehearsal, or performance. Previous research has, therefore, classified dance activity as complex, diverse, non-steady state, intermittent, of moderate to high intensity, and with notable differences between training and performance intensities and durations (Cohen, Segal, Witriol, & McArdle, 1982; Redding & Wyon, 2003; Schantz & Astrand, 1984; Twitchett, Angioi, Koutedakis, & Wyon, 2009; Wyon, Abt, Redding, Head, & Sharp, 2004; Wyon, 2005). Training intensity, during class and rehearsal, has been highlighted as relatively low, with the amount of time spent at higher intensities below the duration necessary to elicit aerobic training adaptation, as reviewed by Beck, Redding, and Wyon (2015) (chapter 2). This is particularly pertinent for student, and low skill or inexperienced, dancers where the time spent giving technical corrections is high and group sizes are often large, limiting the total time spent dancing (Wyon, Head, Sharp, & Redding, 2002). The potential training effect of repeated performance in dancers is, however, often speculated due to a reported high mean intensity of dance performance across different dance genres. As positive training adaption relies not only on sufficient intensity and duration, but also frequency of exercise at that intensity, it is important to also consider the overall training and performance schedule of dancers. Within undergraduate vocational training, the proportion of time spent in class, rehearsal, and performance shifts throughout a programme, from more focus on technique development through class in the first year, to more focus on performance by the third year. Postgraduate courses incorporating work as a pre-professional company allow even more focus on performance and often include an extended performance period/ tour. Therefore, we may be able to hypothesise differences in the fitness levels of individuals at various stages of vocational training. One previous study by Dahlstrom, Inasio, Jansson, and Kaijser (1996), which tracked aerobic fitness throughout a three-year university-based dance training programme, documented a mean increase of 20% in VO_{2max} scores by the end of the third training year. Methodological limitations of this study are, however, noted, such as the use of a sub-maximal cycle ergometer test to predict VO_{2max}. Students in this study were also taught in a range of dance genres during the programme, including ballet, character, contemporary, and jazz. Such data are not available in focused, vocational contemporary dance training; however, previous data comparing the cardiorespiratory fitness of student and professional contemporary dancers, have noted lower fitness levels in student dancers, as previously outlined in section 1.6.

Therefore, it seems that cardiorespiratory fitness may develop throughout progression from student to professional practice.

Very little dance-specific research has examined threshold measurements as a marker of cardiorespiratory fitness. Table 4.1 displays the studies in dance populations that have recorded various threshold measures via incremental treadmill test, although no values for contemporary dancers are available. High values are noted across these studies, which roughly correspond to those previously reported for elite soccer players where values of 80-90% of maximum heart rate are reported (Stølen et al., 2005).

Table 4.1. Previous studies examining VO_{2max} and threshold parameters in dance populations

- Data are presented as mean ± standard deviation.

Study	Genre	Participants	Level	Gender	VO_{2max} ($ml.kg^{-1}.min^{-1}$)	Threshold measure	Threshold VO_2 ($ml.kg^{-1}.min^{-1}$)	Threshold $\%VO_{2max}$
Guidetti et al., 2007; Guidetti, et al., 2008	Ballet	Young pre-vocational (13-16)	A) Low ability	F	38.1 ± 1.9	Anaerobic threshold	20.9 ± 0.9	55.0 ± 5.00
			B) Intermediate		41.7 ± 1.4		24.6 ± 1.4	
			C) High ability		46.2 ± 2.1		27.7 ± 2.5	60.0 ± 5.00
Wyon et al., (2016)	Ballet	Professional company dancers	Principal	M	50.5 ± 1.60	Anaerobic threshold		83.6 ± 4.09
				F	45.9 ± 2.73			84.5 ± 5.60
			Soloist	M	46.1 ± 2.86			81.5 ± 6.03
				F	38.5 ± 4.64			80.8 ± 6.19
			Artist	M	50.1 ± 5.22			73.9 ± 4.66
				F	42.9 ± 3.91			77.1 ± 5.74
Maciejczyk & Feć, 2013	Polish Folk	Students, University Dance Team		M	51.80 ± 7.39	Metabolic acidosis	41.83 ± 1.10	81.9 ± 10.57
				F	43.43 ± 3.81		36.81 ± 2.09	85.1 ± 6.41
Oliveira et al., 2010	Tap	Recreational adults		F	32.2 ± 5.9	Lactate threshold		78.4 ± 9.3

Field based, dance specific tests for assessment of cardiorespiratory fitness have also been developed: the dance aerobic fitness test (DAFT; Wyon, Redding, Abt, Head, & Sharp, 2003), the high intensity dance performance fitness test (Redding et al., 2009), and the ballet-specific aerobic fitness test (Twitchett, Nevill, Angioi, Koutedakis, & Wyon, 2011). Each of these allows the measurement of the relative strain placed upon participants during specific dance movement, but due to their sub-maximal nature, they cannot be reliably compared to other cardiorespiratory fitness test results or extrapolated to give an absolute measure of individual aerobic capacity. However, the DAFT protocol in particular has been adopted in further research studies, including being used to evaluate the effectiveness of supplementary training interventions (Angioi, Metsios, Twitchett, Koutedakis, & Wyon, 2012). A recent study by Redding et al. (2015) presented 10 years of DAFT data, equalling 2046 data sets collected from a mixture of undergraduate full-time vocational student dancers and part-time pre-vocational student dancers all specialising in contemporary dance. Such normative data, specific to the level of experience and dance genre, were highlighted as enabling comparisons to be drawn by dance educators and researchers (Redding et al., 2015). There is a lack of normative data for dance populations and many studies suffer from small sample sizes. The aim of the present study is to assess cardiorespiratory fitness levels of students at various levels of vocational contemporary dance training and provide a large data set for future literature comparisons.

4.3. Methods

4.3.1. Experimental approach to the problem

A cross-sectional descriptive design was employed for this study, where student dancers were measured at one-time point only. Some variation does exist in test protocols adopted, since data are pooled from multiple research projects and screening assessments conducted at a dance conservatoire. Differences between VO_{2peak}, anaerobic threshold (AT; $ml.kg^{-1}.min^{-1}$), and AT (%VO_{2peak}) are reported for students of different levels of experience.

It is hypothesised that significant differences between groups will be found for both VO_{2peak} and AT data, with a null hypotheses that no significant differences will be detected between groups.

4.3.2. Participants

A total of 72 female participants took part in the testing. Participants were 12 first year (UG yr1) and 54 third year (UG yr3) undergraduate student dancers enrolled on a Bachelor of Arts (BA) contemporary dance programme and 6 pre-professional company dancers enrolled on a Masters of Arts (MA) dance performance programme (PG). All participants were recruited from one vocational dance conservatoire in the UK. Basic anthropometric data collected, including age (yrs), stature (m), mass (Kg), and calculation of body mass index (BMI; $Kg.m^{-2}$), are displayed in Table 4.2.

Table 4.2. Participant anthropometric data by level of experience (N = 72)

Experience	Age (yr)	Height (m)	Mass (Kg)	BMI ($Kg.m^{-2}$)
UG yr1 (N = 12)	20 ±1.24	1.65 ±0.09	57.83 ±8.26	21.35 ±2.75
UG yr3 (N=54)	22 ±1.81	1.64 ±0.07	55.00 ±6.23	20.50 ±1.49
PG (N = 6)	23 ±0.52	1.67 ±0.03	58.50 ±3.45	20.97 ±1.69

- Data are presented as mean ± standard deviation. UG yr1 = Undergraduate first year student dancers, UG yr3 = Undergraduate third year student dancers, PG = Postgraduate student dancers.

Each individual project under which data was collected received full ethical approval from the Research Ethics Committee at Trinity Laban Conservatoire of Music and Dance prior to participant recruitment, including approval for anonymous use of all data collected in future research projects. All participants were over 18 years of age (range 18-30 years) and free from injury and illness at the time of their individual assessment. All participants were informed of possible risks and benefits of their participation prior to signing an approved consent document.

4.3.3. Procedures

All individual participants undertook a one-off incremental treadmill test to volitional exhaustion. UG yr3 students undertook the treadmill test during a screening assessment, during the final term (June) of the final year of study, designed to assess fitness levels upon completion of their training. All other data (UG yr1 and PG students) were also collected during the third term (June) of the academic year for specific research studies.

All assessments were treadmill based incremental tests to volitional exhaustion to enable measurement of VO_{2max} and AT; however, there were slight differences in protocols adopted across time due to the nature of data collection. A range of protocols for determining VO_{2max} exist in previous research, including those based on continuous or discontinuous exercise, increments of speed and/or incline, and on treadmill or cycle ergometers. Due to the high variation in protocol design found across available literature, previous studies have attempted to compare different test protocols by undertaking repeated measures on the same participants. However, inconsistent results are reported, including no significant differences between protocols using increments of speed or incline (Davies, Daggett, Jakeman, & Mulhall, 1984; Kasch, Wallace, Huhn, Krogh, & Hurl, 1976), significantly higher VO_{2max} in incline than speed protocols (Pokan et al., 1995), and significantly higher VO_{2max} in a treadmill than a cycle ergometer protocol (Keren, Magazanik, & Epstein, 1980). Previous studies in dance populations have used a variety of protocols, some of which are summarised by Beck et al. (2015) (chapter 2). Guidelines provided by Wyon (2006) recommending short duration treadmill-based tests for dance populations were followed in all protocols used within the present study.

All participants completed a 6-minute warm up prior to the test consisting of 2-minutes walking (5-6 $Km.h^{-1}$) followed by 4-minutes running (7-9 $Km.h^{-1}$). For all protocols, a telemetric gas analyser (Metamax 3B, Cortex Biophysik GmbH, Germany) and heart rate monitor (Polar, Polar Electro, Finland) were fitted to the participant and worn throughout the duration of the test. Protocol 1 was a continuous protocol consisting of 2 minute stages with a speed increase of 1$Km.h^{-1}$ per stage for first 4 stages (8 minutes) and then a 1% increase in incline thereafter (Wilson, Pease, Sleivert, & Shearman, 2003). Start speed was determined based upon heart rate at the end of the warm-up (range 9-12 $Km.h^{-1}$). Protocol 2 was discontinuous to allow for blood lactate measurements between each stage, which were 3 minutes in length. Start speed was determined during the warm-up and set to allow the completion of a minimum of 5 and maximum of 9 stages (range 8-9 Km.h-1) and followed by speed increase of 1 $Km.h^{-1}$ per stage (Spurway & Jones, 2006). Protocol 3 consisted of continuous 1-minute stages with a speed increase of 1 $Km.h^{-1}$ per stage at a 1% incline (Wyon, 2006). Start speed was set based upon speed during the warm up corresponding to a heart rate of 120 $b.min^{-1}$ (range 6-9 $Km.h^{-1}$). All tests continued until volitional cessation or until two of the following criteria were achieved: heart rate within 10 $b.min^{-1}$ of age-predicted maximum, respiratory exchange ratio (RER) above 1.15, VO_2 plateau despite increase in speed, or inability to match treadmill speed. On completion of the test, participants cooled-down by walking at a speed of 5-6 $Km.h^{-1}$ for a further 5 minutes or until a heart rate value of less than 100 $b.min^{-1}$ was achieved. Personal time was then given for stretching and further cool-down.

4.3.4. Data analysis

All breath-by-breath data were smoothed using a 6-breath average, followed by a reduction to 30 second average values, in accordance with methods adopted in previous literature (James, Sandals, Wood, & Jones, 2006; Guidetti, Emerenziani, Gallotta, Da Silva, & Baldari, 2008). All data points were reported as relative VO_2 ($ml.kg^{-1}.min^{-1}$) due to the weight bearing nature of the activity. Whether or not individuals attained true VO_{2max} was determined based upon meeting at least two of the previously detailed stop-test criteria, with additional definition of a VO_2 plateau as a final stage increase in workload, recording an increase in relative VO_2 of less than 2 $ml.kg^{-1}.min^{-1}$ (Howley, Bassett, & Welch, 1995; Poole, Wilkerson, & Jones, 2008). For the majority of participants no plateau in VO_2, despite increase in workload, was seen; therefore, VO_{2peak} values were calculated as the highest 30-second average data point following smoothing procedures and reported in results. Anaerobic threshold was determined using the V-slope method: taken as the point at which VCO_2 output increased relative to VO_2 intake (Wasserman et al., 2011) and expressed as both VO_2 ($ml.kg.^{-1}min^{-1}$) and $\%VO_{2peak}$. Calculation of anaerobic threshold was only possible for a sub-set of participants due to limited availability of full respiratory data sets (N =31).

4.3.5. Statistical analysis

The accepted p-value for significance was set at $p < 0.05$ for all statistical analyses. Three dependent variables, VO_{2peak}, AT ($ml.kg^{-1}.min^{-1}$), and AT ($\%VO_{2peak}$), and one independent variable, level of experience, were identified for analysis. All variables were checked for normal distribution using the Shapiro-Wilk statistic. Due to inconsistency of normal distribution found in dependent variables different statistical tests were used to ensure accurate analysis of findings. VO_{2peak} data were not normally distributed when categorised by experience level; therefore, a Kruskal-Wallis H test with Tamhane's T'2 post-hoc analysis (equal variances not assumed) was run. All AT ($ml.kg^{-1}.min^{-1}$) and AT ($\%VO_{2peak}$) data were normally distributed; therefore, a One-way ANOVA with Bonferroni correction post-hoc analysis was run.

4.4. Results

Statistical analyses revealed a significant difference between levels of experience for mean VO_{2peak} values ($X^2(2) = 12.268$, $p < 0.01$), with significantly lower mean values achieved by UG yr3 students than UG yr1 students (mean difference = -5.09, $p < 0.05$). No significant differences were found relating to AT (as either $ml.kg^{-1}.min^{-1}$ or $\%VO_{2peak}$).

Table 4.3. Mean VO_{2peak} (N = 72) and anaerobic Threshold (AT) (N = 31) of contemporary dance students by level of experience

Level of Experience	VO_{2peak} ($ml.kg^{-1}.min^{-1}$)	Level of Experience	AT ($ml.kg^{-1}.min^{-1}$)	AT ($\%VO_{2peak}$)
UG yr1 (N = 12)	42.81 ±4.59	**UG yr1 (N= 12)**	40.05 ±5.66	93.30 ±4.84
UG yr3 (N = 54)	37.73* ±5.59	**UG yr3 (N = 13)**	35.45 ±9.19	87.26 ±8.11
PG (N = 6)	41.36 ±3.51	**PG (N = 6)**	38.10 ±4.07	92.00 ±2.56

- Data are presented as mean ± standard deviation. UG yr1 = Undergraduate first year student dancers, UG yr3 = Undergraduate third year student dancers, PG = Postgraduate student dancers.

* significant difference to UG yr1 ($p < 0.05$)

4.5. Discussion

The aim of this study was to assess cardiorespiratory fitness levels of students at various levels of vocational contemporary dance training and provide a large data set for future literature comparisons. The primary finding was that limited difference between levels of experience exist across mean VO_{2peak} and AT ($ml.kg^{-1}.min^{-1}$ and $\%VO_{2peak}$) values in vocational contemporary dance students. UG yr3 participants did display significantly lower VO_{2peak} values than UG yr1 participants; however, a clear reason for this difference is not apparent as further discussed below.

Reported VO_{2peak} values for UG yr1 and PG participants are higher than the previously reported mean for female contemporary dance students (Angioi et al., 2009), while the UG yr3 mean value falls slightly below this. The highest VO_{2peak} values in the present study were found for UG yr1 students, which contrasts with the hypothesised effect of continued vocational training and with findings of previous research (Dahlstrom et al., 1996). One previous study has highlighted the potential influence of the time of year measurements are recorded, finding that low cardiorespiratory fitness levels are often documented at the end of a training year or performance season related to fatigue and symptoms of overtraining often detected in dancers at this time (Koutedakis et al., 1999). As all measurements were taken at the end of a busy academic year, this may have influenced results of all three groups in the present study; however, as all were measured at the same time is unlikely to explain differences highlighted between groups.

The differences in protocols undertaken by each group also do not seem to explain the differences noted between groups. All UG yr3 students undertook protocol 1, which included both speed and incline increments, whereas UG yr1 and PG students all undertook protocols 2 or 3, which included speed increments only. As previously discussed, research has produced inconsistent findings regarding the influence of protocol on VO_{2max} values, however incline-increment based protocols have been found to result in VO_{2max} values either no different to (Davies et al., 1984; Kasch et al., 1976), or significantly higher than (Pokan et al., 1995) those calculated from speed-increment based protocols. No previous research has directly compared protocols in dance populations.

Similar trends to those reported for VO_{2peak} were found between groups for AT (ml.kg^{-1}.min^{-1} and %VO_{2peak}); however, these were non-significant. Mean AT (%VO_{2peak}) values in the present study were higher than those previously reported for dancers (Guidetti et al., 2008; Guidetti, Emerenziani, et al., 2007; Maciejczyk & Feć, 2013; Oliveira et al., 2010; Wyon et al., 2016) although direct comparisons are not possible due to differences in dance genres and level of experience of participants. Higher reported values in the present study may also be skewed by VO_{2peak} data, where participants stopping at a submaximal intensity short of their true maximal capacity would lead to a lower VO_2 value and, therefore, a higher percentage representation of AT relative to this.

Limitations of VO_{2peak} data highlighted above, call into question the validity of measuring and reporting this variable in dance populations, since dancers rarely satisfy maximal test criteria. Dancers rarely work maximally or even aerobically for long periods of time therefore requirements of the test are suggested to be unfamiliar to them. This has been highlighted by previous dance research and formed part of the rationale for the development of dance specific fitness tests (Redding et al., 2009; Twitchett, Nevill, Angioi, Koutedakis, & Wyon, 2011; Wyon et al., 2003). It is of note however that all participants were able to reach and continue to work at least slightly above their AT during all test protocols; therefore, this may provide a more reliable measure to report.

A further limitation of the present study design lies in the cross-sectional nature of measurements. Repeated measures on the same participants across time would have allowed for a more systematic analysis of training adaptation throughout the programmes examined, or equally repeated measures on the same participants on different test protocols would give further insight into the influence of the protocol adopted on results. In the current study design there are too many covariates between groups to make a conclusive statement on the differences reported between them. However, this study has achieved its aim to present a normative data set and has highlighted important methodological considerations for future research in this area.

4.6. Conclusions

The present study suggests that limited physiological development is currently being achieved throughout vocational contemporary dance training in the studied sample. Therefore, the null hypothesis of this study was accepted, although a number of limitations to study design are noted. There is benefit to establishing more normative data within specific dance populations to allow comparisons, but further research on appropriate protocols is recommended as well as longitudinal tracking of cardiorespiratory fitness variables in individuals throughout vocational training in order to further our knowledge base.

5. Study 2: Changes in Energy Demand of Dance Activity and Cardiorespiratory Fitness During One Year of Vocational Contemporary Dance Training

5.1. Abstract

Previous literature has demonstrated that the intensity of dance class, as well as its discontinuous nature, is not sufficient to elicit an aerobic training response and that the aerobic capacity of dancers is relatively low. These findings have raised questions as to the suitability of dance training as adequate preparation for the higher recorded intensity of performance. The aim of this study was to describe changes in aerobic fitness and energy cost of dance movement occurring throughout one year of training. Participants were thirteen female dance students, seven first year undergraduate students (UG), and six postgraduate students (PG). At three time-points (TP1, TP2, TP3) during one academic year, each participant completed a treadmill test, to determine VO_{2peak} (ml.kg^{-1}.min^{-1}) and lactate threshold (LT) (ml.kg^{-1}.min^{-1} and %VO_{2peak}), and a standardised four-minute dance sequence, where mean demand was expressed as VO_2 (ml.kg^{-1}.min^{-1}), heart rate (b.min^{-1}), %VO_{2peak}, and %LT. Both groups displayed an overall decrease in mean VO_{2peak} throughout the year, despite a peak in fitness at TP2 in the PG students. No significant changes in LT were noted over time for either group. A significant reduction in the relative intensity of the dance sequence, particularly in relation to mean VO_2 (ml.kg^{-1}.min^{-1}) and %LT data, was observed over time in both groups although the degree of change was less in the UG group than the PG group. Apparent adaptations during a rehearsal period in the PG group are presented in contrast to previous research findings. Recommendations for future research include further investigation into the energy demand of rehearsal and cardiorespiratory adaptation during rehearsal periods as well as further reporting of measures related to LT and movement economy.

Key words: female dancers, training adaptation, energy demand, economy, lactate threshold, VO_{2peak}.

5.2. Introduction

Based upon currently available research, as previously outlined (chapter 2), the lower documented intensity of dance class and rehearsal, compared to performance, is often cited as the primary cause of low cardiorespiratory fitness levels often documented in dancers. This has raised questions about the suitability of training, through class and rehearsal, as adequate preparation for the physical demands of a sustained and successful career in dance. It is, therefore, of interest to document the extent of physiological adaptation to vocational contemporary dance training, in terms of global cardiorespiratory fitness and specific response to dance movement.

The majority of studies in this area have undertaken cross-sectional physiological profiles of dancers across various genres, with only four studies conducting repeated measures over extended periods of time without intervention in training (Dahlstrom, Inasio, Jansson, & Kaijser, 1996; Koutedakis et al., 1999; Martyn-Stevens, Brown, Beam, & Wiersma, 2012; Wyon & Redding, 2005). Very little change in aerobic capacity (VO_{2max}/VO_{2peak}) or heart rate (HR) response to the dance aerobic fitness test (DAFT) (Wyon, Redding, Abt, Head, & Sharp, 2003) is documented in these studies, with the exception of participants participating in extended periods of performance (Wyon & Redding, 2005). Conversely, previous research involving intervention through additional supplementary fitness training has noted significant improvements in the same variables (Angioi, Metsios, Twitchett, Koutedakis, & Wyon, 2012; Koutedakis et al., 2007; Mistiaen et al., 2012; Ramel, Thorsson, & Wollmer, 1997). However, there are many limitations to these studies as outlined in a previous review by the authors of this paper (Beck, Redding, & Wyon, 2015) (chapter 2). As dance activity, in multiple genres, is unanimously described as intermittent and of moderate to high intensity it is also questioned if the variables frequently reported are sensitive to the specific physiological development of dancers. For example, dancers rarely work maximally or aerobically for long periods of time; therefore, the lack of increase in VO_{2max} measures, as found by previous literature, may be expected.

It is of interest to examine the ability of dancers to meet the energy demands of specific sequences of dance movements required in their genre in more depth, particularly in a vocational setting, where dancers develop their technical skill and work towards high-level performance. The purpose of this study is therefore to track changes in key physiological variables over one training year (academic year) in different levels of vocational contemporary dance students.

5.3. Methods

5.3.1. Experimental approach to the problem

The study adopted a longitudinal design where the same participants were measured at three time-points throughout one training/academic year: October (TP1), February (TP2), and June (TP3). Identical testing procedures were used at each time point to allow direct comparison of measures. Dependent variables were aerobic capacity (VO_{2peak} [$ml.kg^{-1}.min^{-1}$]) and lactate threshold (LT [$ml.kg^{-1}.min^{-1}$ and $\%VO_{2peak}$]), as determined by a treadmill test to volitional exhaustion, and relative oxygen uptake (VO_2 [$ml.kg^{-1}.min^{-1}$]), heart rate (HR [$b.min^{-1}$]), percentage of maximal aerobic capacity ($\%VO_{2peak}$), and percentage of lactate threshold (%LT) during performance of a standardised dance sequence. These variables allowed representation of cardiorespiratory fitness and relative demand/intensity of dance movement, as well as any changes in these across time.

It is hypothesised that significant differences will be found in the degree of change between groups (as outlined below) for all stated variables with significant changes only documented following the performance period in the PG group. The null hypothesis is therefore that significant changes in all variables will occur in both groups through training and performance periods.

5.3.2. Participants

Required sample size was calculated, based upon data provided by Wyon & Redding (2005) for adaptation to dance training, as 25 (12 per group) based upon magnitude of effect at 90% confidence intervals. However, only thirteen female participants took part in this study: seven first-year undergraduate students enrolled in a Bachelor of Arts (BA) contemporary dance programme (UG) and six postgraduate students enrolled in a Masters of Arts (MA) dance performance programme (PG). Differences in the two programmes are noted with the PG students forming a pre-professional company and touring performance work from February to June. During this touring period, the PG group typically undertook a 1.5 hour technique class and around two hours of rehearsals each day (range 1-2.5 hours) and performed an average of once per week for 1.25 hours. Before the touring period PG students typically undertook 1.5 hours of technique class, followed by 4-5 hours of rehearsals each day. UG students throughout the year typically have 3 hours of technique class per day, plus choreography and academic classes. Data from research documenting the physiological demands of these activities is available in a previous review by the authors of this paper (Beck et al., 2015) (chapter 2).

Basic anthropometric data collected at time-point 1 including age (yrs), stature (m), mass (Kg), and calculation of body mass index (BMI; $Kg.m^{-2}$), are displayed in Table 5.1.

Table 5.1. Mean participant anthropometric data by level of experience (N = 13)

Experience	Age (yr)	Height (m)	Mass (Kg)	BMI ($Kg.m^{-2}$)
UG (N = 7)	18.86 ±0.90	1.65 ±0.06	59.57 ±4.16	21.78 ±1.32
PG (N = 6)	22.17 ±0.75	1.67 ±0.03	58.50 ±3.45	20.97 ±1.69

- Data are presented as mean ± standard deviation. UG = Undergraduate student dancers, PG = Postgraduate student dancers.

The study was approved by the Trinity Laban Research Ethics Committee. All participants were over 18 years of age (range 18-23 years). All participants were informed of possible risks and benefits of their participation prior to signing an approved informed consent document.

5.3.3. Procedures

All participants completed a Medical Physical Activity Readiness Questionnaire (Par-Q) immediately prior to testing at each time-point. Each participant completed two separate test procedures at each time-point as outlined below.

5.3.3.1. Cardiorespiratory fitness testing

Each participant completed a treadmill test to volitional exhaustion to determine their individual LT and aerobic capacity (VO_{2max}/VO_{2peak}). The British Association of Sport and Exercise Science (BASES) approved test protocol for determining LT was adopted (Spurway & Jones, 2006). This involves the participants running on a treadmill ergometer with the "intensity... being increased every four minutes until the individual attains volitional exhaustion" (Spurway & Jones, 2006). Initial speed is set on an individual basis to allow the completion of a minimum of five and a maximum of nine stages, with a set increment between 0.5 and 1.5 $Km.h^{-1}$ (Spurway & Jones, 2006). To meet these criteria and successfully complete the test participants would have needed to run continuously for a minimum of 20 minutes. Based on previous literature on the aerobic fitness of dancers this may not be possible for all participants and the data collected may therefore be invalid. The suitability of this protocol for dancers was previously trialled by the authors and as a result the protocol was modified from four-minute stages to three-minute stages with increases of 1 $Km.h^{-1}$ each stage. This modification is in line with recommendations of Wyon (2006) to “minimise trauma to the subject”. A warm up was completed prior to each test consisting of two minutes walking at 6.0 $Km.h^{-1}$ and four minutes jogging at the participants’ start speed (range: 7.0-9.0 $Km.h^{-1}$). Throughout the test, data on pulmonary and oxygen uptake values were collected via participants wearing a telemetric gas analyser (Metamax 3B, Cortex Biophysik GmbH, Germany) and a heart rate monitor (Polar, Polar Electro, Finland). Capillary blood samples were collected from the earlobe within 30 seconds of the end of each test stage before the speed was increased and were analysed for blood lactate levels (Lactate Pro, Arkray Inc, Japan). All tests continued until volitional cessation or until two of the stop test criteria, as outlined in study 1, were achieved. Whether or not individuals attained true VO_{2max} was determined based upon meeting at least two these criteria, with additional definition of a VO_2 plateau as a final stage increase in workload recording an increase in relative VO_2 of less than 2 $ml.kg^{-1}.min^{-1}$ (Howley et al., 1995; Poole et al., 2008). If criteria were not satisfied, then the highest 30-second average value was taken as attained VO_{2peak}. Criteria for attainment of VO_{2max} were not consistently satisfied within the data set; therefore, all values were reported as VO_{2peak}. Lactate Threshold (LT) was estimated via a plot of measured blood lactate concentrations against treadmill speed for each individual participant. The threshold point was determined as the corresponding VO_2 ($ml.kg^{-1}.min^{-1}$) value above which net increases in lactate production were observed to result in sustained increase in blood lactate concentration (Wasserman et al., 2011).

5.3.3.2. Dance sequence testing

Each participant performed a four minute, pre-choreographed movement sequence, which was based on stage three of the DAFT (Wyon et al., 2003). This stage was designed to be representative of dance class intensity (Wyon et al., 2003). It has a low technical skill level to minimise the effect of learning and technical ability on measurement and, instead, allow an assessment of physiological responses to the task across time. A pilot test was conducted to ensure the complexity and intensity of the sequence was appropriate. Participants were required to wear the same telemetric gas analyser and heart rate monitor as used during the treadmill test throughout the movement. Measurements enabled determination of any changes in the relative intensity for each minute of the movement sequence across time-points. Each minute was expressed as VO_2 ($ml.kg^{-1}.min^{-1}$), HR ($b.min^{-1}$), $\%VO_{2peak}$, and %LT for each individual. Participants were also filmed while performing the sequence to allow visual checks of consistency in movement across participants and time-points. Any apparent anomalies in physiological data were cross-referenced with video footage to ensure this was not due to incorrect execution of movement.

5.3.4. Data analysis

All breath-by-breath gas data were smoothed, allowing for more accurate data analysis by removing considerable variability in individual data points (James et al., 2006). Following suggestions of BASES (James et al., 2006) and methods adopted in previous dance specific literature (Guidetti, Emerenziani, Gallotta, Da Silva, & Baldari, 2008), a six breath average was applied followed by a reduction to 30 second average values. All data points were reported as relative VO_2 ($ml.kg^{-1}.min^{-1}$), relative to individual body mass due to the weight bearing nature of the activity. Individual body mass was measured at each time-point immediately prior to the treadmill test to enable accurate calculation of VO_2 as $ml.kg^{-1}.min^{-1}$; therefore, any changes in individual body mass throughout the course of the study were taken into account in results. To enable analysis of demand during the dance sequence the mean VO_2 value ($ml.kg^{-1}.min^{-1}$) for the final minute (minute 4) was used to calculate mean $\%VO_{2peak}$ and mean %LT.

5.3.5. Statistical analysis

The accepted p-value for significance was set at $p < 0.05$ for all statistical analyses. All variables were checked for normal distribution using the Shapiro-Wilk statistic. A 2(group) x 3(time) repeated measures ANOVA with within-subjects difference contrast was run on each variable to assess for difference between groups across time. Effect size is reported via partial eta squared values ($p\eta_2$). Care is taken in interpretation of results due to limitations of small sample size. Variables were VO_{2peak} ($ml.kg^{-1}.min^{-1}$), LT (expressed as VO_2 [$ml.kg^{-1}.min^{-1}$] and $\%VO_{2peak}$), and VO_2 ($ml.kg^{-1}.min^{-1}$), HR ($b.min^{-1}$), $\%VO_{2peak}$, and %LT for the final minute of the dance sequence. Data are presented as mean ± standard deviation (SD).

5.4. Results

Key findings demonstrate significant changes in the relative intensity of the dance sequence across time. A peak in cardiorespiratory fitness was found in the PG dancers at TP2; however, overall fitness levels decreased over time in both groups. All variables were normally distributed.

5.4.1. Cardiorespiratory fitness testing

Statistical analyses revealed no significant main effect of time or group on VO_{2peak} values, but did detect a significant time*group interaction ($p < 0.05$, $p\eta_2 = .999$). No further significant differences were detected, despite an increase in mean VO_{2peak} evident at TP2 in the PG group (Table 5.2). Mean VO_{2peak} values recorded throughout the study were relatively low, ranging from 39.56 ±4.07 to 48.48 ±4.27 $ml.kg^{-1}.min^{-1}$ over all three time-points.

No significant differences were found in LT (expressed as either $ml.kg^{-1}.min^{-1}$ or $\%VO_{2peak}$) across time in either group. Trends of change across time (Table 5.2) show the highest mean value for both groups occurring at TP2 for LT ($ml.kg^{-1}.min^{-1}$) and a contrasting gradual increase across time in both groups when expressed as $\%VO_{2peak}$.

Table 5.2. Mean VO_{2peak} and Lactate Threshold (LT) values for each group at each time-point

Group	VO_{2peak} ($ml.kg^{-1}.min^{-1}$)			LT ($ml.kg^{-1}.min^{-1}$)			LT ($\%VO_{2peak}$)		
	TP1	TP2	TP3	TP1	TP2	TP3	TP1	TP2	TP3
UG (N=7)	43.98 ±4.70	43.80 ±4.68	39.56 ±4.07	36.95 ±5.56	37.39 ±2.54	35.49 ±3.72	83.84 ±7.87	86.01 ±9.12	89.03 ±4.02
PG (N=6)	43.05 ±2.81	48.48 ±4.27	41.35 ±3.50	37.39 ±3.59	42.98 ±5.98	39.97 ±1.77	85.74 ±3.79	88.50 ±6.58	93.74 ±3.32

- Data are presented as mean ± standard deviation. UG = Undergraduate student dancers, PG = Postgraduate student dancers, TP1 = Time point 1, TP2 = Time point 2, TP3 = Time point 3

5.4.2. Dance sequence testing

Significant main ($p < 0.05$, $p\eta_2 = .998$) and within-subject effects ($p < 0.05$, $p\eta_2 = .963$) of time were found for mean VO_2 ($ml.kg^{-1}.min^{-1}$) values during the final minute of the dance sequence with a significant difference found between TP3 and previous measures (at TP1 and TP2) for time ($p < 0.01$, $p\eta_2 = .984$) and between TP1 and TP2 for time*group interaction ($p < 0.05$, $p\eta_2 = .918$). Differences between groups were not analysed due to the absence of a main effect for the group factor; however, as is evident in table 5.3, both groups decreased their mean VO_2 over time, with the lowest values observed at TP3. A notable difference in the degree of change between TP1 and TP2 is also evident between groups.

A significant within-subjects effect of time was found between mean HR ($b.min^{-1}$) values during the final minute of the dance sequence ($p < 0.05$, $p\eta_2 = .653$). However, no significant within-subjects contrasts were found, despite decreased values across time in both groups as evident in Table 5.3.

Table 5.3. Mean VO_2 and Heart rate (HR) values during minute four of the dance sequence for each group at each time-point

	VO_2 (ml.kg^{-1}.min^{-1})			HR (b.min^{-1})		
Group	**TP1**	**TP2**	**TP3**	**TP1**	**TP2**	**TP3**
UG	29.86	29.82	25.65Ŧ	148.00	151.50	140.50
(N=7)	±1.53	±4.20	±5.10	±13.64	±11.40	±12.66
PG	33.27	27.34	25.46 Ŧ	151.50	141.75	142.17
N=6)	±4.59	±2.59	±3.85	±23.54	±14.38	±17.34

- Data are presented as mean ± standard deviation. UG = Undergraduate student dancers, PG = Postgraduate student dancers, TP1 = Time point 1, TP2 = Time point 2, TP3 = Time point 3
  Ŧ significant difference to TP1 & TP2 ($p < 0.01$)

No significant differences were found in mean $\%VO_{2peak}$ values during the final minute of the dance sequence, despite a notable difference in the degree of change between TP1 and TP2 between groups as seen in figure 5.1.

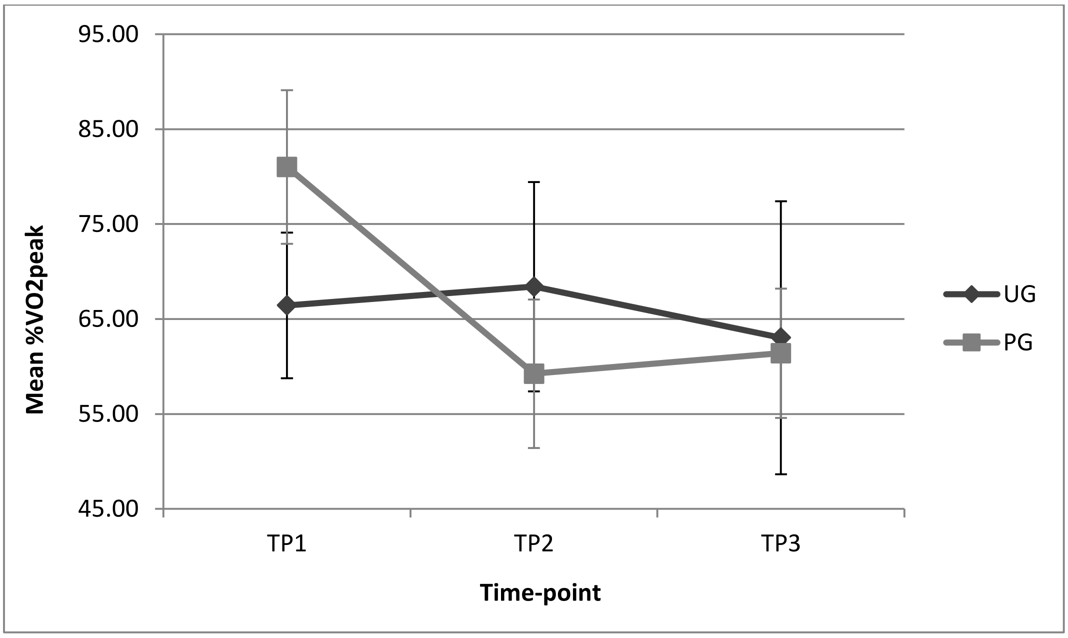

Figure 5.1. Changes in mean $\%VO_{2peak}$ during minute four of the dance sequence across time points for Undergraduate (UG) and Postgraduate (PG) groups

- Data are presented as mean ± SD. UG = Undergraduate student dancers, PG = Postgraduate student dancers, TP1 = Time point 1, TP2 = Time point 2, TP3 = Time point 3

A significant main time*group interaction was found for mean %LT during the final minute of the dance sequence ($p < 0.05$, $p\eta_2 = .999$), along with significant within-subjects effects of time ($p < 0.01$, $p\eta_2 = .935$) and time*group interaction ($p < 0.05$, $p\eta_2 = .827$). Within-subjects contrasts revealed a significant difference for time between TP1 and TP2 ($p < 0.01$, $p\eta_2 = .991$) and between TP3 and previous measures (TP1 and TP2) ($p < 0.05$, $p\eta_2 = .925$), and for time*group interaction between TP1 and TP2 ($p < 0.05$, $p\eta_2 = .970$). Differences between groups were not analysed due to the absence of a main effect for the group factor; however, as is evident in figure 5.2, both groups decreased their mean %LT over time, with the lowest values observed at TP3. A notable difference in the degree of change between TP1 and TP2 is also evident between groups, as in mean VO_2 ($ml.kg^{-1}.min^{-1}$) data.

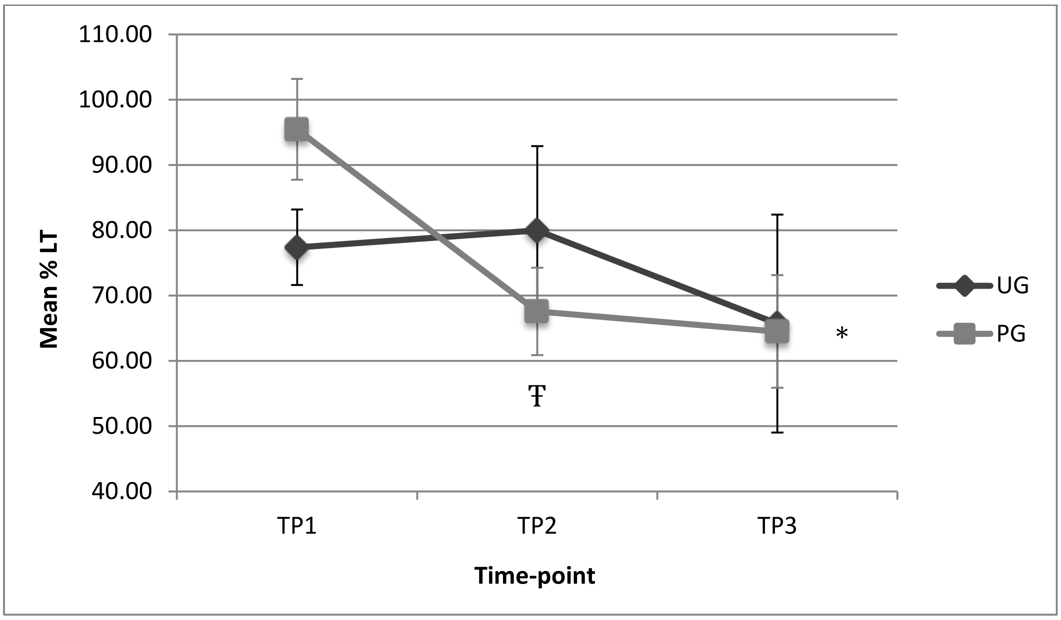

Figure 5.2. Changes in mean % Lactate Threshold (LT) during minute four of the dance sequence across time points for Undergraduate (UG) and Postgraduate (PG) groups

- Data are presented as mean±SD. UG=Undergraduate student dancers, PG=Postgraduate student dancers, TP1=Time point 1, TP2=Time point 2, TP3=Time point 3

  Ŧ significant difference to TP1 ($p < 0.01$)

  * significant difference to TP1 & TP2 ($p < 0.05$)

5.5. Discussion

The aim of this study was to track changes in key physiological variables over one training year (academic year) in different levels of vocational contemporary dance students. The primary finding was that measures of the relative intensity of the dance movement sequence displayed greater change throughout the year than measures of VO_{2peak} and LT. Furthermore, results indicate a high specificity in cardiorespiratory adaptation to the training undertaken, with significant differences found between time-points and significant time*group interactions reported.

Firstly, it is of note that the VO_{2peak} of participants in the present study fell within the range reported in a previous systematic literature review of fitness in contemporary dance, which was documented as 39.2 ±1.9 to 50.7 ±7.5 $ml.kg^{-1}.min^{-1}$ (Angioi et al., 2009). Throughout the year, a gradual decline in VO_{2peak} is noted in both groups from TP1 to TP3 with a peak in values of the PG group at TP2. Although change across time was non-significant, the significant time*group interaction reported does suggest a difference in the degree of change in VO_{2peak} values across time between groups, with the PG group displaying larger fluctuations in reported mean values across the year. This is perhaps reflective of the previously outlined fluctuations in the training schedule of the PG students, between rehearsal time (Sept-Feb) and touring/performance time (Feb-June), compared to the relative consistency of the UG training schedule throughout the year. For both groups, the lowest VO_{2peak} values were reported at TP3. This is largely in agreement with previous research, which has found no significant change over a period of monitoring aerobic fitness (Dahlstrom et al., 1996; Martyn-Stevens et al., 2012). A study by Koutedakis et al. (1999) attempted to explain the decline in fitness measured at the end of the year as related to fatigue and antecedents of overtraining; therefore, suggesting an influence of the timing of data collection and aspects of a dancers schedule at that time on values obtained. In contrast to previous research, the increase in VO_{2peak} values seen in the PG group occurred just before the beginning of the performance period and was not maintained post-performance period. Wyon and Redding (2005) previously documented no significant change in markers of aerobic fitness (HR during stage 5 of the DAFT) over a rehearsal period, but a significant change over the subsequent performance period in professional contemporary dancers. These findings agreed with the previous body of research that suggested that rehearsal intensity is not sufficient to elicit an aerobic training effect, but the higher recorded intensity of performance may be. The contrasting result of the present study, that aerobic fitness increased during the rehearsal period and decreased during the performance period, may be explained by methodological differences. Notably, the Wyon and Redding (2005) study monitored changes in aerobic fitness based upon participants' heart rate during dance specific movement (DAFT) and therefore may be more reliably compared to the relative intensity data presented for the dance sequence in the present study. However, in this comparison, although lower values were maintained post-performance period, the significant reduction in relative demand following the rehearsal period is still presented in contrast to previous literature.

Some similar trends to those observed in VO_{2peak} are noted in LT ($ml.kg^{-1}.min^{-1}$) values throughout the year, with the lowest mean value for the UG group occurring at TP3 and a peak in values of the PG group at TP2. Overall, this was more stable throughout the year in both groups than VO_{2peak}, with no significant changes observed. However, when expressed as $\%VO_{2peak}$, LT displayed a non-significant trend of gradual increase throughout the year in both groups. Typically, LT is expressed as $\%VO_{2peak}$ as it represents the capacity of the individual to work anaerobically within their overall cardiorespiratory capacity; however, in the present study this presents a challenge in analysis due to the variability around attainment of true VO_{2max}. Criterion for satisfaction of VO_{2max} were only obtained in 48.7% of tests conducted throughout the study and only two participants satisfied the criteria on all three of their individual test occasions. Therefore, the VO_{2peak} data presented may not be an accurate representation of participants' true capacity. However, all participants were able to surpass the intensity (VO_2 [$ml.kg^{-1}.min^{-1}$]) at which they reached individual LT on all tests undertaken throughout the study. Dancers rarely work maximally or aerobically for long periods of time, but may intermittently work at intensities close to the LT; therefore, LT may be a more familiar and applicable measure. Guidetti, Gallotta, Emerenziani and Baldari (2007) comment on the importance of relating measurements to individual ventilatory and anaerobic thresholds as they found these proved more sensitive to detect differences between groups of varying skill levels compared to $\%VO_{2max}$ or %HR reserve or absolute HR. This highlights important considerations for future cardiorespiratory fitness testing in dance populations.

Lastly, a significant reduction in the degree of physiological effort (relative intensity) required to complete the dance sequence was observed in both groups over time. Significant decreases throughout the year are particularly evident for mean VO_2 ($ml.kg^{-1}.min^{-1}$) and %LT data during the dance sequence for both groups, although the degree of change from TP1 to TP2 was less in the UG group than the PG group. As previously discussed, the differences noted between groups may be due to differences in training schedule throughout the year and findings of Wyon and Redding (2005) differ to those in the present study where no significant differences were noted over the course of a rehearsal period. Very little other research has examined the physiological intensity characteristics of dance rehearsal or the adaptation in dance specific movement economy during rehearsal periods, in contrast to a larger pool of previous studies examining class and performance characteristics (Beck et al., 2015) (chapter 2). Based on the findings of the present study, it may therefore be of interest to examine this more closely in future research in order to establish the degree of training adaptation possible through extended periods of dance rehearsal. In addition to VO_2 and %LT, as discussed above, a significant main effect of time was also noted for HR, however no significant differences were noted over time for mean

$\%VO_{2peak}$ during the dance sequence. This is suggested to be partly due to the different pattern of change displayed in VO_{2peak} data throughout the year when compared to all other measured variables, which would undoubtedly impact upon $\%VO_{2peak}$ values calculated from these data points. Therefore, in addition to previously raised concerns about the ability of dancers to reach a true representation of VO_{2max}, this may highlight an important consideration for future research regarding the validity and reliability of this measure within dance populations.

The noted reduction in the relative intensity of the dance sequence across time may provide an interesting hypothesis regarding the development of movement economy through dance training. As dance is a highly skill-based activity it stands to reason that individuals developing their technical skill and proficiency throughout a vocational training programme would become more economical in movement; in other words, they would be able to complete the same movement sequence at a lower relative intensity. This adaptation is highly specific to dance movement and, therefore, may not be detected by more traditional cardiorespiratory fitness tests. To the knowledge of the authors, movement economy has not been specifically addressed in previous dance specific research. This may; however, represent a key gap for future research to further investigate and devise appropriate measurement protocols for.

The influence of the adopted methodology of the present study on the applicability of findings should also be considered. As the dance sequence was conducted at a steady-state intensity below that of the LT, we are unable to speculate as to the effects of training on high intensity, intermittent movement. Limitations in the study sample size are also noted, with a final sample size of 13 subjects, despite a calculated required sample power of 25. This may partly explain the lack of significant change across time in VO_{2peak} and LT, beyond the time*group interaction detected for VO_{2peak} values, although other important factors relating to this finding, as discussed, should not be disregarded. The small sample size achieved is likely due to the longitudinal nature of measurement as also experienced by a similar study by Wyon and Redding (2005) who, from a starting sample of 22 subjects, experienced a 23% drop out rate. A final limitation is noted with regard to the specific training exposure experienced by each group, within the three training periods, throughout the year. Although, as outlined previously, consistency is noted in the UG group and difference in the PG group between rehearsal (Sept-Feb) and touring/performance time (Feb-June), a record of training exposure, detailing hours spent in class, rehearsal, and performance for each group, was not collected. Such data would have allowed for a more detailed analysis of trends seen in training adaptation and allowed for further speculation of the causes of these adaptations.

5.6. Conclusions

Results of the present study suggest that some positive adaptation of the cardiorespiratory systems is possible through contemporary dance training and emphasise the importance of monitoring variables that closely relate to the specific training stimulus. It is not possible to fully accept or reject the null hypothesis due to complex data patterns found throughout. Through a more in-depth understanding of the demands placed upon dancers in training and perhaps particularly during rehearsal periods, appropriate recommendations for optimising their physical preparation for performance may be made. Particular focus may need to be directed to rehearsal periods leading up to a performance period or tour, relative to the specific demands of the performance repertoire. It is recommended that future research continue to investigate the relevance and importance of monitoring LT and movement economy in dance specific physiological research and investigate specific training methodologies to enhance these parameters.

6. Study 3: Changes in Cardiorespiratory Demand of Contemporary Dance Repertoire During a Performance Period

6.1. Abstract

Previous literature has questioned the suitability of dance training, solely through class and rehearsal, as adequate preparation for the physical demands of dance performance. Even though little in-depth data are available, the intensity of dance performance, in multiple genres, is almost unanimously described as high/ heavy, with an intermittent nature, utilising both aerobic and anaerobic energy systems. It has therefore been suggested that performance itself may elicit a cardiorespiratory training response over an extended period of performing, for example a tour. The present study aims to describe changes in cardiorespiratory fitness and the relative intensity of performing contemporary dance repertoire in a company of dancers through one performance period/tour (N=8). A secondary aim was to use the repertoire data collected to further investigate the demand placed on contemporary dancers by performance. Individual VO_{2peak} and lactate threshold (LT) values were determined via a treadmill test and subsequent measurement of VO_2, $\%VO_{2peak}$, %LT, heart rate (HR), and $\%HR_{max}$ during performance of contemporary dance repertoire that was conducted immediately before (pre-test) and immediately following (post-test) a 14 week performance period (tour). Time-motion analysis was conducted on the repertoire piece and found two or three peaks in demand per individual, interspersed with lower intensity periods and long periods of rest. Mean percentage dance time was recorded as 53.67% (±18.16) for female participants and 40.50% (± 3.54) for male participants. Results demonstrate no significant changes in cardiorespiratory fitness measures over time. A significant decrease ($t = 3.503$, $p < 0.05$) over time was seen in peak %LT during dance repertoire, in addition to non-significant trends of decrease in VO_2 and HR values. Further examination of the intensity of and diversity within contemporary dance repertoire is necessary as well as investigation of the development of LT and movement economy through prolonged periods of performance.

Key words: Contemporary dance, performance, energy demand, economy, lactate threshold, cardiorespiratory fitness.

6.2. Introduction

Previous research, in various genres of dance, has highlighted a disparity in the demand of dance training and that of high level dance performance. However, very few studies have attempted to measure the demand of contemporary dance repertoire and data available are limited to mean VO_2, heart rate (HR) and energy expenditure (EE) during rehearsals (Wyon, Abt, Redding, Head, & Sharp, 2004), mean HR, peak HR, and end blood lactate during performance (Redding et al., 2009), and classification of the intensity of a range of contemporary dance repertoire using time-motion analysis techniques (Wyon et al., 2011). Even though little in-depth data exists, the intensity of dance performance, across multiple genres, is almost unanimously described as high/ heavy, with an intermittent nature, utilising both aerobic and anaerobic energy systems (Beck, Redding, & Wyon, 2015) (chapter 2). The resultant assumption of a possible training stimulus provided by repeated performance of repertoire requires further investigation, due to limited available longitudinal data specifically examining adaptation to performance across time.

The previous body of research, particularly in relation to the suggestion that training does not adequately prepare dancers for the demands of performance, raises a number of interesting questions. Firstly, how are dancers able to complete performance repertoire to the desired standard if the stimuli provided by their training supposedly does not adequately physically prepare them for it? Secondly, does the speculated increase in cardiorespiratory fitness during prolonged periods of performance result in a notable change in the relative intensity experienced by dancers when performing repertoire?

The present study therefore aims to describe changes in cardiorespiratory fitness and the relative intensity of performing contemporary dance repertoire through one performance period/tour. A secondary aim was to combine temporal data relating to work and rest periods with real-time measurement of metabolic data in work and rest, in order to be able to quantify the demand of contemporary dance repertoire more accurately.

6.3. Methods

6.3.1. Experimental approach to the problem

The present study was designed to assess a company of contemporary dancers immediately before (pre-test) and immediately following (post-test) a 14-week performance period (tour). During the performance period the company completed a 1.5 hour technique class, around two hours of rehearsals each weekday (range 1-2.5 hours), and performed one to two shows per week with one to two week gaps between shows, totalling 14 performances over the 14-week period. Each performance consisted of three repertoire pieces, made specifically for the company by three independent choreographers, with a total performance duration of 1.25 hours. Limited previous literature detailing the content or frequency of performances is available; however, one study noted 240 ±16 performances annually in a professional contemporary dance company (Ojofeitimi & Bronner, 2011), representing a much higher performance workload than that of the present study.

Identical test procedures were adopted at both measurement time-points to allow documentation of the degree of change in dependent variables throughout the performance period. Dependent variables were; VO_{2peak} and LT (determined via completion of a treadmill test), and peak $\%VO_{2peak}$
and peak %LT, plus %time spent in HR categories, during performance of contemporary dance repertoire. Time-motion analysis was also conducted on the repertoire examined, in order to allow detailed description of its characteristics and to enable this to be related to the physical data collected.

It was hypothesised that significant differences in both cardiorespiratory training variables and those related to relative demand of the repertoire would be found between pre and post measurements. Therefore, the null hypothesis was that no significant differences would be found.

6.3.2. Participants

Required sample size was calculated as six for statistical significance at 90% confidence intervals, based upon data provided by Wyon & Redding (2005) for adaptation to dance performance. Eight participants in total took part in the study; six female and two male postgraduate students enrolled on a Masters of Arts (MA) dance performance programme. The two male participants only partially participated in the study due to injury and equipment failure effecting data collection procedures; therefore, data referring to measured physiological demand is presented for the six female participants only. Basic anthropometric data collected during pre-testing, including age (yrs), stature (m), mass (Kg), and calculation of body mass index (BMI; $Kg.m^{-2}$), are displayed in table 6.1.

Table 6.1. Mean participant anthropometric data by gender (N=8)

Gender	Age (yr)	Height (m)	Mass (Kg)	BMI ($Kg.m^{-2}$)
Female (N=6)	22 ±0.75	1.67 ±0.03	58.50 ±3.45	20.97 ±1.69
Male (N=2)	22 ±0.71	1.76 ±0.01	69.50 ±9.19	22.55 ±2.80

- Data are presented as mean ± standard deviation.

The study was approved by the Research Ethics Committee at Trinity Laban Conservatoire of Music and Dance and informed consent was obtained from all participants. The Company Director also provided consent and was involved in measurement scheduling to ensure minimal disruption to company rehearsals.

6.3.3. Procedures

Each participant completed two separate test procedures during pre- and post-testing as detailed below.

6.3.3.1. Cardiorespiratory fitness testing

Each participant completed a treadmill test to volitional exhaustion to determine individual lactate threshold (LT) and aerobic capacity (VO_{2max}/VO_{2peak}). The adopted protocol was based on recommendations of The British Association of Sport and Exercise Science (BASES: Spurway & Jones, 2006) and slightly modified for the specific population based on recommendations of Wyon, (2006) and previous trials by the authors of the present study. Initial speed is set on an individual basis to allow the completion of a minimum of 5 and maximum of 9 stages, with a set increment of 1 $Km.h^{-1}$ every 3 minutes until the participant reaches volitional exhaustion. All participants completed a Medical Physical Activity Readiness Questionnaire (Par-Q) immediately prior to the test at each time-point. A warm up was completed prior to each test consisting of 2 minutes walking at 6.0 $Km.h^{-1}$ and 4 minutes jogging at the participants' start speed (either 8.0 or 9.0 $Km.h^{-1}$). Throughout the test, data on pulmonary and oxygen uptake values were collected via a telemetric gas analyser (Metamax 3B, Cortex Biophysik GmbH, Germany) and a heart rate monitor (Polar, Polar Electro, Finland). Capillary blood samples were collected from the earlobe at the end of each test stage and analysed for blood lactate concentration (Lactate Pro, Arkray Inc, Japan), before speed was increased. All tests continued until volitional cessation or until two of the stop test criteria, as outlined in study 1, were achieved. Whether or not individuals attained true VO_{2max} was determined based upon meeting at least two these criteria, with additional definition of a VO_2 plateau as a final stage increase in workload recording an increase in relative VO_2 of less than 2 $ml.kg^{-1}.min^{-1}$ (Howley, Bassett, & Welch, 1995; Poole, Wilkerson, & Jones, 2008). If criteria were not satisfied, then the highest 30-second average value was taken as attained VO_{2peak}. Criteria for attainment of VO_{2max} were not consistently satisfied within the data set, therefore all values were reported as VO_{2peak}. Lactate threshold was estimated via a plot of measured blood lactate concentrations against treadmill speed for each individual participant. The threshold point was determined as the corresponding $\%VO_{2peak}$ value above which net increases in lactate production were observed to result in sustained increase in blood lactate concentration (Wasserman et al., 2011).

6.3.3.2. Repertoire testing

Each participant performed the same one piece of the company's current performance repertoire as pre-determined by the researcher. The selected piece was chosen (out of three pieces) based on the perceived minimal disturbance to the movement by the equipment. The piece was 12.07 minutes in duration and involved sections of technical jumps, partner work, and lifting sequences, interspersed with lower intensity movement and rest periods. The piece was performed by six dancers, as the company of twelve was split into two casts. Measurements were conducted during full-company run-throughs of the piece, maintaining partnering, group work and spacing characteristics, in an attempt to replicate performance as closely as possible. Participants were required to wear a portable metamax gas analyser and a heart rate monitor throughout one full run-through. Two dancers were measured per run-through, with a total of four measurement occasions per time-point. Rehearsals were filmed in order to allow time-motion analysis to be undertaken retrospectively, building upon methods of Wyon et al. (2011). Rather than subjectively determined exercise intensities (as in Wyon et al., 2011), percentage of total time spent in intensity categories, defined as percentage of age predicted HR_{max} (as per Garber et al., 2011; Table 6.2), was calculated to determine exercise intensity during the piece. Repertoire was also characterised in terms of discrete skill frequency, including standing to floor transitions, jumps, lifts, and supports (number of times performed per minute ($n.min^{-1}$)). Peak values of VO_2 and HR were identified as well as relative intensity, classified as $\%VO_{2peak}$ and %LT, with reference to individually calculated VO_{2peak} and LT.

Table 6.2. Classification of exercise intensity (Garber et al., 2011) by percentage age-predicted heart rate max (%HR_{max})

Intensity	%HR_{max}
Very Light	< 57
Light	57-63
Moderate	64-76
Vigorous	77-95
Near-maximal to maximal	≥96

6.3.4. Data analysis

Respiratory and heart rate data collected were analysed, and subsequently reported, for female participants only due limitations of the male data, as previously outlined. All breath-by-breath gas data were smoothed to allow more accurate data analysis by removing considerable variability in individual data points (James et al., 2006). Following suggestions of BASES (James et al., 2006) and methods adopted in previous dance specific literature (Guidetti, Emerenziani, Gallotta, Da Silva, & Baldari, 2008), a 6 breath (10-15 second) average was applied, followed by a reduction to 30 second average values. All data points were reported as relative VO_2 (ml.kg^{-1}.min^{-1}), relative to individual body mass due to the weight bearing nature of the activity. Individual body mass was measured at each time-point immediately prior to the treadmill test to enable accurate calculation of VO_2 as ml.kg^{-1}.min^{-1}, therefore any changes in individual body mass throughout the course of the study were taken into account in the results.

Descriptive data collected through time-motion analysis of video recordings were analysed and reported for both male and female participants (N = 8). Filmed footage of each piece was tagged for discrete skill frequency using Dartfish Easy Tag (Dartfish, Switzerland). Discrete skills were work (of any intensity), rest (no movement at all either on or off stage for period of at least five seconds), jump (single footed or two footed jump with both feet leaving the floor), standing to floor transition, floor to standing transition, lift (participant lifts another dancer on their own), assisted lift (lift with participant plus other(s) helping or with dancer being lifted helping by jumping in the direction of the lift), and support (participant supporting another dancer who has one or both feet on the ground) as per Wyon et al. (2011). Work and rest data were used to calculate % dance time and work to rest ratio.

6.3.5. Statistical analyses

The accepted p-value for significance was set at $p < 0.05$ for all statistical analyses. All variables were checked for normal distribution using the Shapiro-Wilk statistic. Paired samples t-tests were undertaken on physical data variables to assess for difference pre to post. Variables were VO_{2peak}, LT, and peak VO_2, peak HR, peak $\%VO_{2peak}$, peak %LT, plus %time spent in HR intensity categories during the repertoire run-through.

6.4. Results

Key findings demonstrate no significant differences in cardiorespiratory fitness measures from pre- to post-test conditions, but reveal a decrease in the relative intensity of performing repertoire through a significant decrease in %LT, and non-significant decreases in VO_2 and HR. All variables were normally distributed.

6.4.1. Description of repertoire characteristics

The company was split into two casts of six dancers for the performance of the piece. Direct comparison of individuals performing the same roles was not possible due to subtle differences observed between casts based on partnering and short sections that were individually improvised during the choreographic process, but then fixed for performance. For females, mean percentage dance time was 53.67% (±18.16) resulting in a mean work to rest ratio of 1:1. For male participants, mean percentage dance time was 40.50% (± 3.54) resulting in a mean work to rest ratio of 2:1. Other temporal and discrete skill characteristics are reported in Table 6.3. Statistical analyses were not conducted on these variables.

Table 6.3. Discrete skill frequency by gender

Gender	S >F ($n.min^{-1}$)	F>S ($n.min^{-1}$)	Jump ($n.min^{-1}$)	Assisted Lift ($n.min^{-1}$)	Lift ($n.min^{-1}$)	Support ($n.min^{-1}$)
Female (N=6)	0.50 ±0.33	0.47 ±0.29	1.27 ±0.34	0.00 ±0.00	0.00 ±0.00	0.45 ±0.12
Male (N=2)	0.23 ±0.06	0.23 ±0.06	0.72 ±0.14	0.18 ±0.00	0.18 ±0.00	0.59 ±0.18

- Data are presented as mean ± standard deviation.

6.4.2. Physical data

As outlined within the methods, physical data are reported for female participants only (N = 6). Results demonstrate no significant changes in cardiorespiratory fitness measures over time. Variation is noted between responses of individual participants. Only one participant increased their VO_{2peak} score, by 1.60 ml.kg^{-1}.min^{-1}, with all other participants decreasing by a minimum of -3.00 and a maximum of -14.00 ml.kg^{-1}.min^{-1}. Similarly, two participants increased their LT (ml.kg^{-1}.min^{-1}) value, with all other participants decreasing by a minimum of -6.65 and a maximum of -9.57 ml.kg^{-1}.min^{-1}. In contrast, when LT was expressed as a %VO_{2peak} all individual participants either maintained or improved their individual LT, with the degree of change being the source of variation in this instance.

Table 6.4. Cardiorespiratory fitness measures pre and post tour for females

Measure	VO_{2peak} (ml.kg^{-1}.min^{-1})	LT (ml.kg^{-1}.min^{-1})	LT (%VO_{2peak})
Pre	48.48 ±4.27	42.98 ±5.98	88.50 ±6.58
Post	41.35 ±3.50	39.94 ±1.81	93.74 ±3.32

- Data are presented as mean ± standard deviation.

During performance of the dance repertoire, the greatest proportion of time was spent at moderate and vigorous intensities; however, high variation is noted between individual participants. No significant differences in percentage time spent at each intensity category were noted from pre to post, despite an evident decrease in time spent at near maximal intensities during post testing (Table 6.5).

Table 6.5. Time spent in age-predicted heart rate maximum intensity category (Garber et al., 2011), expressed as a percentage of the total time for females

	% HR_{max} (% total time)				
Measure	**Very light (<57%)**	**Light (57-63%)**	**Moderate (64-76%)**	**Vigorous (77-95%)**	**Near maximal (≥96%)**
Pre	17.83 ±13.01	9.67 ±5.50	23.00 ±16.30	35.50 ±18.01	13.83 ±9.58
Post	11.00 ±17.15	12.00 ±8.53	31.00 ±10.92	42.67 ±22.84	3.67 ±5.82

- Data are presented as mean ± standard deviation.

Two or three peaks in demand were identified per individual, interspersed with lower intensity periods and long periods of rest. Peak values were calculated as a mean of the VO_2 and HR values at each of the two or three peaks for each individual dancer. Figure 6.1 shows an example of pulmonary response to the repertoire and illustrates three peaks for this dancer. Peak HR and VO_2 displayed non-significant decrease from pre to post; however, this was not mirrored in $\%VO_{2peak}$ values. A significant decrease ($t = 3.503$, $p < 0.05$) over time was seen in peak %LT (Table 6.5).

Table 6.6. Peak intensity data while performing repertoire for females

Measure	Peak HR ($b.min^{-1}$)	Peak VO_2 ($ml.kg^{-1}.min^{-1}$)	Peak $\%VO_{2peak}$	Peak %LT
Pre	190 ±12.03	37.62 ±3.89	76.57 ±6.18	88.94 ±11.43
Post	173.17 ±13.88	33.50 ±4.20	81.85 ±15.15	82.38* ±11.85

- Data are presented as mean ± standard deviation.

  * Significant difference to pre measure ($p < 0.05$)

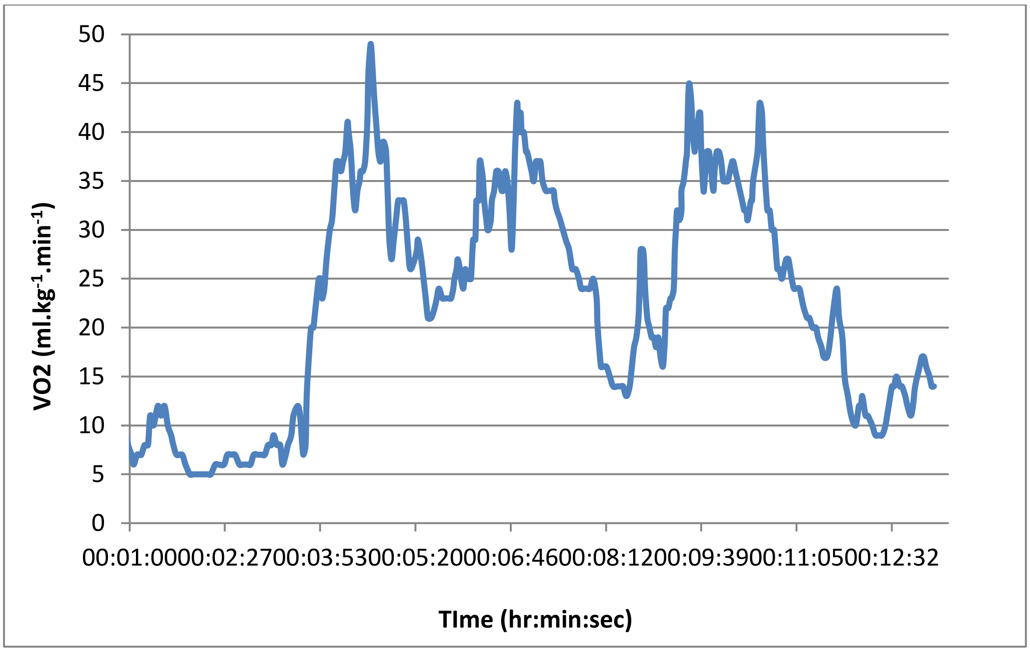

Figure 6.1. Individual example VO_2 data profile during repertoire (pre-test) for one female participant

6.5. Discussion

The aim of this study was to describe changes in cardiorespiratory fitness and the relative intensity of performing contemporary dance repertoire through one performance period/tour.

The primary finding was that measures of the relative intensity of the performance repertoire displayed greater change throughout the year than measures of cardiorespiratory fitness.

Comparison of time-motion analysis data generated by the present study to that collected by Wyon et al. (2011) is possible, although caution must be taken due to differences in methods of quantifying intensity and differences in data representation (% total time vs. $s.min^{-1}$). Similarity can mostly be seen between study results for discrete skill frequency, with a relatively low number of jumps, lifting actions, and level (floor-standing/ standing-floor) transitions across both. Wyon et al. (2011) reported a mean rest time for female contemporary dancers of $18.65s.min^{-1}$ (±10.78) and a total percentage dance time of 71.28% (±18.18), compared to $20.06s.min^{-1}$ (±7.69) rest and 66.56% (±12.79) total dance time for males. These values are in contrast to results of the present study, where a lower percentage dance time is reported, due to longer rest periods throughout the piece in both sexes. However, both studies do demonstrate that male dancers report shorter dance and longer rest times than females within the same repertoire.

In their comparison of ballet and contemporary dance Wyon et al. (2011) explained the higher percentage dance time reported in contemporary dance pieces through less time spent working at hard and very hard intensities and more at very light, light, and moderate intensities. In the present study, despite high variation around the mean, the greatest proportion of total time was spent working at a vigorous intensity (77-95% HR_{max}) in both pre- and post-test conditions, which may go some way to explaining the lower recorded total dance time. Near maximal peak HR data in the pre-condition is in agreement with peak HR values of 187 $b.min^{-1}$ during contemporary dance performance as reported by Redding et al. (2009). Peak $\%VO_{2peak}$ and %LT values close to 80% at both time-points could also be classified as intermittently vigorous exercise, although comparable data in contemporary dance are not available as only one study has reported only mean VO_2 values (Wyon et al., 2004).

Through examination of all data collected on the repertoire piece, the intensity may be best described as moderate-vigorous, with infrequent, intermittent periods of near-maximal work. It is, however, also important to consider the relative nature of intensity measurement of any given activity, whereby the individual's fitness level is the largest influence on an exercise of a set absolute intensity, such as pre-choreographed movement. A comparison of VO_{2peak} values of the dancers in the present study to those previously recorded in contemporary dancers (Angioi et al., 2009) reveals similar levels as professionals (mean $49.1ml.kg.min^{-1}$) at pre-testing, and similar to students (mean $39.2ml.kg.min^{-1}$) at post-testing. Caution is noted in the apparent non-significant increase in LT over time, when expressed as %VO_{2peak}, as this presents the opposite pattern to that seen in the VO_2 at which LT occurred (Table 6.3) and is therefore likely skewed by the greater decrease in VO_{2peak} values over time. Representing any value as %VO_{2peak} is perhaps only valid if the VO_{2peak} value itself represents the individual's maximal aerobic capacity (although not sustained to meet criteria of VO_{2max} attainment) and not just a sub-maximal point at which the test was voluntarily terminated. It is also of note that individual LT (ml.kg^{-1}.min^{-1}) values decreased to a lesser degree than VO_{2peak} values from pre to post. Both variables represent valid markers of cardiorespiratory fitness; however, as all individuals were able to surpass the intensity at which LT was reached but not all were able to continue to maximal effort, LT may be a more reliable indicator of cardiorespiratory training adaption in this specific population.

The observed, although non-significant, decrease in both cardiorespiratory fitness markers over time contrasts with a previous study, which suggested that performance can lead to increases in fitness (Wyon & Redding, 2005). This may however be partly explained by an examination of the dancers' schedule. Participants undertook intense rehearsals in the two weeks leading up to the tour (pre-test), of three to four hours of rehearsal per day consisting entirely of full run-throughs of the three repertoire pieces. Whereas during the 14-week tour they performed on average once per week, with less training volume (in terms of class and rehearsal) during this time. Another explanation for the contrasting findings to Wyon and Redding (2005) may lie in the different testing procedures adopted to measure changes in cardiorespiratory fitness. Wyon and Redding (2005) utilised the DAFT, which requires participants to perform a dance specific movement sequence that increases in intensity throughout the test (Wyon et al., 2003). A reduced HR measured at any test stage over time indicates a reduction in the relative intensity of that movement; therefore, results of this test may be more reliably compared to the relative intensity of the dance repertoire experienced by participants in the present study. By this comparison to findings of Wyon and Redding (2005), some similar trends of improved response over the course of the performance period are noted.

A significant decrease in the peak %LT worked at during the repertoire over time, along with non-significant decreases in peak VO_2 and peak HR, suggest a reduction of the relative intensity experienced by participants when performing the dance repertoire. While it was previously highlighted that during exercise of a set absolute intensity the largest influence on relative intensity experienced is suggested to be the individual's fitness level, i.e. their ability to cope with the imposed demand, relative intensity could also be influenced by the individual's movement economy. Dance, as a high skilled-based activity, lends itself to a potential reduction in demand as an individual becomes more skilled at performing specific movement, or perhaps just more familiar with that movement. Over the performance period the repertoire was performed a total of 14 times, with daily full run-throughs also completed. Therefore, it is possible that highly specific adaptations occurred in the individual dancers relevant to the specific repertoire that were not detected by traditional fitness tests. Jones and Carter (2000) highlight that enhanced endurance performance is achieved through four key parameters: VO_{2max}, exercise economy, lactate threshold, and O_2 uptake kinetics. It is perhaps also worth investigating the proportional development of these four parameters in adaptation to dance specific training and performance, rather than an over-reliance on VO_{2max} as has been seen in the previous dance specific literature. Furthermore, the significant reduction in %LT could be suggested as a feature of the specific training stimuli the dancers experience, where they intermittently work at intensities similar to that at which LT occurs, but rarely attain maximal values or work aerobically for long periods of time. This finding also draws upon the previously discussed notion that LT may be a more valid, reliable, and sensitive variable than VO_{2peak} to assess cardiorespiratory training adaptation in dance populations. The opposite trend seen in %VO_{2peak} data to other variables as measured during the performance of repertoire, further highlights the potential lack of reliability in the VO_{2peak} results obtained in this study.

Findings of the present study highlight the complexity of physiological response to contemporary dance performance repertoire. Further examination of the intensity and diversity of contemporary dance repertoire is necessary as well as investigation of LT and movement economy as suggested valid and sensitive variables of focus to detect positive cardiorespiratory adaption in this specific activity and population.

6.6. Conclusions

Primary findings highlighted that measures of the relative intensity of the performance repertoire displayed greater change throughout the year than measures of cardiorespiratory fitness. The null hypothesis is, therefore, neither accepted nor rejected due to different trends reported across the different variables. The results of this study have highlighted the need for further scrutiny of the methods commonly used to document both the cardiorespiratory fitness of dancers and the relative intensity of performing specific dance repertoire. A more comprehensive understanding of the degree of cardiorespiratory strain placed upon dancers during repertoire and how they adapt to this over time would enable the creation of appropriate training programmes for dancers to ensure they are physically prepared to perform.

7. Study 4: The Cardiorespiratory Demands of Contemporary Dance Repertoire

7.1. Abstract

Previous literature has highlighted significant differences between the cardiorespiratory demands of dance training and dance performance and, therefore, questioned the adequacy of training, through class and rehearsal, in physically preparing the dancer for performance. In order to perform to the best of their ability, ideally a dancer's fitness levels prior to any performance should be matched to the demand faced. Therefore, it is important that we sufficiently understand what the demand faced is. The present study is a detailed descriptive study aiming to further examine the cardiorespiratory demands placed upon contemporary dancers during performance of specific repertoire following recommendations outlined by previous research. A total of 25 participants took part in the study (16 female, 9 male). In total five pieces of repertoire were examined in five discrete groups of dancers. Measurements were taken during rehearsals in the week leading up to the beginning of a tour/ performance period, therefore, capturing demand during final rehearsals. Results, describing the repertoire examined in depth, displayed an overall dance time of 50.31% (±12.98) for female student dancers and 41.60% (±5.73) for male student dancers, compared to 74.25% (±5.12) for male professionals. High variation is noted within and between all pieces although the majority of time was spent at either moderate or vigorous intensities across all pieces for the majority of participants. Peak metabolic data implies a high intensity, which was reached infrequently during each piece. While the present study does provide a detailed description of the repertoire measured, concerns continue to be raised regarding which variables and measurement techniques provide a sensitive, reliable, and valid representation of the cardiorespiratory demand faced during performance of contemporary dance repertoire. It is important for future research to continue to document the demands of a range of repertoire to help develop our understanding of the demands faced and therefore allow us to investigate ways to better prepare dancers to meet these.

Key words: energy demand, intensity, contemporary dance, performance

7.2. Introduction

In order to perform to the best of their ability, a dancer's physiological preparation and fitness levels prior to any performance should ideally be matched to the demand faced. Therefore, building upon the rationales and findings of the prior three studies, it seems necessary to further examine the cardiorespiratory demands of contemporary dance performance repertoire through an in-depth descriptive study in order to sufficiently understand the demand faced during performance.

When examining the available literature on the demands of performance in more depth, the common description of contemporary dance performance as high-intensity in nature is less well substantiated (chapter 2). A study by Wyon et al. (2011) undertook time-motion analysis of 45 contemporary dance pieces, as well as 48 classical ballet pieces, and, therefore, provides the most comprehensive overview available in the literature of a variety of repertoire. Using subjective criteria to identify exercise intensity, the majority of work time was found to be spent at light and moderate intensities, with infrequent peaks at hard intensities (Wyon et al., 2011). This finding is consistent with findings of Redding et al. (2009) and Wyon Abt, Redding, Head, & Sharp (2004), who collected real-time metabolic data during contemporary dance repertoire in order to classify intensity. These studies reported mean heart rate values ranging from 101-132 $b.min^{-1}$ (Redding et al., 2009; Wyon et al., 2004) peak heart rate values of 187 $b.min^{-1}$ (Redding et al., 2009), and mean VO_2 values ranging from 23.34-24.85 $ml.kg^{-1}.min^{-1}$ (Wyon et al., 2004). It is of note that in intermittent activity, such as contemporary dance performance, reporting of mean data may not give a true representation of the full spectrum of demands faced; however, in this instance mean data presented are consistent with exercise heart rates expected at light to moderate intensity (Garber et al., 2011). Peak heart rate data available does suggest that high intensity exercise is reached intermittently within contemporary dance performance; however, how frequently these peaks in demand occur is not reported.

There are however many methodological limitations of the previous body of literature, both relating to data collection procedures used and the variation of these procedures between studies, making comparisons of study findings difficult. Notably, the validity of reporting mean data is questioned due to the intermittent nature of dance activity. Movement classification based upon speed, dynamics, and frequency of powerful moves such as lifts and jumps (such as that used by Wyon et al., 2011) should indicate the demand faced; however, low fit individuals may experience high relative demand even in pieces that appear lower intensity based upon these classifications. It is important to highlight that in pre-set and closed movement such as choreographed dance repertoire, the largest influence on relative intensity experienced is the individual’s cardiorespiratory fitness, which is often reported as low for dancers of all levels. Therefore, the accuracy of using subjective movement descriptors to quantify the intensity of dance activity is questioned. A review by Beck, Redding, and Wyon (2015) (chapter 2) set out recommendations for future measurements including genre specific research with detailed descriptions of the repertoire, examination of a greater breadth of repertoire within genres, a greater focus on threshold measurements, and combining temporal and metabolic data in real-time work and rest conditions (Beck et al., 2015) (chapter 2).

The present study therefore aims to further examine the cardiorespiratory demands placed upon contemporary dancers during performance of specific repertoire following recommendations outlined by previous research.

7.3. Methods

7.3.1. Experimental approach to the problem

The present study was designed as an in-depth descriptive study examining the cardiorespiratory demands of five pieces of contemporary dance repertoire, as performed by undergraduate student, postgraduate student, and professional companies, on a one-off, cross sectional basis. This consisted of two postgraduate student company pieces, two first year undergraduate student pieces, and one professional company piece. Key variables calculated to document the cardiorespiratory demand of the repertoire pieces were percentage dance time (% dance time), work to rest ratio (W:R), frequency of discrete skill performance per minute (standing to floor transitions, floor to standing transitions, jump, assisted lift, lift, support; $n.min^{-1}$), percentage total time spent in intensity categories (very light, light, moderate, vigorous, near maximal) defined based on age-predicted heart rate maximum ($APHR_{max}$), peak heart rate (peak HR; $b.min^{-1}$), peak $\%APHR_{max}$, and peak oxygen uptake (peak VO_2; $mk.kg^{-1}.min^{-1}$). For a sub-set of participants, peak percentage of aerobic capacity ($\%VO_{2peak}$; $ml.kg^{-1}.min^{-1}$) and the number of peaks above individual anaerobic threshold (AT) were also calculated based upon values obtained from a separate incremental treadmill test.

7.3.2. Participants

A total of 25 participants took part in the study (16 female, 9 male). Participants were taken from different groups in order to represent different experience levels in contemporary dance: undergraduate student dancers were first year students enrolled on an Undergraduate Contemporary Dance degree programme, postgraduate student dancers were students enrolled on a Postgraduate Dance Performance degree programme, and professional dancers were under full-time contract in a contemporary dance company. Basic anthropometric data, including age (yrs), stature (m), mass (Kg), and calculation of body mass index (BMI; $Kg.m^{-2}$), is displayed in Table 7.1. In total five pieces of repertoire were examined in five discrete groups of dancers (Table 7.2).

Table 7.1. Participant anthropometric data by gender and level of experience (N = 25)

Gender	Experience	Age (yr)	Height (m)	Mass (Kg)	BMI ($Kg.m^{-2}$)
Female (N = 9)	PG	24 ±3.08	1.68 ±0.03	57.28 ±4.54	20.41 ±1.97
Male (N = 5)	PG	23 ±1.48	1.76 ±0.04	70.00 ±5.87	22.61 ±1.89
Female (N = 7)	UG	19 ±0.90	1.66 ±0.11	59.29 ±8.23	21.60 ±3.19
Male (N = 4)	Pro	27 ±1.73	1.73 ±0.05	73.35 ±6.95	24.53 ±1.06

- Data are presented as mean ± standard deviation. PG = postgraduate student dancers, UG = undergraduate student dancers, Pro = professional dancers.

Table 7.2. Breakdown of participants by repertoire piece performed

Piece	Level	N	Male (N)	Female (N)
1	PG (group 1)	8	2	6
2	PG (group 2)	6	3	3
3	UG (group 1)	3	0	3
4	UG (group 2)	4	0	4
5	Pro	4	4	0

- PG = postgraduate student dancers, UG = undergraduate student dancers, Pro = professional dancers.

A sub-set of 17 participants (13 female, 4 male) also completed AT and VO_{2peak} testing in order to allow representation of the intensity of repertoire examined relative to individual cardiorespiratory fitness levels. Participants were 11 postgraduate student company dancers (7 female, 4 male) and 6 first year undergraduate student dancers (6 female). It was not possible to conduct this test with all participants due to some withdrawing from this aspect of the study and limited access to a treadmill for the professional dancers.

The Research Ethics Committee at Trinity Laban Conservatoire of Music and Dance approved the study and informed consent was obtained from all participants. The choreographers and/or rehearsal directors of each piece also provided consent and were involved in measurement scheduling to ensure minimal disruption to rehearsals.

7.3.3. Measuring the intensity of physical activity

Estimates of physiological demand are deemed important in many different physical activities and there is a wealth of descriptive research in this area. A wide range of methodologies have been used in these studies to quantify demand, largely due to equipment use restrictions during real-time measurements, leading to the need to develop field-based and predictive solutions.

A review by Beck et al. (2015) (chapter 2) outlines previous research that has measured the cardiorespiratory demands of dance class, rehearsal and performance with a focus on the methodologies adopted. Restrictions of measurements during dance performance are largely due to the aesthetic requirements of the art form. Previous research taking measurements during real-time dance performance or competition, has typically been restricted to equipment that can be discretely worn underneath costumes, such as heart rate monitors (Cohen, Segal, & McArdle, 1982; Baillie, Wyon, & Head, 2007; Redding et al., 2009). Twitchett, Angioi, Koutedakis, and Wyon (2009) and Wyon et al. (2011) adopted time-motion analysis techniques to retrospectively assess a range of ballet and contemporary dance repertoire via video recordings. Performance analysis techniques such as this have long been used in team field-sports in order to quantify discrete characteristics of match play such as changes in direction, as well as calculation of time spent sprinting, running, or walking. More recently, however, sports such as Rugby Union have utilised Global Positioning System (GPS) tracking devices worn by players throughout match play in order to more objectively measure demand characteristics (Cunniffe, Proctor, Baker, & Davies, 2009). Other research has used dress-rehearsal measurements to represent performance and the intensity of the specific repertoire being performed (Wyon, Abt, Redding, Head, & Sharp, 2004). Research in Dance Sport has used simulation of competition in order to replicate the competition set-up without having to measure real-time, including breaks between dances, and inclusion of semi-final and final rounds (Blanksby & Reidy, 1988; Kļonova & Kļonovs, 2010; Bria et al., 2011; Liiv, Jurimae, Klonova, & Cicchella, 2013; Massidda, Cugusi, Ibba, Tradori, & Calo, 2011). If simulation is to be used it is important to replicate performance as much as possible, for example in maintaining spacing, partnering, and temporal characteristics of the piece. Where possible rehearsals would take place on stage rather than in a studio and with lighting and costumes. For the purpose of this study full-cast rehearsals in a studio were used to represent performance of repertoire.

7.3.4. Procedures

7.3.4.1. Repertoire testing

Measurements were taken during rehearsals in the week leading up to the beginning of a tour/ performance period or single performance; therefore, capturing demand during final rehearsals where full run-throughs of the piece were being completed by the full cast. Participants wore a telemetric gas analyser (Metamax 3B, Cortex Biophysik GmbH, Germany) and heart rate monitor (Polar, Polar Electro, Finland) throughout one full run-through of the piece each. The piece was also filmed to allow retrospective time-motion analysis.

7.3.4.2. Cardiorespiratory fitness testing

A sub-set of participants, as previously outlined, completed a treadmill test to volitional exhaustion to determine their individual $VO_{2max/peak}$ and anaerobic threshold (AT). The adopted protocol was based on recommendations of The British Association of Sport and Exercise Science (BASES: Spurway & Jones, 2006) and slightly modified for the specific population based on recommendations of Wyon (2006) and previous trials by the authors of the present study. Following a brief on the test procedure, a five-minute warm up was conducted starting at 5 $Km.h^{-1}$ on a 1% incline and increasing by 1 $Km.h^{-1}$ every minute (after first 2-minutes) until a heart rate of 120 $b.min^{-1}$ was achieved. The finish warm-up speed was used as the start speed for the test (range 6-9 $Km.h^{-1}$). During the test, the speed of the treadmill was increased by 1 $Km.h^{-1}$ every minute until two of the stop test criteria, as outlined in study 1, were achieved. The adopted protocol allowed for minimal running time required of the dancers (test duration range: 5-9mins) as is recommended by Wyon (2006). Following completion of the test, the treadmill speed was returned to 5 $Km.h^{-1}$ and participants continued walking at this speed until a heart rate of less than 100 $b.min^{-1}$ was recorded. Throughout the test, data on pulmonary and oxygen uptake values were collected via participants wearing a telemetric gas analyser and a heart rate monitor as detailed above.

7.3.5. Data analysis

In order to allow detailed description of characteristics of the five performance repertoire pieces examined, data were analysed using the following methods. No statistical analyses were undertaken due to the aim of this study being purely descriptive.

Filmed footage of each piece was tagged for discrete skill frequency using Dartfish Easy Tag (Dartfish, Switzerland). Discrete skills were work (of any intensity), rest (no movement at all either on or off stage for period of at least five seconds), jump (single footed or two footed jump with both feet leaving the floor), standing to floor transition, floor to standing transition, lift (participant lifts another dancer on their own), assisted lift (lift with participant plus other(s) helping or with dancer being lifted helping by jumping in the direction of the lift), and support (participant supporting another dancer who has one or both feet on the ground) as per Wyon et al. (2011). Work and rest data were used to calculate % dance time and work to rest ratio. Overall frequency of other discrete skills were then converted to number of times performed per minute ($n.min^{-1}$) to allow comparison between the pieces examined, despite differences in the total length of the pieces (Wyon et al., 2011).

All breath-by-breath respiratory data were smoothed to allow more accurate data analysis by removing considerable variability in individual data points (James et al., 2006). Following suggestions of BASES (James et al., 2006) and methods adopted in previous dance specific literature (Guidetti, Emerenziani, Gallotta, Da Silva, & Baldari, 2008), a 6 breath moving average was applied, followed by a reduction to 30 second average values. All data points were reported as relative VO_2 ($ml.kg^{-1}.min^{-1}$) due to the weight baring nature of the activity.

Continuous HR and VO_2 data were used to determine percentage total time spent working within different intensity categories defined based on individual age predicted maximum heart rate ($APHR_{max}$) and, where available from treadmill testing, HR_{max} and VO_{2peak} (as per ACSM guidelines, Garber et al., 2011; outlined in study 3).
Whether or not individuals attained true VO_{2max} during the treadmill test was determined based upon meeting at least two of the previously detailed stop-test criteria, with additional definition of a VO_2 plateau as a final stage increase in workload recording an increase in relative VO_2 of less than 2 $ml.kg^{-1}.min^{-1}$ (Howley, Bassett, & Welch, 1995; Poole, Wilkerson, & Jones, 2008). For the majority of participants no plateau in VO_2, despite increase in workload, was seen; therefore, VO_{2peak} values were calculated as the highest 30-second average data point following smoothing procedures and reported in results. Anaerobic threshold was determined using the V-slope

method, taken as VO_2 value at which VCO_2 output increased relative to VO_2 intake (Wasserman et al., 2011).

7.4. Results

7.4.1. Time-motion analysis

Student pieces recorded a lower overall percentage dance time than that recorded in the professional piece. Differences are also noted for the two postgraduate student pieces between male and female dance time, with males spending longer at rest (Table 7.4).

Table 7.4. Percentage total dance time (% Dance Time) and work to rest ratio (W:R) by piece and gender

Piece	Gender	% Dance Time	W:R
1	Female (N = 6)	53.67 ±18.16	1:1
1	Male (N = 2)	40.50 ±3.54	1:2
2	Female (N = 3)	46.33 ±5.86	1:1.5
2	Male (N = 3)	42.33 ±7.57	1:1.5
3	Female (N = 3)	50.67 ±11.72	1:1
4	Female (N = 4)	48.00 ±16.43	1:1
5	Male (N = 4)	74.25 ±5.12	2:1

- Data are presented as mean ± standard deviation.

More assisted lifts and lifts were performed by male participants than by female participants across all pieces; however, high variation is noted within and between all pieces for discrete skill frequency. A higher overall discrete skill occurrence is observed in the professional dance piece, compared to the other four pieces (Table 7.5).

Table 7.5. Discrete skill frequency per minute by piece and gender

Piece	Gender	S >F (n.min^{-1})	F>S (n.min^{-1})	Jump (n.min^{-1})	Assisted Lift (n.min^{-1})	Lift (n.min^{-1})	Support (n.min^{-1})
1	Female (N = 6)	0.50 ±0.33	0.47 ±0.29	1.27 ±0.34	0.00	0.00	0.45 ±0.12
1	Male (N = 2)	0.23 ±0.06	0.23 ±0.06	0.72 ±0.14	0.18 ±0.00	0.18 ±0.00	0.59 ±0.18
2	Female (N = 3)	0.53 ±0.15	0.50 ±0.15	0.55 ±0.36	0.05 ±0.05	0.03 ±0.06	0.11 ±0.16
2	Male (N = 3)	0.34 ±0.05	0.29 ±0.05	0.50 ±0.14	0.39 ±0.27	0.13 ±0.15	0.07 ±0.03
3	Female (N = 3)	0.58 ±0.12	0.53 ±0.16	0.77 ±0.18	0.06 ±0.10	0.00	0.00
4	Female (N = 4)	0.85 ± 0.41	0.85 ±0.41	0.07 ±0.03	0.00	0.07 ±0.08	0.07 ±0.05
5	Male (N = 4)	1.38 ±0.28	1.38 ±0.28	1.44 ±0.26	0.32 ±0.10	0.13 ±0.07	0.39 ±0.10

- Data are presented as mean ± standard deviation. S>F = standing to floor transition, F>S = floor to standing transition.

7.4.2. Intensity data

The majority of time was spent at either moderate or vigorous intensities across all pieces for the majority of participants (Figure 7.1). For piece 1, the mean highest proportion of time (35.50% ±18.01) was spent at vigorous intensity for female participants and at moderate (29.00% ±1.41) and vigorous (29.00% ±22.63) intensities equally for male participants. For piece 2, 32.33% ±9.02 was spent at vigorous intensity for females, and 54.33% ±8.02 for males. For piece 3, 39.00% ±2.83 of total time was spent at vigorous intensity, for piece 4, 31.67% ±1.53 at moderate intensity, and for piece 5, 50.50% ±15.61 at vigorous intensity. A high variation is noted between individuals within the same piece as displayed by standard deviations presented here; however, it is not displayed in figure 7.1.

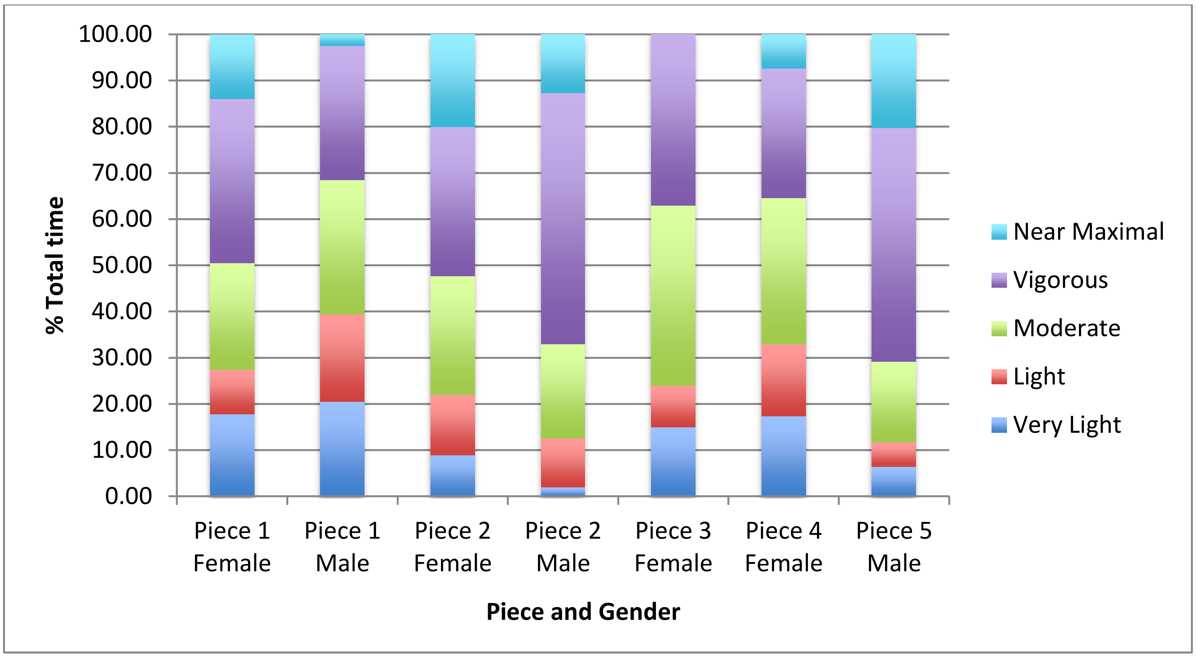

Figure 7.1. Percentage of total time spent in each intensity category by piece and gender based upon age-predicted heart rate maximum ($APHR_{max}$). Data are presented as mean. F = female, M = male.

Peak data imply a high intensity, which was reached infrequently during each piece (Table 7.6). Peak $\%APHR_{max}$ values ranged from 89.41% to 105.61% across all five pieces and where available peak $\%VO_{2peak}$ data ranged from 86.93% to 106.66%. Participants infrequently reached intensities above their individual AT, ranging from 0 to 3 times over the five pieces.

Mean VO_{2peak} for participants who undertook the treadmill test was 46.6 ±4.80 $ml.kg^{-1}.min^{-1}$ for females (N = 13) and 52.73 ±7.01 $ml.kg^{-1}.min^{-1}$ for males (N = 4). Mean AT was 88.5% ±13.3 and 95.18% ±3.75 for female and male participants respectively.

Table 7.6. Peak metabolic data by piece and gender

Piece	**Gender**	**Peak HR ($b.min^{-1}$)**	**Peak $\%APHR_{max}$**	**Peak VO_2 ($ml.kg^{-1}.min^{-1}$)**
1	Female (N = 6)	189.83 ±12.06	95.95 ±6.03	43.56 ±5.17
1	Male (N = 2)	177.50 ±9.19	89.41 ±4.31	43.50 ±4.48
2	Female (N = 3)	194.67 ±23.02	100.56 ±9.92	48.78 ±6.42

Piece	**Gender**	**Peak $\%VO_{2peak}$**	**Peaks above AT**
1	Female (N = 5)	89.86 ±5.17	1.20 ±1.30
1	Male (N = 1)	86.93 ±0.00	0.00 ±0.00
2	Female (N = 2)	106.66 ±0.00	3.00 ±0.00

2	Male (N = 3)	207.33 ±20.40	105.61 ±10.50	56.20 ±7.20	**2**	Male (N = 3)	102.49 ±1.26	1.67 ±0.58
3	Female (N = 3)	182.67 ±13.58	90.71 ±6.34	36.94 ±6.28	**3**	Female (N = 2)	92.58 ±12.47	0.50 ±0.71
4	Female (N = 4)	190.00 ±7.00	94.85 ±3.76	44.56 ±6.14	**4**	Female (N = 4)	92.78 ±9.86	0.50 ±0.58
5	Male (N = 4)	191.75 ±16.90	99.15 ±9.45	61.33 ±9.34	**5**	/	/	/

- Data are presented as mean ± standard deviation.

7.5. Discussion

The aim of this study was to further examine the cardiorespiratory demands placed upon contemporary dancers during performance of specific repertoire following recommendations outlined by previous research. The primary finding was a high variation in all variables measured both within and between the five pieces of repertoire examined, suggesting a high variation of physiological demands within contemporary dance. Notable differences were also found between student work of varying levels and professional work.

Firstly, in relation to time-motion analysis data notable differences are displayed in many variables between student and professional work. Due to the inclusion of only one professional piece in the present study, we are unable to determine if this is true of the comparison of all student and professional work, or just a one off. However, as Wyon et al. (2011) assessed 45 professional contemporary dance pieces some direct comparison is available there. In the present study, student pieces (at both levels) reported roughly 40-50% dance time versus 75% dance time in the professional piece, which is similar to that documented by Wyon et al. (2011) of 66.56% ±12.79 in males and 71.28% ±18.18 in females. While comparative student data are, unfortunately, not available, it does seem that the professional piece documented in the present study follows a similar pattern of dance and rest time to other professional contemporary dance pieces. Wyon, Head, Sharp, and Redding (2002) previously highlighted the potential impact of group size on the total percentage dance time; however, this does not necessarily explain the noted variation in the present study. While the UG groups were larger (around 25 in each piece), both the professional and PG groups were smaller (4-12 in each piece); therefore, the trends seen in percentage dance time are not mirrored by group size trends.

Reported discrete skill frequencies, as also documented by time-motion analysis techniques, in the present study, displayed less consistent comparison to the findings of Wyon et al. (2011). For standing to floor (S>F), and floor to standing (F>S) transition frequency the present study displayed higher frequency in the UG pieces, much higher frequency, in the Pro pieces, and lower frequency in the PG pieces compared to professional pieces as examined by Wyon et al. (2011). It should be noted that the inclusion or omission of floor-work within contemporary dance repertoire is very much a stylistic choice of the choreography. This is displayed by the high standard deviations reported in the Wyon et al. (2011) study of a mean S>F frequency of 0.45 ±0.39 and a F>S frequency of 0.43 ±0.51. Frequency of jumps was lower in all five pieces than the mean of 1.71 ±2.21 documented by Wyon et al. (2011), although, again, the high standard deviation reported here highlights the variation in this across pieces as inclusion or omission of powerful moves such as jumps is again a choreographic and stylistic choice. Low values were also reported in the present study for supports, assisted lifts, and lifts frequency across all five studies as they were by Wyon et al. (2011). A similar trend was also found for the difference between males and females for lift frequency, with males completing more lifts across pieces in the present study and on average across pieces examined by Wyon et al. (2011) (female mean 0.01 ±003, male mean 0.25 ±0.29).

The greatest proportion of time was spent at moderate and vigorous intensities in all five pieces in the present study, represented as mean %APHR$_{max}$. This is in contrast to Wyon et al. (2011) who reported the highest proportion of time across contemporary dance pieces to be spent at light and moderate intensities. This contrast may be explained by methodological differences in the studies as previously highlighted. Subjective classifications used by Wyon et al. (2011), such as “light: subject is undergoing light work e.g., walk pace with upper body movement, moderate: subject is undergoing moderate work e.g., jog pace with upper body movement, can include jumps (low)” (p. 2), are devised based upon the expected absolute demand of different movements, whereby running is of a higher intensity than walking, for example. While the premise of this classification is accurate, the relative intensity that an individual experiences in response to any set movement task is largely determined by their individual fitness level. As previously stated, low fit individuals may experience high relative demand even in movement that appears low intensity in its classification. Caution is, however, also urged in interpretation of the absolute work time inferred from calculations based upon heart rate data, due to heart rate remaining elevated during rest periods to facilitate recovery. This may, perhaps, therefore lead to an over-estimation in total work time and should instead be interpreted with consideration of the earlier presented % total dance time and work to rest ratio data. Further limitations in the use of heart rate data to classify intensity include high variability within individuals, and with the use of age-predicted maximum values, which often under-predict true individual maximum heart rate. This under-prediction is demonstrated in the present study by some participants reaching over 100% of age-predicted HR_{max} values during the dance repertoire. Participants also recorded values over 100% of measured VO_{2peak} during dance repertoire, which highlights a potential inaccuracy of these measurements also. With the majority of participants not satisfying criteria for attainment of VO_{2max} during the treadmill test, we are unable to determine if reported VO_{2peak} values represent the upper limit of their aerobic capacity or not, although VO_{2peak} values reported in the present study are slightly higher than a range from 39.2 ±1.9 to 50.7 ±7.5 $ml.kg^{-1}.min^{-1}$ previously reported for male and female, student and professional contemporary dancers (Angioi, Metsios, Koutedakis, et al., 2009). Comparative peak VO_2 or $\%VO_{2peak}$ values during contemporary dance performance are not available; therefore, we are unable to determine if values reported in the present study are typical. However, with a range of 86.93 ±0.00 to 106.66 ±0.00 $\%VO_{2peak}$ across the five pieces, each could be classified as reaching intermittently vigorous to near maximal work. This pattern is mirrored by $\%APHR_{max}$ data as previously discussed. Peak HR values were similar to the 187 $b.min^{-1}$ reported by Redding et al. (2009). However, peaks in demand were met very infrequently, ranging from once to three times across all pieces, with some of these peaks occurring below the intensity of individual AT. This is mirrored in the small mean percentage of time spent at near maximal intensities as displayed in figure 7.1.

While the present study does provide a detailed description of the repertoire measured, a number of methodological concerns have been discovered by analysis. Questions continue to be raised regarding which variables and measurement techniques provide a sensitive, reliable, and valid representation of the cardiorespiratory demand faced during performance of contemporary dance repertoire. Limitations of HR data, subjective movement classifications, and $\%VO_{2peak}$ data are all discussed above and continue to pose a challenge for future research to attempt to overcome. A further limitation of the present study, and of previous research, is that the repertoire examined is completed by different participants. Ideally, to understand the effects of different movement sequences, the same participants would be measured across varying repertoire to remove the variance caused by individual fitness and skill levels. However, despite these limitations, with little comparative data currently available, it is important for future research to continue to document the demands of a range of contemporary dance repertoire to help develop our understanding of the demands faced and therefore allow us to investigate ways to better prepare dancers to meet these.

7.6. Conclusions

The descriptive nature of the present study allowed for a detailed account of five pieces of performance repertoire in different groups/ levels of dancers and highlighted important considerations for future research. For example, in acknowledging limitations posed by intensity measurement in dance, highlighting the high variation found both between individual dancers in the same piece and between different pieces, and avoiding conclusive statements regarding a dance genre as a whole. Given the relative nature of intensity measurement, it may be pertinent to focus upon the physiological preparation of dancers during rehearsals in the lead up to a particular performance, in relation to the specific movement tasks executed in the piece and the individual dancers' cardiorespiratory fitness levels at the time, with the overall aim of reducing the strain experienced during performance.

8. Study 5: The Relationship Between Performance Competence and Cardiorespiratory Fitness in Contemporary Dance

8.1. Abstract

While a foundation of basic cardiorespiratory fitness is beneficial for coping with the physiological demands placed on the body through dance training and performance and for general health, the extent to which dancers' cardiorespiratory fitness levels are related to the outwardly observable performance ability of that dancer is not all-together clear. Therefore, in order to provide context as to the importance of examining cardiorespiratory fitness through the prior four studies contained within this thesis, the aim of the present study was to directly compare aerobic capacity (VO_{2peak}) and anaerobic threshold (AT), to a measure of aesthetic competence (ACM) in student contemporary dancers to further examine their possible relationship. Participants were 18 vocational contemporary dance students (14 female, 4 male) and all undertook a one-off treadmill test to volitional exhaustion in the week leading up to a performance to determine VO_{2peak} and AT. In the same week, a final rehearsal for the performance was filmed to allow retrospective analysis of specific performance competence by an experienced dance educator. No significant correlations were found between cardiorespiratory fitness variables and ACM scores. Regression analyses revealed experience level to be the only significant predictor of total ACM score ($p < 0.05$, R^2=0.12, SEE=11.91). Results suggest that within this cohort and for this choreography no direct relationship exists. However, there are a number of limitations in the present study, such as the range of choreography used for assessment. Nevertheless, as level of experience did significantly predict ACM total score, it is suggested that vocational dance training may be developing the performance and technical skills of students, but not their physical conditioning. Further investigation of this topic is warranted to further unpick the relevance of cardiorespiratory conditioning within dance training and performance, as either a supportive or crucial element.

Key words: performance competence, contemporary dance, cardiorespiratory fitness, anaerobic threshold

8.2. Introduction

Through the prior four studies contained within this thesis, elements of cardiorespiratory fitness, demand, and training adaptation within contemporary dance training and performance have been examined. As outlined in sections 1.5 and 1.6, the importance of cardiorespiratory fitness within dance is often debated; although, its role within training and performance could be suggested to be related to both the experience of fatigue and related injury risk and concepts of performance enhancement. Therefore, in order to provide context to the importance of the prior four studies, the aim of this fifth study was to directly compare aerobic capacity (VO_{2peak}) and anaerobic threshold (AT), to a measure of aesthetic competence (ACM) in student contemporary dancers to further examine their possible relationship.

It is essential to highlight the importance of not just technique and other outwardly visible elements in dance performance, but also foundational physiological elements that underpin actions of the moving body. Koutedakis and Jamurtas, (2004) state that "dance performance... is a rather complex phenomenon made up of many elements that have direct and indirect effect on outcome" (p. 651–652). Sport coaching has started to focus on the 'aggregation of marginal gains'. In this training philosophy, every factor that could marginally impact performance is acted upon and improved on the basis that the accumulation of all small gains will lead to a significant improvement overall (Kirkland, Hopker, & Jobson, 2013). Sir Dave Brailsford, former Performance Director of British Cycling and General Manager of Team Sky, is often cited for adopting this training approach, throughout which it is emphasised that the basics have to be right first in order for these marginal gains to take effect, including elements such as nutrition, training, and sleep quality (Kirkland et al., 2013). Approaches such as this speak to the complex and multi-disciplinary nature of elite performance enhancement work and the importance of physical and psychological foundations upon which to build technique and skill based elements.

In dance of all genres, technical aspects are often the sole focus of training; however, the importance of cardiorespiratory fitness in dance training and performance has been a topic of investigation in previous research (Angioi, Metsios, Twitchett, Koutedakis, & Wyon, 2009, 2012; Cohen, 1984; Kirkendall & Calabrese, 1983; Koutedakis et al., 2007; Koutedakis & Jamurtas, 2004; Rafferty, 2010; Ramel, Thorsson, & Wollmer, 1997; Twitchett, Angioi, Koutedakis, & Wyon, 2011; Twitchett, Koutedakis & Wyon, 2009; Twitchett, Angioi, Koutedakis, & Wyon, 2010; Wyon, 2005). Within this body of research, it is suggested that the importance of cardiorespiratory fitness for dancers goes beyond the potential benefit to aesthetic or performance ability of the dancer that is outwardly observable during performance and extends to general health benefits, fatigue resistance, and the dancers overall ability to cope with the physiological demands placed upon them by training and performance. Previous research has; however, consistently reported low cardiorespiratory fitness levels in various dance populations, as previously outlined. From the body of available literature, however, the extent to which this impacts upon the observable performance ability of the dancer is not clear.

As outlined in section 1.6, previous studies have attempted to document the direct relationship between fitness components and performance ability and present conflicting results. Direct correlational analysis made between cardiorespiratory fitness levels (expressed as VO_{2max} or HR response to the dance aerobic fitness test) and measures of aesthetic competence have found no significant relationship between these variables (Angioi et al., 2009; Angioi et al., 2012; Koutedakis et al., 2007). Indirect links have, however, been drawn between cardiorespiratory fitness and performance ability, through significant differences documented between fitness levels in different dancer ranks in classical ballet (principals, soloists, first artists, and corps de ballet/ artists) (Schantz & Astrand, 1984; Wyon et al., 2007, 2016) and in student and professional contemporary dancers (Bronner, Codman, Hash-Campbell, & Ojofeitimi, 2016).

Through the previous body of available literature, the extent to which a dancers' cardiorespiratory fitness level is directly related to the performance ability of that dancer is not all-together clear. It seems that professional dancers, and higher ranked professionals in ballet, have greater cardiorespiratory capacity than students, and lower ranked professionals in ballet, but correlational studies have found no significant relationship between aerobic fitness measures and measures of aesthetic competence. A number of benefits to higher cardiorespiratory fitness levels amongst dancers are seen to exist; however, we are currently only at the beginning of our understanding how this translates in an individual dancer's outwardly visible skill and overall performance ability. Therefore, this study will examine this relationship directly in order to address an important, outstanding, question in the overall premise of this thesis.

8.3. Methods

8.3.1. Experimental approach to the problem

The present study was designed to assess the relationship between measures of cardiorespiratory fitness (VO_{2peak} and AT) and aesthetic competence in vocational contemporary dance students. Therefore, a correlational, cross-sectional design was employed whereby two groups of student dancers undertook testing on a one-off basis.

It was hypothesised that no significant correlation would be found between measures of cardiorespiratory fitness and scores on the aesthetic competence measure (as outlined below). The null hypothesis was therefore that a significant correlation would be detected.

8.3.2. Participants

Required sample size was calculated as 12 based upon magnitude of effect at 90% confidence intervals, based upon data provided by Angioi et al. (2009). Participants were 18 vocational contemporary dance students (14 female, 4 male) enrolled on either the first year of a Bachelor of Arts (BA) contemporary dance (UG; 7 female) or Masters of Arts (MA) dance performance (PG; 7 female, 4 male) degree programme. Basic anthropometric data collected including age (yrs), stature (m), mass (Kg), and calculation of body mass index (BMI; $Kg.m^{-2}$) are displayed in Table 8.1.

Table 8.1. Participant anthropometric data by gender and level of experience (N = 18)

Gender	Experience	Age (yr)	Height (m)	Mass (Kg)	BMI ($Kg.m^{-2}$)
Female (N = 7)	UG	20 ±1.25	1.63 ±0.11	56.57 ±10.49	21.26 ±3.52
Female (N = 7)	PG	24 ±3.00	1.65 ±0.03	57.21 ±4.54	20.90 ±1.50
Male (N = 4)	PG	23 ±1.26	1.76 ±0.05	68.50 ±5.57	22.13 ±1.79

- Data are presented as mean ± standard deviation. UG = Undergraduate student dancers, PG = Postgraduate student dancers.

This study received full ethical approval from the Research Ethics Committee at Trinity Laban Conservatoire of Music and Dance prior to participant recruitment. All participants were over 18 years of age (range 18-23 years) and free from injury and illness at the time data collection. All participants were informed of possible risks and benefits of their participation prior to signing an approved informed consent document.

8.3.3. Procedures

Participants undertook a one-off treadmill test to volitional exhaustion to determine VO_{2peak} and AT in the week leading up to a performance. In the same week, a final rehearsal for the performance was filmed to allow retrospective analysis of specific performance ability/aesthetic competence.

8.3.3.1. Cardiorespiratory fitness testing

Each participant completed an incremental treadmill test to volitional exhaustion to determine his or her individual VO_{2peak} and AT. The adopted protocol followed specific recommendations made for testing dance populations, whereby the total time of the test is minimised (Wyon, 2006). Initial start speed for the test was set based upon the corresponding speed at a heart rate of 120 $b.min^{-1}$ for each individual participant during a five-minute warm up (range 6-9 $Km.h^{-1}$). During the test the speed was increased by 1 $Km.h^{-1}$ every minute. The test was terminated when any two of the stop test criteria, as outlined in study 1, were achieved. Throughout the test, data on respiratory gas values was collected via participants wearing a telemetric gas analyser (Metamax 3B, Cortex Biophysik GmbH, Germany) and a heart rate monitor (Polar, Polar Electro, Finland).

8.3.3.2. Aesthetic competence testing

Outcome measures within sports are often clearly defined and relate to maximum attainable speeds, distances, and heights as well as winning or losing. Defining clear outcome measures within non-competitive dance forms is more challenging, although the necessity of these in order to be able to assess the efficacy of any training intervention is particularly noted within dance science research. Various qualitative measures for scoring or judging the performance ability or performance/ aesthetic competence of dancers have been developed for use in previous research (Koutedakis et al., 2007; Chatfield, 2009; Krasnow & Chatfield, 2009; Angioi et al., 2009; Twitchett, et al., 2011; Angioi et al., 2012). Measures commonly assess aspects such as posture/ alignment, skill/ technique, space, time/ rhythm, energy, phrasing, control, and performance quality/ presence, with descriptors given for each characteristic to aid scoring. Due to its previous use in assessing the correlation between dance performance scores and aerobic fitness measures, the aesthetic competence measure (ACM) was chosen for the present study, as designed, validated, and used by Angioi et al. (2009) and used again later in a study comparing developments in physicality and aesthetic competence pre- and post- training intervention (Angioi et al., 2012). This measure demonstrated high inter-rater and intra-test-retest reliability in the initial reliability study (Angioi et al., 2009).

Video footage of each dancer was obtained from a final rehearsal in the week leading up to a performance. Full-cast rehearsals were filmed in order to retain spatial and timing characteristics of the piece and replicate performance as closely as possible. From rehearsal footage, a single film was produced, which included approximately 90 seconds of footage of each participant in turn, during which the individual participant was clearly visible. One experienced contemporary dance educator, with 18 years of experience, was recruited to undertake judging of the film. As per Angioi et al., (2009) the judge was instructed "1. to mark all dancers from the video on the same day, 2. not to rewind the video clips at any time once the scoring procedure had begun, 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 8.2)." (p.117).

Table 8.2. Assessment Criteria and Scoring Guidelines for the ACM (Angioi et al., 2009)

Criterion	Description	Mark 1-10
1. Control of movements	Controlled landing from jump/ turn, controlled lifting/ lowering of limbs, controlled shifting of body weight. Core strength, alignment, posture.	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 and body alignment; generally well controlled movements. 9-10: Well co-ordinated movement and controlled work all of the time, with accurate alignment.
2. Spatial skills	Spatial awareness, accuracy and intent.	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 space, with accuracy and intent.
3. Accuracy of movements	Arm placement, feet positions, fully stretched leg extensions (if required).	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: Good positioning shown about 80% of the time. 9-10: Precise placing with well articulated gestures of limbs.

4. Technique	Elevation, turning and falling techniques, height of extensions, balance, posture, placement, articulation.	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.
5. Dynamics, timing and rhythmical accuracy	Dancing with correct timing and ability to perceive movement and rhythmic patterns. Showing awareness for changes in musical dynamics and phrasing.	1-3: Little or no ability to perform and respond 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.
6. Performance qualities	Ability to execute the work for an audience. Presence, expressiveness, memory recall.	1-3: Few 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. Mature approach, with understanding of motivation for the movement.
7. Overall performance	Does the performance overall impress the markers?	1-3: Dancer made little impression on the audience. 4-6: Dancer not at full potential yet, OR strong work but lacking ability to impress overall. 7-8: Dancer has the ability to shine, but was hindered by minor aspects of performance. 9-10: Impressive!

8.3.4. Data analysis

All breath-by-breath data from the treadmill test was smoothed using a 6 breath moving average, followed by a reduction to 30 second average values, in accordance with suggested methods of previous literature (James et al., 2006; Guidetti, Emerenziani, Gallotta, Da Silva, & Baldari, 2008). All data points were reported as relative VO_2 (ml.kg.min^{-1}) due to the weight bearing nature of the activity. VO_{2peak} was reported, as the majority of participants did not fulfil criteria of a maximal effort, and was calculated as the highest 30 second average data point following smoothing procedures. Anaerobic threshold was determined using the V-slope method, taken as the point at which VCO_2 output increased relative to VO_2 intake (Wasserman et al., 2011) and expressed as both VO_2 ($ml.kg.^{-1}min^{-1}$) and $\%VO_{2peak}$. Scores provided for each of the seven categories of the ACM were used to calculate a total score for each dancer.

8.3.5. Statistical analysis

The accepted p-value for significance was set at $p < 0.05$ for all statistical analyses. All variables were checked for normal distribution using the Shapiro-Wilk statistic. All data were normally distributed. Pearson's r correlation analyses were run to assess the relationship between each of the seven criteria separately on the ACM as well as total score, and measured VO_{2peak}, AT ($ml.kg^{-1}.min^{-1}$), and AT as a $\%VO_{2peak}$. To ensure that all variance in scores (fitness and performance ability) were taken into account in the analysis, correlations were run for mean values as displayed in Table 8.3 and Table 8.4 and not split by gender or experience level. Stepwise multiple regression analyses were also undertaken to establish which, if any, cardiorespiratory fitness variables or participant classifications were able to predict ACM total score. The independent variables were experience level, gender, VO_{2peak} ($ml.kg^{-1}.min^{-1}$), AT ($ml.kg^{-1}.min^{-1}$), and AT as a $\%VO_{2peak}$, and the dependent variable was total ACM score. R^2 values were reported as an estimate of effect size and standard error of the estimate (SEE) scores account for the amount of error in the prediction.

8.4. Results

Results demonstrated no significant correlations between mean cardiorespiratory fitness variables and ACM scores (Figures 8.1-3). Little variation is noted between mean scores of the different ACM criteria within groups, however PG scores are higher than UG scores throughout (Table 8.4). PG males display the highest total ACM score and UG females the lowest (Table 8.4). In line with these trends multiple regression analysis revealed experience level to be the only significant predictor of performance (total ACM score) ($p < 0.05$, R^2=0.12, SEE=11.91).

Table 8.3. VO_{2peak} and AT data of contemporary dance students by gender and level of experience

Gender	Level of Experience	VO_{2peak} (ml.kg^{-1}.min^{-1})	AT (ml.kg^{-1}.min^{-1})	AT (%VO_{2peak})
Female (N = 7)	UG	44.92 ±4.06	42.95 ±5.06	95.48 ±4.96
Female (N = 7)	PG	47.53 ±5.46	39.33 ±7.67	83.31 ±16.25
Male (N = 4)	PG	52.73 ±7.01	50.32 ±8.15	95.18 ±3.75
Mean (N = 18)	Mean	47.67 ±5.84	43.18 ±7.72	90.68 ±11.87

- Data are presented as mean ± standard deviation. UG = Undergraduate student dancers, PG = Postgraduate student dancers.

Table 8.4. ACM scoring data of contemporary dance students by gender and level of experience

		ACM scoring criteria							
Gender	**Level of Experience**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Total score**
Female (N = 7)	UG	6.71 ±1.11	7.71 ±1.11	7.71 ±1.50	6.71 ±1.11	7.00 ±0.82	6.43 ±1.40	6.71 ±1.89	49.00 ±8.19
Female (N = 7)	PG	7.71 ±1.38	7.57 ±1.27	7.86 ±1.35	7.71 ±1.11	8.29 ±0.95	7.43 ±1.13	7.57 ±1.40	54.14 ±7.90
Male (N = 4)	PG	7.50 ±1.73	8.00 ±1.41	8.25 ±1.71	7.75 ±1.89	8.50 ±1.29	8.00 ±1.41	8.50 ±1.91	56.50 ±10.85
Mean (N = 18)	Mean	7.28 ±1.36	7.72 ±1.18	7.89 ±1.41	7.33 ±1.33	7.83 ±1.15	7.17 ±1.38	7.44 ±1.76	52.67 ± 8.74

- Data are presented as mean ± standard deviation. UG = Undergraduate student dancers, PG = Postgraduate student dancers. ACM criteria: 1 = control of movement, 2 = spatial skills, 3 = accuracy of movement, 4 = technique, 5 = dynamics, timing, and rhythmical accuracy, 6 = performance qualities, 7 = overall performance.

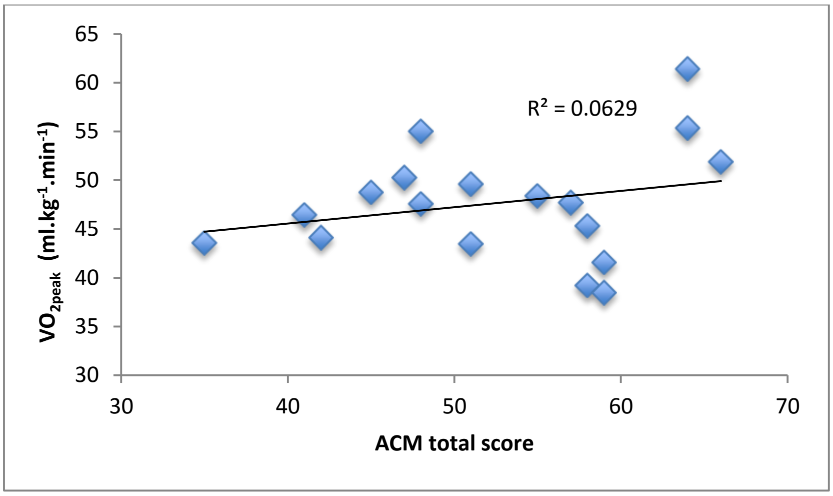

Figure 8.1. Correlation plot displaying the relationship between mean ACM total score and mean VO_{2peak} for all participants

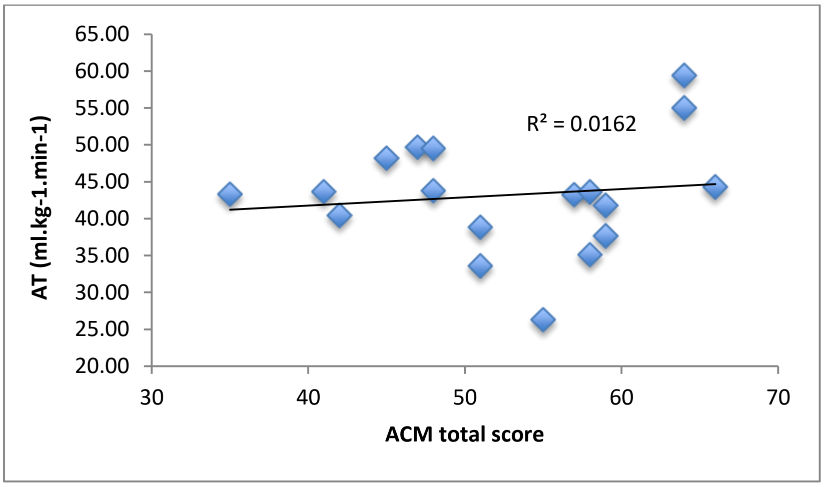

Figure 8.2. Correlation plot displaying the relationship between mean ACM total score and mean AT for all participants

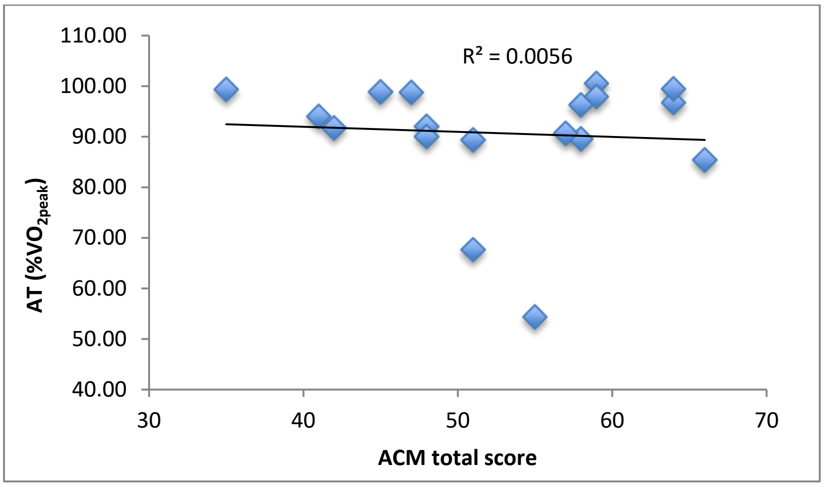

Figure 8.3. Correlation plot displaying the relationship between mean ACM total score and mean AT (%VO_{2peak}) for all participants

8.5. Discussion

The aim of this study was to directly compare commonly used markers of cardiorespiratory fitness to a previously developed and used measure of aesthetic competence (ACM) in student contemporary dancers. Results of this study concur with those of Angioi et al. (2009) that a direct correlation is not observable between measures of cardiorespiratory fitness and performance ability as measured by the ACM, despite differences in the measures of cardiorespiratory fitness used across the two studies. VO_{2peak} scores in the present study, in both group and overall mean values, are higher than those previously reported for contemporary dance students, as reviewed by Angioi et al. (2009) (Table 8.3). Such comparison is not directly available for AT values, although values from various other dance genres for adult professionals and students range from 73.9 – 85.1 %VO_{2peak} (Maciejczyk & Feć, 2013; Oliveira et al., 2010; Wyon et al., 2016), which is lower than the overall mean in the present study (Table 8.3). Higher scores were also found in individual criteria and total scores in the ACM than previous studies using the same measure (Angioi et al., 2009, 2012) (Table 8.4). Therefore, it appears that, on average, the dancers in the present study had higher cardiorespiratory fitness and performance levels than those of previous studies. However, the limited range of scores presented on both measures may have influenced the findings of the present study. In order to examine the relationship between variables accurately the full spectrum of high and low scores for both variables is necessary to allow a direct comparison of high and low fit individuals with high and low scores on the ACM.

Level of experience was the only significant predictor of ACM total score. As dance is a high skill based activity this is perhaps unsurprising, however it is also worth highlighting that the number of years of experience and training an individual dancer has completed are not necessarily directly related to their level of skill. Nevertheless, it is interesting to see that within two groups who are training at the same institution, and therefore under similar ethos and focus, the dancers who are further through their training score higher on the ACM. This may, however, also merely be reflective of the higher standard of the PG group, whereby only twelve dancers are chosen for the programme each year out of those who audition. The same high selection standards are not imposed on the UG group, which has an average year group size of 90 students. This higher skill level in the PG dancers may also be reflective of the importance of technical skill for successfully transitioning from student to professional dance, whereby only those with a high technical mastery of skills are likely to succeed. In support of this, Angioi et al. (2009) state that technical mastery of skills seems to be the essential factor in achieving aesthetic competence during dance performance.

Findings of this study further highlight the potential value of cardiorespiratory fitness as falling outside of the aesthetics of dance performance, emphasising the importance of a good foundation fitness level to support training and performance. A higher level of fitness theoretically should allow dancers to push their technical development further, by being able to train at a higher intensity for longer, or at a lower relative intensity for a given movement thereby preserving energy; however, the magnitude of this indirect impact upon aesthetic competence is perhaps difficult to quantify. As previously discussed, technical skill development is currently the focus of vocational dance training and while this is undoubtedly a very important aspect of dance performance, it is often developed at the detriment of other aspects which perhaps contribute more indirectly to performance. Injury rates continue to be high in dancers of all levels and fitness levels are consistently documented as low suggesting that current training is not adequately addressing the supportive physiological development of dancers. Wyon and Redding (2005) state that enhancement of the aerobic system is required, particularly at the pre-rehearsal stage, in order to allow dancers to develop the physiological capability to cope with the stresses of performance.

There are notable limitations of this study, which must be taken into account in analysing the results. Firstly, although possessing adequate power, the sample used exhibited limited variation about mean values for fitness and performance variables, the potential implications of which were previously discussed. A further limitation exists in the nature of the performance video clips used for ACM scoring, which was inconsistent both between and within groups. Most notably, dancers were assessed on different pieces of choreography. Confounding variables of temporal and intensity characteristics of the pieces, may alter perceptions of their ability to execute the movement fully. Furthermore, clips of each individual dancer were not taken from consistent time points within the piece; some were closer to the end of the piece, some closer to the beginning. As is the case with most dance performance some individual dancers also had bigger roles in the pieces than others and, therefore, spent a greater proportion of the time dancing. Features of the piece such as these may help in determining the applicability of technique based measures as we may see decrements in technique in less fit dancers over a longer period of continuous dancing. This calls into question the applicability, validity, and reliability of performance and aesthetic competence measures to compare to fitness variables. The highly subjective nature of dance performance assessment means that it is challenging to assess the accuracy of any such tool developed for its measurement. Only one judge was used for scoring in the present study; however, using two or three judges in future research could help to identify inconsistencies in scoring.

8.6. Conclusions

The primary finding of the present study was no significant relationship between cardiorespiratory fitness measures reported and aesthetic competence; therefore, the null hypothesis was rejected. Given the limitations of this study, a larger scale study is warranted with a more diverse sample and which takes into account many of the confounding variables mentioned above in its design. Further discussion and investigation of appropriate outcome measures for dance is also needed in order to allow more accurate appraisal of the impact of the various factors integral in building towards optimal performance from a multi-disciplinary viewpoint. The primary focus of current dance training practices remains on technical skill development; however, it appears that there is a strong enough evidence-based rationale for training to allow some portion of this focus to shift to ensuring appropriate physiological development. Further intervention studies are warranted to examine the potentially wide-ranging impacts of this approach.

9. Discussion

The discussion chapter is divided into three sections based upon the three aims of the PhD as outlined in chapter 3:

1. To investigate cardiorespiratory demands of contemporary dance performance repertoire
2. To investigate cardiorespiratory adaptation to contemporary dance training and performance
3. To critically appraise methods commonly used in physiological investigation into dance and propose recommendations for future research

These aims are evaluated in turn with regard to related findings from each of the five studies and in relation to relevant literature as reviewed in chapters 1 and 2. The contributions that each of the five studies make to the knowledge base are discussed as well as their implications for future research and for dance training and performance practices.

9.1. Aim 1: The Cardiorespiratory Demands of Contemporary Dance Performance Repertoire

Results of the systematic literature review (chapter 2) highlighted agreement in previous literature regarding the intermittent nature of dance performance, however inconsistency was uncovered with regard to the intensity and the variability of performance both within and between dance genres. Barriers to consensual conclusion were fully discussed, such as inconsistency in variables reported and in measurement techniques. Findings of the fourth study of the present thesis (chapter 7) allow some further insight and evaluation of this previous body of literature.

The fourth study highlights variety in the cardiorespiratory demand of contemporary dance performance repertoire between repertoire pieces, between student and professional work, and, perhaps most notably, between individuals in the same piece. This high variation of demands between individuals is not something that has been thoroughly addressed in previous research. Twitchett, Angioi, Koutedakis, and Wyon (2009) found significant differences between the demands of the different positions/ ranks within a classical ballet company (principals, soloists, first artists, and corps de ballet/ artists) in terms of time spent resting and working at moderate intensities during performance, however this appears to be the only reference to individual variation made within previous literature. Two previous studies have compared different repertoire pieces through time-motion analysis techniques, as previously reviewed

(Twitchett et al., 2009; Wyon et al., 2011). While Twitchett et al. (2009) commented on the limited variation between classical ballet repertoire pieces, Wyon et al. (2011) reported high standard deviations in mean temporal and intensity data for the 45 professional contemporary dance pieces examined, suggesting a high variation in demands across the different repertoire. Findings of study 4 support this view. The balance of evidence shows, therefore, that contemporary dance repertoire is highly varied. Future research should more fully explore the complexity and variety of the physiological demands of contemporary dance in order for the evidence base to more thoroughly reflect the nature of this genre of dance.

It is important for future research to carefully consider which variables are to be measured to document intensity. Future researchers should be wary of using peak data to conclude the near-maximal intensity of contemporary dance performance due to the limited time spent at these intensities. Across the five pieces examined in study 4, intensities of over 90% individual capacity were often sustained for less than one minute and only reached two to three times within a 20-30 minute piece, overall representing 0-20% of total time. It is also worth noting that this limited time may still be over-predicted due to the continued elevation in heart rate and VO_2 values following change in intensity or cessation of exercise to facilitate recovery. Use of mean data has also previously been discouraged for reporting on intermittent activities, and for dance in particular (Kirkendall & Calabrese, 1983; Redding & Wyon, 2003), as it does not take account of fluctuations in intensity. Within the literature review, performance intensity data were reported as peak and mean VO_2 and $\%VO_{2max}$, peak and mean heart rate (HR), mean $\%HR_{max}$, end-exercise blood lactate concentration, total energy expenditure, % total time at rest, moderate intensity, and high intensity, and mean time at rest, very light, light, moderate, hard, and very hard intensities, mostly in professional dancers and across ballet, contemporary, dance sport, highland, and jazz genres. Within study 4 intensity data were reported as % total time spent at very light, light, moderate, vigorous, and near maximal intensities, peak HR, peak $\%APHR_{max}$, peak VO_2, peak $\%VO_{2peak}$, and number of peaks above individual anaerobic threshold, for student and professional contemporary dancers. This variety of reported data, within a relatively small pool of studies, with added variation in methods used to collect these data, means that limited accurate comparison can be made across available studies; further limiting the ability to make generalisable conclusions. Regardless of this, understanding of the cardiorespiratory demands of a range of dance genres is developing through continued research of this kind. Analysis is becoming increasingly detailed and, through continued, critical, investigation into the demands of performance repertoire and appropriate methodologies for investigating this, understanding may develop further.

In terms of meeting the first aim of this thesis, study 4 investigates the demands of contemporary dance performance, and in doing so has highlighted important considerations for both the appraisal of existing data and collection of future data. The accuracy of previous attempts to document the demands of contemporary dance repertoire, given the noted complexity and variety, is somewhat called into question. It is, however, also worth examining the demands of contemporary dance repertoire through investigation of cardiorespiratory training adaptation; whereby the cardiorespiratory demand of an activity may be inferred from its resultant training effect, as examined by the second aim of this PhD.

9.2. Aim 2: Cardiorespiratory Training Adaptation Through Contemporary Dance Training and Performance

Overall, combining previous study findings as outlined in chapter 2, and findings of studies 2 and 3, limited evidence is available for a generalised positive cardiorespiratory adaptation from contemporary dance training and performance. As highlighted in chapter 2, previous study findings suggest that in order to elicit positive adaptation in markers of cardiorespiratory fitness, supplementary training is required. One previous study has documented a significant positive training effect of prolonged performance in relation to decreased $\%HR_{max}$ during the dance aerobic fitness test (Wyon & Redding, 2005), one documented significant increase in predicted VO_{2max} from the start to the end of the third year of student training (Dahlstrom, Inasio, Jansson, & Kaijser, 1996), and one previous study has documented significant improvements in peak power output during rehearsals (Martyn-Stevens, Brown, Beam, & Wiersma, 2012). However, these findings are not directly comparable to each other and have not been corroborated through additional research.

Studies 2 and 3 (chapters 5 and 6) collected longitudinal data tracking measures of cardiorespiratory adaptation in contemporary dance student participants. When combining results of these two studies it appears that significant changes in the cardiorespiratory response to dance movement can occur with both training and extended performance. The two dance specific movement tasks evaluated in these studies are very different in nature, although both exhibit similar changes throughout longitudinal measurement. Study 2 utilised a steady-state repetitive dance movement sequence, which was standardised and somewhat controlled, whereas study 3 utilised real, current repertoire being performed by the dancers, which included intermittent periods of work and rest over the course of the 12 minute piece. The relative intensity of both activities reduced over measurement occasions, suggesting that dance specific adaptations occur irrelevant of the dance task executed in measurement. Although no detailed account of workload during each training and/or performance period was documented, periods monitored involved a range of class, rehearsal, and performance activities. In line with previous literature speculating the possible training effect of dance performance (Wyon, Abt, Redding, Head, & Sharp, 2004; Wyon & Redding, 2005), the dancers who undertook more performance activity did exhibit a greater degree of change. In relation to the demands of contemporary dance performance it is therefore possible to state, based on findings of studies 2 and 3, that the demand is sufficient to elicit improvements in dance movement economy over an extended period of time but not to improve global cardiorespiratory fitness as documented by measures such as VO_{2peak} or anaerobic threshold. Furthermore, the act of running through performance repertoire repeatedly in rehearsals may have the same training effect, as documented by significant changes in the postgraduate students during their rehearsal period in study 2. However, the variety of performance repertoire in contemporary dance must again be highlighted. Some pieces may involve movement of a sufficient intensity, that is sustained for a sufficient length of time, to provide adequate overload for training adaptation for some individuals within that piece; however, this cannot be generalised to all contemporary dance repertoire nor to all dancers. Additionally, it is important to again highlight the relative nature of intensity measurement where an individual's current fitness levels will largely determine what is 'adequate' stimulus for them. Therefore, this will vary considerably amongst a group/ cast. Features such as the number of performances per week, the length of the piece, the role of the individual, the initial fitness level of the individual, the work to rest ratio, and the intensity of the piece all impact upon the training stimulus provided.

Although not including longitudinal measures in the same participants, study 1 found that dancers do not improve their fitness (as documented by VO_{2peak}) throughout vocational dance training, as there were no significant differences in VO_{2peak} of dancers at various stages of training. Only one previous study has tracked VO_{2max} throughout training and measures were unreliable due to prediction from submaximal testing (Dahlstrom et al., 1996). As previously discussed however, studies have noted differences between student and professional contemporary dancers (Bronner, Codman, Hash-Campbell, & Ojofeitimi, 2016) and between professional classical ballet dancers of different company ranks/ positions (Wyon et al., 2007, 2016). Therefore, it may be of interest to expand study 1 in future research to include measures from professional contemporary dancers as well for further comparison, or to undertake repeated measures of individuals over a longer period of time and through transition from student to professional settings. Further direct comparisons of performance level/ ability and cardiorespiratory fitness were provided by study 5. In this study no direct relationship was found between ratings on an aesthetic competence measure and VO_{2peak} and anaerobic threshold values. In other words, there was no relationship between the fitness variables measured and aesthetic performance. This finding is similar to that of previous research that has performed correlation analysis between fitness and performance variables (Angioi, Metsios, Twitchett, Koutedakis, & Wyon, 2009). Studies 1 and 5 therefore both suggest no relationship between cardiorespiratory fitness and direct and indirect indicators of performance competence. This finding furthers the discussion of the relevance of aiming to ensure cardiorespiratory adaptation throughout dance training. Where direct relationships with performance are not currently available, importance should instead be placed upon other benefits of a good cardiorespiratory fitness foundation for dancers to support their training and performance practices. As previously highlighted, a higher level of fitness theoretically should allow dancers to push their technical development further, by being able to train at a higher intensity for longer, or at a lower relative intensity for a given movement; thereby preserving energy. Given the potential implications of inadequate cardiorespiratory fitness levels on a dancer's ability to meet the demands of performance in particular, for example in relation to fatigue and injury risk, it is suggested as important to not ignore these purely for the pursuit of the aesthetic aspects of performance enhancement in dance.

Based upon findings presented in this thesis, adaptation through dance activity appears more related to movement economy than other cardiorespiratory fitness measures. It is important to highlight that movement economy has not previously been addressed in applied physiology research in dance, which may be due to two distinct reasons. Firstly, successful performance in dance is not based upon the dancer's ability to move economically, as is perhaps the case in endurance based activities such as cycling or running where economy and conservation of energy are paramount to the individual's ability to complete the activity. The point of dance, on the other hand, as a performance art, is to present artistically and technically impressive work for the subjective enjoyment of an audience. However, it may be suggested that dancers use of skill and technique ensures economy in their movement, particularly in relation to the finding that their cardiorespiratory fitness levels are too low to cope with the demands of performance. Furthermore, economy may develop with familiarity with particular movement. However, until research is able to investigate economy in dance further these suggestions are based upon speculation. Secondly, accurately measuring the economy of dance movement has limited scope due to the necessity to record VO_2 during steady-state movement of a constant power output or velocity. Developed dance specific fitness tests provide repeatable, standardised movement sequences (Redding et al., 2009; Twitchett, Nevill, Angioi, Koutedakis, & Wyon, 2011; Wyon, Redding, Abt, Head, & Sharp, 2003) and could potentially allow an indication of economy, although the inability to control the level of effort put into completion of these tests by participants across different measurement occasions presents a limitation to this use. Therefore, further investigation and experimentation with appropriate methods to document economy in dance seems warranted.

An important point needs to be raised in terms of the appropriateness of utilising dance class, rehearsal, and performance as a means of cardiorespiratory fitness training. Particularly in the case of performance, where, if relying on the performance period itself to elicit the positive adaptation dancers will begin by working at high intensity and likely experiencing fatigue during performance. In order to allow peak performance from the start of a tour, fitness levels would ideally be matched to the demand faced before opening night. Therefore, the aim really should be for performance to not provide a training stimulus and instead be comfortable for individuals to perform within their abilities.

Overall, studies 2 and 3 meet the second aim of this thesis in investigating cardiorespiratory adaptation to contemporary dance training and performance, through their longitudinal measurements, methods used, and variables reported. As noted in the literature review (chapter 2) only four previous studies have undertaken longitudinal cardiorespiratory fitness measures, observing adaptation to dance training and/or performance periods without intervention. However, this thesis contributes an additional consideration with regard to economy of movement in dance, which has previously not been explored but does warrant further investigation.

9.3. Aim 3: Methodological Considerations

Throughout all five studies presented in this thesis and the literature review, methodological considerations have emerged as paramount concerns in the evaluation of all available data. The four recommendations made for future research in the literature review (chapter 2) were: genre specific research, examination of a greater breadth of performance repertoire within and between genres, a greater focus on threshold measurements, and combining temporal and metabolic data in work and rest periods. The studies undertaken for this PhD were designed with the recommendations of the literature review in mind; therefore, it is important to evaluate how these studies meet these recommendations.

Firstly, genre specific research, with a detailed account of technical and stylistic elements of movement vocabulary, was recommended. All research within this thesis was conducted on contemporary dance. Accounts were not always given of technical and stylistic elements although time-motion analysis techniques utilised do allow for some description of the pieces. Reported frequencies of jumps, lifts and floor-work do allow comparison across pieces in terms of their movement characteristics.

Secondly, examination of a greater breadth of performance repertoire within and between genres was recommended. This thesis conducted genre specific research examining a range of performance repertoire within contemporary dance. Once more is understood about the demands of individual dance genres, future research could look to compare genres in order to interrogate the implications of similarities or differences between these for students who train in multiple genres or professionals who perform in multiple genres. Given the high proportion of professional dancers who work freelance on a wide range of projects and current trends such as professional ballet companies performing both classical and contemporary repertoire within the same season, it seems appropriate for research to explore this further.

Thirdly, a greater focus on threshold measurements was recommended due to the complex interplay between aerobic and anaerobic energy systems in dance. Threshold measures were included in all five studies, however further complexities and limitations of these became apparent through measurement. Difficulties in collecting lactate threshold data were highlighted by studies 2 and 3, due to the requirement for use of a discontinuous treadmill testing protocol, where it was necessary for participants to run for approximately 20 minutes in order to complete 5-9, 3 minute stages. This goes against recommendations made my Wyon (2006) for treadmill testing in dancers, where a short duration test is preferable consisting of 1 minute stages in order to minimise trauma to the participant. Lactate measures during dance activity were also difficult to obtain in any systematic or consistent way; therefore, it was not possible within these studies to accurately determine if dancers were working above or below their lactate threshold during dance. Studies 1, 4, and 5 documented anaerobic threshold, removing the necessity for blood lactate measurements and focusing instead on respiratory data. This allowed a shorter, continuous treadmill testing protocol to be used, which was in line with recommendations of Wyon (2006) and, therefore, seen as more appropriate for the specific population. This also removed the limitation of some participants opting out of blood measurements. Limited threshold data are available in dance specific research, and are collected through a combination of blood and respiratory methods. Throughout this thesis both methods have been trialled. It is difficult to accurately compare the measures reported by these two methods, however it would seem that anaerobic threshold may be a more appropriate measurement to report for dancers due to reasons outlined above.

Lastly, the literature review recommended combining temporal and metabolic data in work and rest. Difficulties in accurately combining data were highlighted due to the delay in heart rate and VO_2 data response to changing intensity. In order to accurately document response in work and rest as well as transitions between this and different intensities, it may be necessary to specifically examine that aspect of the continuous data collected. This may allow examination, in a more systematic way, of the oxygen uptake on- and off-kinetics during dance and provide a fuller picture of the complex response of the body to dynamic dance movement.

Further to these recommendations, as outlined by the literature review (chapter 2), all studies in this thesis uncovered the limitations of treadmill testing to volitional exhaustion and resultant measures of $VO_{2max/peak}$ in the dance population. Within the literature review 'validity, reliability and sensitivity of cardiorespiratory fitness tests for dancers' was highlighted as a key limitation of previous research. The importance of ensuring test protocols adopted are weight bearing, i.e. undertaken on a treadmill rather than a cycle ergometer, as well as considerations for the timing of testing and familiarity of participants with protocols were highlighted. Considerations with regard to the timing of testing relate to noted fluctuations in the schedule of both student and professional dancers throughout a year and previously documented burnout experienced at the end of a performance season (Koutedakis et al., 1999.). It is therefore important to document details of the dancers' schedule in the lead up to measurements, note potential implications of the time of year in which measurements are taken, and ensure consistency in timing across comparative studies. An additional limitation was highlighted by all five studies in the inability to report VO_{2max} due to criteria not being met by the majority of participants. This also places a limitation on $\%VO_{2peak}$ data presented for the dance movement tasks across these studies and of anaerobic/ lactate threshold values when expressed as $\%VO_{2peak}$. This raises further issues in relation to appropriate means of assessing cardiorespiratory fitness in dancers, as related to the validity, reliability, specificity, and sensitivity of test protocols and reported variables. Enhancement of the cardiorespiratory system has previously been linked to maximal aerobic capacity, exercise economy, lactate/ anaerobic threshold, and oxygen uptake kinetics (Jones & Carter, 2000); therefore, it is perhaps worth experimenting with and devising appropriate testing protocols for measurement of each of these four parameters in dance populations and investigating the proportional impact each may have upon the dancers' ability to meet the demands of training and performance practices as well as their relationship to performance competence.

These studies are deemed to sufficiently meet recommendations outlined within the literature review, and furthermore practically trial and evaluate these recommendations in terms of their applications for future research. A meaningful contribution to the literature/ knowledge by this thesis is a proposal of key methodological considerations for investigation of cardiorespiratory physiology in dancers.

9.4. Limitations

Many of the limitations of the studies presented in this thesis are discussed above in relation to methodological considerations for research of this kind, however some further specific limitations are addressed here.

Firstly, if each study had achieved larger sample sizes, this would have allowed a more thorough examination of the noted individual variations and/or trends of similarity. The samples utilised for each study were diverse; they included participants from different year groups of undergraduate and postgraduate courses, as well as professional dancers. While this did allow some insight into differences between these groups, it split the available sample and reduced generalisability of findings.

Secondly, the cross-sectional nature of measurements and inter-individual comparisons made in studies 1, 4, and 5, limited interpretation of the findings, due to considerable co-variants reported. Adopting repeated measures designs might have reduced the impact of co-variants on findings. For example, in study 1, repeated measures on the same individuals throughout their programme of study would allow for a more accurate representation of adaptation to training. Equally, a design comparing attained VO_{2peak} and AT values for each individual on different test protocols would have allowed more accurate comparison of the various protocols adopted. For study 4, it would be of interest for future research to measure the entire cast/ company in one piece of repertoire to gain a full picture the varied demands, or indeed to compare responses to different pieces of repertoire by the same individuals. For study 5, a major limitation was the use of different dance movement clips for each individual for grading with the ACM. Particularly where comparisons are being made to fitness levels, it is important to remove variation in intensity between movement tasks evaluated.

However, with regard to overcoming the limitations outlined in the literature review, the studies that form this PhD have achieved this as well as allowing for further practical examination of appropriate methods. The five key limitations outlined in the literature review were use of mean data, use of predicted VO_2 in dance activity, validity, reliability, and sensitivity of cardiorespiratory fitness tests for dancers, choice of variables reported, and not accounting for the conditions of data collection. In the design of the five studies contained within this thesis, mean metabolic data was not reported and real-time gas analysis during all movement tasks, including scheduled rehearsals, removed the necessity for predictions of VO_2. Limitations of cardiorespiratory fitness test protocols for dancers were further explored throughout the use of varied protocols in the five presented studies and key considerations for future research were highlighted, as discussed under aim 3. Discussion is provided throughout all five studies regarding which variables provide an accurate, and adequately sensitive, account of both the cardiorespiratory demands of, and the adaptation of cardiorespiratory systems to, dance activity. Measures related to the relative demand experienced by individuals during a given movement sequence are highlighted in particular in relation to potential development of movement economy, which warrants further investigation. Lastly, in relation to the conditions under which data are collected, detailed accounts were given of the experimental set-up and efforts were made to replicate performance conditions as closely as possible, through use of scheduled full-cast rehearsals, within one week of performance, with the rehearsal director present. Therefore, while there are limitations of the five studies presented within this PhD, as outlined throughout this chapter, studies do make substantial attempts to overcome limitations of previous research. Furthermore, a thorough appraisal of a wide range of methodological limitations is provided and used to make recommendations for future research of this kind.

9.5. Future Research

A number of recommendations for future research are made throughout the five studies and this discussion. Three primary recommendations for future research investigating the cardiorespiratory demands of dance activity are made. Firstly, in highlighting the necessity for thorough documentation and appraisal of the variety within and between performance repertoire within the same dance genre, secondly in urging caution in making conclusive or generalised statements about any dance genre as a whole, and lastly in appropriately acknowledging limitations of intensity measurement in such dynamic and complex movement. Additionally, in light of noted limitations of intensity measurement, it may be pertinent for future research to focus more on basic needs analysis of performance repertoire for individual pieces and experiment with training intervention methods, which seek to prepare individual dancers to meet the specific demands posed. Based upon the findings of studies 2 and 3, it is also recommended for training interventions to look to the development of lactate/ anaerobic threshold and movement economy. Outcome related measures may allow for effective evaluation of such interventions based upon relative demand experienced; such as, incidence of fatigue (acute and chronic), perceived performance and/or aesthetic competence, and perhaps more long-term tracking of injury prevalence. This would allow a switch of focus to appropriate preparation, with consideration of important principles of training such as specificity and individuality.

In relation to appropriate cardiorespiratory fitness testing in dance populations, further research with a focus on evaluating protocols, and the resultant reported variables, is necessary. Cardiorespiratory fitness in dancers has been demonstrated to be highly specific by findings of this PhD and it is suggested that commonly reported variables, such as $VO_{2max/peak}$, are not necessarily sensitive to this. A more comprehensive assessment of cardiorespiratory fitness indicators is recommended, including measurement of exercise economy, anaerobic threshold, and oxygen uptake kinetics, as well as $VO_{2max/peak}$. Furthermore, it is recommended for future research to undertake repeated measures of individual fitness levels throughout vocational training and further into the individual's transition into their professional career, to more accurately document training adaptation.

9.6. Summary and Implications

This chapter has discussed how each of the five studies presented in this thesis relate to one another and how they address three overarching aims regarding the cardiorespiratory demand of performance, how the cardiorespiratory systems respond and adapt to contemporary dance activity, and methodological considerations for accurately documenting these parameters through continued research. These aims considered together allow discussion surrounding the relevance and importance of cardiorespiratory fitness in contemporary dance training and performance, which has potential implications from both the researcher perspective and the dance educator perspective.

A strong emphasis throughout this PhD is placed upon scrutiny of methods used in previous research and in the five research studies presented herein. From this detailed discussion and analysis, a range of recommendations for future research are made. Although primarily aimed at researchers, recommendations made throughout do have potential implications for dance educators. These recommendations are not explicitly discussed in this context throughout the thesis, however, key points highlighted have implications for training and performance practices. For example, as outlined in chapter 1, training, rehearsal, and performance practices are currently primarily based upon development of technical and artistic proficiency and often follow a set structure of learning and practicing of movement material. In other words, class and rehearsal practices remain relatively consistent across different pieces of repertoire and for the whole group. Given the highlighted variation between different repertoire pieces and between individuals, training methods could be rethought with respect to principles of training such as specificity and individuality. Further research is, therefore, warranted to experimentally trial training interventions designed with these principles in mind and investigate their effectiveness, in order to enable appropriate, evidence-based, recommendations to be made to dance educators.

The following chapter outlines conclusions and summarises contributions of the PhD.

10. Conclusions

The present thesis investigated the relevance and importance of cardiorespiratory fitness in contemporary dance training and performance. Through the initial introduction and literature review (chapters 1 and 2), gaps in the current understanding of, and challenges presented by, current training and performance practices were highlighted. Five commonly presented conclusions of previous research were highlighted; firstly, that dance activity predominantly consists of intermittent work periods of varying intensities, secondly that significant differences exist in the cardiorespiratory demands of class, rehearsal, and performance, thirdly that class and rehearsal intensity is insufficient to elicit an aerobic training response, fourth that the aerobic capacity of dancers is relatively low, and, lastly that high injury rates in dancers are often attributed to fatigue and overwork. However methodological limitations of previous research put into question the accuracy and validity of these statements. In order to develop understanding and overcome some of these limitations, five research studies were designed, conducted, and presented herein. Studies had a particular focus on methodology and provide an in-depth critique and analysis of current understanding of cardiorespiratory fitness concerns within contemporary dance. Studies addressed themes such as fitness levels of vocational students, the demands of varied performance repertoire, and adaptation to training and performance.

Following discussion and appraisal of the three stated aims of this PhD, with full acknowledgement of limitations, the overall contributions of the research are two-fold. Firstly, original data are presented that contribute to that currently available in previous literature. Study 1 presents cardiorespiratory fitness data on the largest ever sample of vocational student contemporary dancers, as a specific population of interest. Studies 2 and 3 present longitudinal data, which are lacking in previous literature, and examine variables that are not normally reported in dance specific research; namely, lactate threshold and relative intensity of dance movement, and in doing so provide an estimate of movement economy, highlighting a key gap in the current understanding of the body's response to dance movement. Study 4 presents individual variability data within repertoire and relates this to anaerobic threshold. Study 5 directly correlates measures of VO_{2peak} and anaerobic threshold to performance aspects. Data presented are highlighted as highly specific to the current structure of vocational contemporary dance training and therefore provide an in-depth insight into this setting. Secondly, this thesis presents a detailed account and interrogation of the methodologies used in previous dance science research. It is imperative that we begin to critically evaluate the strength of the evidence base built so far in dance science and apply more rigor going forward; since, to date, far too many conclusions have been drawn from a small pool of studies.

This PhD thesis furthers our current understanding of the physiological underpinning of dance activity, generates new knowledge, highlights limitations of previous research, and proposes a research-informed way forward for those responsible for the education and training of contemporary dancers. It provides data to extend the knowledge base regarding cardiorespiratory fitness levels of vocational contemporary dance students, longitudinal tracking of cardiorespiratory adaptation to vocational dance training, interrogation of the intensity of contemporary dance performance, and examination of the relevance of cardiorespiratory fitness to perceived performance ability. In particular, this thesis refutes the generalisability of previous research undertaken in dance and advises future research design and appraisal to acknowledge the complexity of dance in its many forms.

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Appendices

1. Literature review supplementary material

1.1. **Supplementary Table 1.** Summary of methods and results of studies measuring the energy demand of dance class or the execution of a single exercise within a class setting

Author (reference)	Participants	Dance Genre	Method	Results		
Cohen, Segal, Witriol, & McArdle, 1982	N = 15 (7 men, 8 women) 10 measured in class 3 completed VO_{2max} testing Professional (principle/ solo/ corps)	Ballet	Setting: Individual classes conducted for purpose of testing (not usual class), all led by the same teacher Measurement details: VO_2 collected every 2 minutes via open circuit spirometry Gross caloric expenditure derived from VO_2 measures HR recorded every 30 seconds via ECG	Mean VO_2 (ml.kg.min-^{1}) Barre exercise: 16.49 ± 3.38 - female 18.48 ± 1.95 - male	Mean VO_2 (ml.kg.min-^{1}) Centre exercise: 20.06 ± 4.13 - female 26.32 ± 3.39 – male	
				Peak % VO_2max Barre exercise: 51% - average	Peak % VO_2max Centre exercise: 60% - female 71% - male	
				Mean HR (b.min^{-1}) Barre exercise: 117 ± 20 - female 134 ± 15 - male	Mean HR (b.min^{-1}) Centre exercise: 137 ± 17 - female 153 ± 11 - male	
					Peak HR (b.min^{-1}) Centre exercise: 158 - female 178 - male	
				Mean EE (Kcal.min^{-1}) Barre exercise: 3.96 ± 0.96 - female 5.85 ± 1.04 – male	Mean EE (Kcal.min^{-1}) Centre exercise: 4.86 ± 1.08 - female 8.38 ± 1.54 – male	
Schantz & Astrand, 1984	N = 13 (6 male, 7 female) Professional	Ballet	Setting: 6 different classes measured (75 minutes each) Work and rest periods noted in each class Measurement details: VO_2 collected via Douglas bag and analysed in a balanced spirometer Fingertip BLa samples	Mean % VO_2max Barre exercise: 36% - average	Mean % VO_2max Moderate centre exercise: 43% - average	Mean % VO_2max Severe centre exercise: 46% - average
				Mean BLa (mmol.L^{-1}) Class: 3 – average		
				Mean work and rest periods (sec) Barre exercise: Work - 60 Rest - 30	Mean work and rest periods (sec) Moderate centre: Work - 35 Rest - 85	Mean work and rest periods (sec) Severe centre: Work - 15 Rest - 75

Rimmer et al., 1994	N = 13 (4 male, 9 female) Students (theatre dance major)	Ballet	Setting: 90 minute class: 45-60min barre, 5-10min adagio, 20-25min petit and grand allegro Measurement details: HR recorded every minute via wireless monitor	Total mean time at 60-90% HRmax (min) 46.8 % total time at 60-90% HRmax 52%
Guidetti, Gollotta, et al., 2007	N = 39 (female) Pre-vocational students (13 low ability, 14 intermediate, 12 high)	Ballet	Setting: 71min ± 7 min class One dancer at a time, same pre-recorded music used each time Measurement details: Continuous HR, VE, VO_2, and VCO_2 measurement by breath-by-breath analyser BLa taken after each class section and 3, 6, and 10 min following class	*Raw class data not reported* Mean work and rest periods (sec) Work - 68 Rest - 92
Guidetti, Emerenziani, et al., 2007	N = 12 Pre-vocational students	Ballet	Setting: Single exercise of continuous movement of 25 tours piques on full point performed during 30sec period Evaluated in two separate sessions: one cold and one after warm up Measurement details: Continuous VO_2 measurement via breath-by-breath analyser during exercise and 25min of sitting recovery BLa at rest, warm up end, 3, 6, and 10 min into recovery Calculations: Aerobic source: amount of VO_2 above resting (VO_2ex)	Mean overall O2 cost ($ml.kg^{-1}$) 38 ± 3 - no warm-up 37 ± 3 – after warm-up Mean aerobic energy system usage ($ml.kg^{-1}$) 10 ± 2 - no warm-up 14 ± 2 - after warm-up Mean anaerobic alactic energy system usage ($ml.kg^{-1}$) 21 ± 2 - no warm-up 18 ± 2 - after warm-up

			Anaerobic alactic source: estimated from fast component of recovery after exercise (VO_2al) Anaerobic lactic source: estimated from blood lactate accumulation during recovery time (VO_2la-)	Mean anaerobic lactic energy system usage (ml.kg^{-1}) 7 ±1 - no warm-up 4 ±1 - after warm-up		
Guidetti et al., 2008	N = 25 (female) Pre-vocational students (13 low ability, 12 high ability)	Ballet	Setting: Single exercise lasting 210sec (72bpm, 4/4 music) of grand adage on pointe in centre (warm up of pre-barre and plié at bar) Measurement details: Continuous VO_2 measurement via breath-by-breath analyser BLa taken 1, 3, 5, and 7 min into recovery Calculations: Aerobic source: VO_2 above rest during the exercise, Anaerobic alactic source: estimated from the fast component of the post-grand adage exercise VO_2, Anaerobic lactic source – net blood lactate accumulation during recovery – subtracting rest value from peak value. Energy equivalent of 1mmol.L BLa increase assumed to be 3ml O_2 kg	Mean overall O_2 cost (ml.kg^{-1}) 81 ± 10 - group A 94 ± 9 - group B		
				Mean aerobic energy system usage (ml.kg^{-1}) 53 ± 6 – group A 73 ± 8 – group B		
				Mean anaerobic alactic energy system usage (ml.kg^{-1}) 19 ± 2 – group A 17 ± 2 – group B		
				Mean anaerobic lactic energy system usage (ml.kg^{-1}) 10 ± 1 – group A 4 ± 1 – group B		
Wyon et al., 2002	N = 27 Students (10 female – final year) Graduates (3male, 4 female)	Modern/ Contemporary	Setting: All participant groups measured in situ (different classes) Classes of 1.5hr duration Measurement details: VO_2 and HR data collected continuously via breath-by-breath analyser Caloric expenditure was calculated from oxygen uptake data (4.8 kcal/L O_2)	Mean VO_2 (ml.kg.min^{-1}) 16.8 ± 2.3 – undergrad 20.4 ± 4.8 – graduates 18.3 ± 3.8 –professional	Mean VO_2 (ml.kg.min^{-1}) Warm up phase: 13.2 ± 2.9 – undergrad 20.2 ± 5.5 – graduates 15.1 ± 3.5 -professional	Mean VO_2 (ml.kg.min^{-1}) Centre phase: 18.9 ± 2.8 – undergrad 20.6 ± 4.7 – graduates 21.2 ± 4.1 -professional
				Mean HR (b.min^{-1}) 118 ± 9 – undergrad 133 ± 7 – graduates 111 ± 9 – professionals	Mean HR (b.min^{-1}) Warm up phase: 103 ±7 – undergrad 133 ± 7 – graduates 98 ± 12 - professionals	Mean HR (b.min^{-1}) Centre phase: 125 ± 14 – undergrad 132 ± 11 – graduates 121 ± 12 - professionals

	Professionals (4male, 6 female)		Classes filmed in order to calculate work-to-rest ratio	Mean EE (Kcal.min^{-1}) 4.8 ± 0.9 – undergrad 6.4 ± 2.4 – graduates 5.3 ± 1.6 – professionals	Mean EE (Kcal.min^{-1}) Warm up phase: 3.7 ± 0.8 – undergrad 5.9 ± 2.3 – graduates 4.4 ± 1.4 - professionals	Mean EE (Kcal.min^{-1}) Centre phase: 5.7 ± 1.0 – undergrad 7.3 ± 3.3 – graduates 6.3 ± 1.7 - professionals
					Mean % work time (of total time) Warm up phase: 69 ± 4 – undergrad 78 ± 7 – graduates 79 ± 6 - professional	Mean % work time (of total time) Centre phase: 33 ± 15 undergrad 49 ± 4 – graduates 41 ±12 - professional
Wyon et al., 2004	N = 40 Mixed: student, graduate, professional	Modern/ Contemporary	Setting: All participant groups measured in situ (different classes) Measurement details: VO_2 and HR data collected continuously via breath-by-breath analyser Filmed in order to calculate work-to-rest ratio	Mean VO_2 (ml.kg.min^{-1}) 17.42 ± 2.75 – female 22.06 ± 5.86 – male	Mean VO_2 (ml.kg.min^{-1}) Warm up phase: 14.67 ± 3.87 - female 18.65 ± 4.72 – male	Mean VO_2 (ml.kg.min^{-1}) Centre phase: 19.39 ± 3.24 - female 24.78 ± 7.07 – male
				Mean HR (b.min^{-1}) 117 ± 11.58 - female 118 ± 15.24 - male	Mean HR (b.min^{-1}) Warm-up phase: 107 ± 16.6 - female 108 ± 19.72 - male	Mean HR (b.min^{-1}) Centre phase: 122 ± 12.58 - female 126 ± 14.63 - male
				Mean EE (Kcal.min^{-1}) 4.73 ± 0.81 - female 6.67 ± 1.95 - male	Mean EE (Kcal.min^{-1}) Warm-up phase: 3.97 ± 0.82 - female 4.73 ± 0.81 - male	Mean EE (Kcal.min^{-1}) Centre phase: 5.67 ± 1.08 - female 8.06 ± 2.77 - male
					Mean % work time (of total time) Warm up phase: 74.83 ± 7.88 - female 80.93 ± 5.32 - male	Mean % work time (of total time) Centre phase: 41.85 ± 13.28 - female 46.45 ± 10.07 - male
Dahlstrom et al., 1996	N = 16 Students	Multiple: Ballet, Modern, Jazz, Character	Settings: 2 classes in each of the 4 styles measured, 2 students per lesson (total of 32 measurement occasions) Measurement details: HR measured continuously by ECG tape recorder with 2 electrodes Fingertip blood samples obtained 3-6min after class	Median HR (b.min^{-1}) 134 ± 17 – all 126 ±22 – ballet 124 ± 13 – modern 144 ± 13 – jazz 140 ±13 – character	Median HR (b.min^{-1}) Warm-up phase: 123 ± 18 – all 117 ± 25 – ballet 118 ± 13 – modern 126 ± 20 – jazz 133 ± 16 - character	Median HR (b.min^{-1}) Execution phase: 143 ± 15 – all 134 ± 25 – ballet 137 ± 11 – modern 153 ± 10 – jazz 146 ± 6 - character
				Mean BLa (mmol.L^{-1}) End class: 6.6 ± 1.0 – ballet 3.8 ± 0.6 – modern		

				2.6 ± 0.8 – jazz 4.9 ± 1.3 – character		
				Mean % work time (of total time) 55.3 ± 2 – ballet 57.3 ± 1.9 – modern 39.6 ± 0.7 - jazz 49.5 ± 0.0 – character	Mean % work time (of total time) Warm up phase: 60 – ballet 64 – modern 52 – jazz 60 - character	Mean % work time (of total time) Execution phase: 46 – ballet 45 – modern 30 – jazz 45 - character
					Mean work and rest periods (sec) Warm-up phase: Work - 102 Rest - 65	Mean work and rest periods (sec) Execution phase: Work - 44 Rest - 63
Dahlstrom, 1997	N = 11 (female) Students	Multiple: Ballet, Modern, Jazz, Character	Setting: 2 classes lasting 80min (67-87min), separated by 1-2 weeks Measurement details: HR recorded every 15 seconds using Polar HR monitor Fingertip blood samples taken 1-2mins after class	Median HR ($b.min^{-1}$) 134 ± 13 – class 132 ± 16 – warm-up phase 137 ± 12 – execution phase		
				Median % HRmax 71 ± 7 – class 69 ± 9 – warm-up phase 72 ± 6 – execution phase		
				Median BLa ($mmol.L^{-1}$) 3.0 ± 0.8		
Baillie et al., 2007	N = 9 (female) Professionals (championship competitors)	Other: Highland	Setting: Class consisting of: 9 minute warm-up, 29 minutes of technique, 9 minutes of practice, total of 25mins of rest periods Measurement details: HR recorded every 5 seconds via telemetric HR monitor	Mean HR ($b.min^{-1}$) 151.9 ± 7.4		
Oliveira et al., 2010	N = 8 (female) Students	Other: Tap	Setting: Single exercise of traditional American tap in 9 stages of 3 minutes with 1 minute rest between Measurement details:	Mean VO_2 ($ml.kg.min^{-1}$) 28.2 ± 4.6		
				Mean % VO_2max 68.9 ± 11.3		
				Mean % LT-VO_2 88.2 ± 15.7		
				Mean HR ($b.min^{-1}$)		

			Continuous VO_2, VCO_2, RER, and metabolic equivalent measured using a breath-by-breath analyzer, BLa measured from the earlobe at each 1min interval between stages and throughout rest period RPE collected throughout	171.0 ± 15.0 Mean % HRmax 83.8 ± 6.2 Mean % LT-HR 93.0 ± 10.8 Mean end BLa (mmol.L^{-1}) 1.7 ± 0.4 Mean EE (METS) 8.1 ± 1.3 Mean RPE 13.0 ± 2.0
Maciejczyk & Feć, 2013	N = 8 (4 female, 4 male) Students	Other: Folk	Setting: Single exercise (Mazur) completed for 8 minutes Measurement details: VO_2 calculated by work rate-HR linear relationship and HR-O_2 linear relationship using data from prior treadmill test, HR continuously recorded, Energy expenditure estimated by indirect calorimetry (assumed as 5Kcal per L O_2)	Mean VO_2 (ml.kg.min^{-1}) 34.23 ± 4.36 - female 37.75 ± 2.05 - male Mean % VO_2max 81.1 ± 12.23 - female 74.3 ± 12.47 - male Mean HR (b.min^{-1}) 178.3 ± 5.62 - female 167.8 ± 16.68 - male Mean % HRmax 91.0 ± 3.83 - female 85.0 ± 8.68 – male Mean EE (Kcal.min^{-1}) 10.08 ± 2.03 – female 14.52 ± 2.09 - male

1.2. Supplementary Table 2. Summary of methods and results of studies measuring the energy demand of dance rehearsal

Author (reference)	Participants	Dance Genre	Method	Results	
Schantz & Astrand, 1984	N = 5 Professionals	Ballet	Setting: Measurement during final rehearsals (or performance) of Giselle, Sleeping Beauty, Les Noces, and Pulcinella Measurement details: HR measured using ECG (radio telemetry) Fingertip BLa samples	HR "frequently close to max" Peak BLa ($mmol.L^{-1}$) 11	
Rimmer et al., 1994	N = 13 (4 male, 9 female) Students (theatre dance major)	Ballet	Setting: Series of practice sessions consisting of the dance pieces which were 1.5 to 6 minutes long Rehearsals ranged from 28-156 minutes (mean 80.5min) Measurement details: HR recorded every minute via ECG	Total mean time at 60-90% HRmax (min) 45.1 % total time at 60-90% HRmax 56%	
Wyon et al., 2004	N = 40 Mixed: student, graduate, professional	Contemporary/ Modern	Setting: Each participant group was tested in situ Measurement details: VO_2 measured continuously via telemetric breath-by-breath analysis system HR measured continuously via HR monitor Filmed to calculate work: rest ratio	Mean VO_2 ($ml.kg.min^{-1}$) Rehearsal: 10.17 ± 6.63 – female 17.19 ± 3.28 – male Mean HR ($b.min^{-1}$) Rehearsal: 108 ± 26.31 – female 112 ± 6.44 – male Mean EE ($kcal.min^{-1}$) Rehearsal: 2.63 ± 1.87 - female 5.93 ± 1.33 – male	Mean VO_2 ($ml.kg.min^{-1}$) Dress rehearsal: 23.34 ± 3.83– female 24.85 ± 5.83 - male Mean HR ($b.min^{-1}$) Dress rehearsal: 132 ± 9.76 – female 134 ± 14.28 – male Mean EE ($kcal.min^{-1}$) Dress rehearsal: 6.67 ± 1.05 - female 8.49 ± 2.58 - male
Baillie et al., 2007	N = 9 (female) Professionals (championship competitors)	Other: Highland	Setting: 77 minute rehearsal consisting of performance of 3 dances with 50 minutes recovery Measurement details: HR recorded every 5 seconds using telemetric HR monitors	Mean HR($b.min^{-1}$) 172.6 ± 5.4 – all 165.6 ± 6.1 – highland fling 176.9 ± 8.1 – sword dance 174.0 ± 6.0 – Sean Truibhas	

1.3. Supplementary Table 3. Summary of methods and results of studies measuring the energy demand of dance performance

Author (reference)	Participants	Dance Genre	Method	Results		
Cohen, Segal, & McArdle, 1982	N = 13 (6 male, 7 female) Professionals (1 principle, 5 soloists, 7 corps)	Ballet	Setting: Dancer's monitored one at a time through an entire act of classical ballet or contemporary rep using classical technique Measurement details: HR's continuously recorded on stage during actual performance (radio telemetry) Dance action recorded and timed with a stopwatch Results presented based on individual dancer movement sequence characteristics	Mean HR ($b.min^{-1}$) 170 – variations 160-180 – allegro 140 - adagio		
				Mean % HRmax 85 – variations 80-95 – allegro 72 - adagio		
				Peak HR ($b.min^{-1}$) 188 - variations 180-197 – allegro 158 - adagio		
				Work: rest ratio 1:3.3 – variations 1.16-1.19 - allegro		
Twitchett, Angioi, et al., 2009	48 performances (24 male, 24 female) Professionals (16 principals, 16 soloists, 16 artists)	Ballet	Setting: Retrospective video analysis conducted on performance recordings Measurement details: Data recorded in each field every 30sec Exercise intensity judged by qualitative description of intensity Time spent at each intensity calculated in minutes and as % of whole performance	Mean % total time at rest 75.2 ± 15.1 – soloists 53 ± 24.1 - principals	Mean % total time at moderate intensity 9.0 ± 5.9 - artists 8.7 ± 9.6 – soloists 17.3±12.1 - principals	Mean % total time at high intensity 8.6 ± 8 – soloists 14 ± 11.5 - principals

Wyon et al., 2011	N = 45 contemporary (21 males, 24 females) N = 48 classical ballet (24 male, 24 female) (16 principles, 16 soloists, 16 artists) Professional	Multiple: Ballet & Contemporary/ Modern	Setting: Retrospective movement analysis conducted with time motion and match analysis systems on performance recordings Measurement details: Data recorded in each field every 30sec Exercise intensity judged by qualitative description of intensity Time spent at each intensity calculated in minutes and as % of whole performance	Mean % total time dancing Ballet: 62.76 ± 13.74 – female 61.65 ± 14.33 - male	Mean % total time dancing Contemporary: 71.28 ± 18.18 – female 66.56 ± 12.79 - male
				Mean time spent at rest ($s.min^{-1}$) Ballet: 37.22 ± 13.73 – female 38.50 ± 14.51 - male	Mean time spent at rest ($s.min^{-1}$) Contemporary: 18.64 ± 10.78 - female 20.06 ± 7.69 - male
				Mean time spent at very light intensity ($s.min^{-1}$) Ballet: 4.88 ± 3.81 – female 6.21 ± 4.91 - male	Mean time spent at very light intensity ($s.min^{-1}$) Contemporary: 8.33 ± 10.95 – female 8.95 ± 8.11 - male
				Mean time spent at light intensity ($s.min^{-1}$) Ballet: 3.55 ± 3.75 – female 2.85 ± 2.61 – male	Mean time spent at light intensity ($s.min^{-1}$) Contemporary: 16.41 ± 10.79 – female 13.74 ± 12.43 – male
				Mean time spent at moderate intensity ($s.min^{-1}$) Ballet: 8.34 ± 7.05 – female 5.59 ± 4.79 - male	Mean time spent at moderate intensity ($s.min^{-1}$) Contemporary: 13.77 ± 7.19 – female 9.99 ± 6.0 - male
				Mean time spent at hard intensity ($s.min^{-1}$) Ballet: 7.68 ± 6.83 – female 4.61 ± 3.79 - male	Mean time spent at hard intensity ($s.min^{-1}$) Contemporary: 4.28 ± 5.53 – female 6.59 ± 7.27 - male
				Mean time spent at very hard intensity ($s.min^{-1}$) Ballet: 2.06 ± 2.89 – female 3.34 ± 4.04 - male	Mean time spent at very hard intensity ($s.min^{-1}$) Contemporary: 0.00 – female 0.589 ± 1.08 – male
Redding et al., 2009	N = 8 Professionals	Contemporary/ Modern	Setting:	Mean HR ($b.min^{-1}$) 101	
				Peak HR ($b.min^{-1}$)	

			Continuous measurement while performing four dance pieces of current five-piece repertoire Measurement details: Continuous HR measurement via HR monitor Fingertip BLa sample taken at the end of each piece	187 Mean end BLa ($mmol.L^{-1}$) 1.6 ± 0.4 – piece 1 3.9 ± 1.6 – piece 2 2.3 ± 1.0 – piece 3 2.0 ± 0.4 – piece 4	
Galanti et al., 1993	N = 8 (female) Students	Other: Jazz	Setting: Measurement during performance consisting of 3 choreographed sequences ranging from 2-5min in length Measurement details: HR recorded after each dance during the performance	Mean % HRmax 94.3 ± 6.8 – all 93.5 ± 11.9 - Dance 1 100.0 ± 4.1 - Dance 2 89.6 ± 7.2 - Dance 3	
Baillie et al., 2007	N = 9 (female) Professionals (championship competitors)	Other: Highland	Setting: 3 dances performed by each participant during one competition, with a total recovery period averaging 50minutes Measurement details: HR recorded every 5 seconds using telemetric HR monitors BLa samples taken before and after each dance during competition	Mean HR($b.min^{-1}$) 195.0 ± 6.5 – all 194.2 ± 10.0 – highland fling 196.3 ± 6.3 – sword dance 194.6 ± 6.3 – Sean Truibhas	
				Mean BLa ($mmol.L^{-1}$) End dance: 4.5 ± 1.86 - highland fling 6.9 ± 2.96 - sword dance 7.3 ± 2.96 - Sean Truibhas	
Blanksby & Reidy, 1988	N = 20 (10 couples: 10 male, 10 female) Professionals	Other: Dance Sport (Modern and Latin American)	Setting: Simulated competition with costumes Each completed modern (modern waltz, tango, foxtrot, quickstep, & Viennese waltz) and Latin American (samba, rumba, paso double, cha cha, & jive) sequence with 15-20sec break between each dance and 30mins rest between sequences	Mean VO_2 ($ml.kg.min^{-1}$) Modern: 34.7 ± 3.8 - female 42.8 ± 5.7 - male	Mean VO_2 ($ml.kg.min^{-1}$) Latin American: 36.1 ± 4.1 - female 42.8 ± 6.9 - male
				Mean % VO_2max Modern: 82.8 ± 6.9 - female 82.3 ± 8 – male	Mean % VO_2max Latin American: 85.9 ± 4.0 - female 81.9 ± 2.3 - male
				Mean HR ($b.min^{-1}$) Modern:	Mean HR ($b.min^{-1}$) Latin American:

			Measurement details: HR recorded every 5 seconds using telemetric HR monitors VO_2 values predicted from VO_2-HR relationship during previous VO_2max test	173 - female 170 – male	177 – female 168 - male	
				Mean % HRmax Modern: 88 ± 6 - female 86 ± 5 - male	Mean % HRmax Latin American: 91 ± 6 - female 85 ± 7 – male	
Kļonova & Kļonovs, 2010	N = 24 (12 couples: 12 male, 12 female) Professionals	Other: Dance Sport (Ballroom)	Setting: Sequence completed with 15-20sec rest between dances: slow waltz, tango, Viennese waltz, slow foxtrot, quickstep Completed twice: with and without partners' close contact (30min rest between) Measurement details: HR measured using HR monitors	Mean HR ($b.min^{-1}$) With contact: 171.3 ± 5.22 – female 167.2 ± 4.68 - male	Mean HR ($b.min^{-1}$) Without contact: 174.8 ± 5.54 – female 170.4 ± 5.32 - male	
Bria et al., 2011	N = 24 (12 couples, 12 male, 12 female) Professional (6 Latin-American couples, 6 Standard couples)	Other: Dance Sport (Standard & Latin American)	Setting: Simulated competition of Standard and Latin American sequences Measurement details: Continuous measurement of VO_2 BLa measured between dances	Mean%VO_2peak Standard: 72.5 ± 12.8 - female 75.7 ± 10.6 - male	Mean%VO_2peak Latin American: 70.8 ± 13.8 - female 84.2 ± 11.2 – male	
				PeakBLa Standard: 6.91± 2.6 – female 6.50 ± 2.1 - male	PeakBLa Latin American: 6.04 ± 2.5 – female 7.95 ± 2.1 - male	
Massidda et al., 2011	N = 10 (5 couples, 5 males and 5 females) Professional	Other: Dance Sport (Latin American)	Setting: Performed competitive dance simulation; semifinal and final phases each consisting of five dance types, with 30.1min rest between Total length of simulation 1 hr 15 Measurement details: Sensewear Pro armband recorded minute-by-minute analysis of Kcal and METs expenditure	Mean total EE (Kcal) 159.9 ± 16.4 – female 251 ± 27.8 - male	Mean total EE (Kcal) Semi-final: 70.2 ± 7.4 - female 107.7 ± 5.5 - male	Mean total EE (Kcal) Final: 39.1 ± 5.3- *female* 52.8 ± 12.4 - *male*

Liiv et al., 2013	N = 16 (8 couples, 8male, 8 female) Professional (mean world ranking 1.657WDSF)	Other: Dance Sport (Ballroom - Modern/ Standard)	Setting: Simulated ballroom competition one trial of 11mins, 20sec recovery interval between each dance Measurement details: VO2 measurement during trial via telemetric gas analysis system BLa measured at rest and 3-5mins after simulated competition	Peak VO_2 ($ml.kg.min^{-1}$) 43.8 ± 9.9 - female 50.5 ± 7.3 - male Peak % VO_2max 88.1 – female 75.8 - male Mean end BLa ($mmol.L^{-1}$) 8.7 ± 0.35 – female 8.0 ± 2.7 - male

1.4. Supplementary Table 4. Summary of methods and results of studies examining the impact of dance training/ performance on cardiorespiratory fitness

Author (reference)	Participants	Dance Genre	Method	Results	
Ramel et al.,1997	N = 20 (10 in control, 10 training) Professionals	Ballet	Testing protocols: VO_{2max} test: cycle ergometer to exhaustion Expired gas collected continuously in a mixing chamber, measurements obtained every 20sec during exercise, VO_{2max} taken as highest value recorded during last minute of exercise, Fingertip BLa samples after 4min of exercise, every 2mins, at end of test, and 4min into recovery Intervention: At least 30mins 2 times per week using aerobic training activity of their choice at 70-80% HRreserve	Mean VO_2max (ml.kg.min^{-1}) Pre: 47.8 (33.9-58.8) – training 50.9 (45.2-55.1) - control	Mean VO_2max (ml.kg.min^{-1}) Post: 50.9 (47.7-63.5) – training 51.3 (40.6-55.5) – control
				Mean Max BLa (mmol.L^{-1}) Pre: 9.1 (6.1-12.9) – training 9.1 (4.1-13.5) - control	Mean Max BLa (mmol.L^{-1}) Post: 9.5 (6.2-13.6) - training 8.9 (5.9-10.1) - control
Koutedakis et al., 1999	N = 17 (female) Professionals	Ballet	Testing protocols: Treadmill ergometry: 5min warm up 9km/h, progressive 1min increments of 0.5km/h until exhaustion, VO_{2max} and VE_{max} calculated via automated gas analyser measuring respiratory parameters every 30sec Anaerobic Wingate test: 20sec protocol, mean power & peak power calculated Setting: Assessed just before and after summer break, during which little or no physical work was undertaken 8 dancers assessed a 3rd time 2-3months into new season	Mean VO2max (ml.kg.min-1) 41.2 ± 8.5 – pre-rest 45.2 ± 7.1 – post-rest 48.4 ± 6.8 – post-prep period	
				Mean average power output (W) 285.9 ± 41.1 – pre-rest 292 ± 38.5 – post-rest 299 ± 28.3 – post-prep period	Mean peak power output (W) 350 ± 46.2- pre-rest 400 ± 35.1 – post-rest 405 ± 33.3 – post-prep period

Wyon & Redding, 2005	N = 17 (8 males, 9 females) Professionals 2 company's (group 1/ group 2)	Contemporary/ Modern	Testing protocols: Dance Aerobic Fitness Test (DAFT) completed with HR monitors worn to provide end-stage HR values BLa sample 1min after testing Setting: Initial test 1-2 weeks after return from break and 2-3 weeks before start of rehearsals, Second test 1 week before start of performing (week 12), Final test 1 week following the end of tour (week 20)	Mean HR DAFT stage 5 ($b.min^{-1}$) Pre-rehearsal period: 167 ± 10.65 –group 1 190 ± 3.07 – group 2	Mean HR DAFT stage 5 ($b.min^{-1}$) Pre-performance period: 166 ± 10.55– group 1 189 ± 4.19 – group 2	Mean HR DAFT stage 5 ($b.min^{-1}$) Post-performance period: 155 ± 12.86 –group 1 179 ± 4.76 – group 2
				Mean % HRmax DAFT stage 5 Pre-rehearsal period: 84.7 ± 4.89- group 1 96.3 ± 1.96 – group 2	Mean % HRmax DAFT stage 5 Pre-performance period: 84.1 ± 4.99 – group 1 95.8 ± 2.23 – group 2	Mean % HRmax DAFT stage 5 Post-performance period: 77.9 ± 6.18 – group 1 91.8 ± 3.17 – group 2
				Mean end BLa DAFT stage 5 ($mmol.L^{-1}$) Pre-rehearsal period: 2.2 ± 0.92 – group 1 3.4 ± 1.12 - group 2	Mean end BLa DAFT stage 5 ($mmol.L^{-1}$) Pre-performance period: 2.1 ± 0.90 – group 1 3.4 ± 1.15 - group 2	Mean end BLa DAFT stage 5 ($mmol.L^{-1}$) Post-performance period: 1.5 ± 0.77 – group 1 2.8 ± 1.09 - group 2
Koutedakis et al., 2007	N = 32 (5 males, 27 females) Students	Contemporary/ Modern	Testing protocols: Treadmill VO_{2max}: 5 min warm up at (9km.h), followed by 0.5km.h increase in 1min increments until exhaustion Dance test: choreographed movement phrase repeated until fatigue related technical detriment, marking criteria with 5 elements (posture/ alignment, use of articulation in upper body, lower body, total body coordination, presentation of movement)	Mean VO_2max ($ml.kg.min^{-1}$) Pre: 50.7 ± 7.5 – exercise 49.2 ± 5.5 - control	Mean VO_2max ($ml.kg.min^{-1}$) Post: 56.6 ± 9.3 – exercise 48.5 ± 5.4 – control	
			Intervention: Aerobic training 20-40mins of swimming/ jogging/ cycling 2-3 times per week for 12 weeks, 70-75% age-predicted HR_{max}	Mean dance test score (points) Pre: 73.9 ±16.2 – exercise 76.0 ± 19.4 - control	Mean dance test score (points) Post: 109.2 ± 21.3 – exercise 81.5 ± 11.8 - control	

Angioi et al., 2012	N = 24 (female) 14 Students, 10 professional	Contemporary/ Modern	Testing protocols: Aerobic fitness via Dance Aerobic Fitness Test (DAFT), HR monitors worn throughout to calculate mean HR of the last minute of stage 5 Aesthetic Competence test consisting of a 90sec choreographed contemporary dance routine scored on a scale	Mean HR DAFT stage 5 ($b.min^{-1}$) Pre: 196 ± 9.71 – conditioning 196 ± 3.59 - control	Mean HR DAFT stage 5 ($b.min^{-1}$) Post: 177 ± 15.5 – conditioning 185 ± 7.07 – control	
			Intervention: 6 week programme Conditioning group 2x1hr exercise per week (Dance specific circuit training/ whole body vibration training), Control group 1 extra hour of contemporary technique class per week	Aesthetic competence score (points) Pre: 38 ± 12.92 – conditioning 45 ± 6.22 – control	Aesthetic competence score (points) Post: 43 ± 6.34 – conditioning 42 ± 3.34 - control	
Martyn-Stevens et al., 2012	N = 18 (female) Students	Contemporary/ Modern	Testing protocols: VO_{2max} graded treadmill test (Bruce protocol) using a metabolic cart Wingate anaerobic bike test, 30 second protocol Setting: Measured pre- and post-season over 2 days of screening; pre- 10-12 weeks before dance performance, post- 1-2 weeks after performance	Mean VO_2max ($ml.kg.min^{-1}$) 42.66 ± 4.33 – pre 42.55 ± 4.26 - post		
				Mean peak power output (W) 430.08 ± 61.24 – pre 463.92 ± 58.95 - post		
				Mean peak power output ($W.kg^{-1}$) 7.43 ± 1.01 – pre 8.00 ± 0.78 – post		
				Mean fatigue index (%) 33.38 ± 9.72 – pre 38.91 ± 7.49 - post		
Galanti et al., 1993	N = 8 (female) Students	Other: Jazz	Testing protocols: VO_{2peak} graded treadmill test (Bruce protocol) to exhaustion VO_2 and HR recorded using metabolic cart every 15se Intervention: Participated in dance training 4 days a week for ~90min per session, finishing with a final performance	Mean VO_2max ($ml.kg.min^{-1}$) 37.4 ± 4.1 – pre 43.0 ± 3.5 – post		
Dahlstrom et al., 1996	N = 53 *Year 1* (N = 52	Multiple: Ballet, Modern, Jazz, Character	Testing protocols:	Mean VO_2 max ($ml.kg.min^{-1}$) Year 1:	Mean VO_2 max ($ml.kg.min^{-1}$) Year 2:	Mean VO_2 max ($ml.kg.min^{-1}$) Year 3:

	Year 2) (N = 43 *Year 3*) Students		Predicted VO_{2max} from submax. cycle ergometer test 4 times per year (mid and end semester; *TP1, TP2, TP3, TP4*) over the 3 year programme Setting: Three year undergraduate dance programme (no intervention in training)	46 ± 9 – TP1 47 ± 8 – TP2 47 ± 8 – TP3 48 ± 9 – TP4	48 ± 9 – TP1 48 ± 9 – TP2 48 ± 8 – TP3 49 ± 9 – TP4	49 ± 9 – TP1 47 ± 9 – TP2 50 ± 9 – TP3 52 ± 10 – TP4
Mistiaen et al., 2012	N = 40 (2 male, 38 female) Students	Multiple	Testing protocols: Submax. cycle-ergometer test consisting of 25W increases until 75% of predicted HRmax VO_2 and HR monitored by breath-by-breath analysis system Intervention: 6 month training programme 3 sessions per week of 90mins each	Mean VO_2 at 75% HRmax ($ml.kg.min^{-1}$) 27.62 ± 6.71 – pre 29.67 ± 6.10 – post Mean power output at 75% HRmax ($W.kg^{-1}$) 2.28 ± 0.60 – pre 2.44 ± 0.60 - post		

2. Ethics documentation

2.1. Information sheet, informed consent, and Medical Par-Q for chapters 5 and 6

Participant Information Sheet - BA

Study Title: Energy cost of dance activity and physiological adaptations to training in different skill levels of dancers across one training year.

Investigator: Sarah C Beck **Tel:** [redacted] **Email:** [redacted]

You are invited to participate in a study for an MPhil/PhD student at Trinity Laban that involves longitudinal tracking of physiological adaptation over one training year (academic year) in both first year undergraduate dance students and Transitions dance company members.

Objective: The main aim of this study is to describe changes in aerobic fitness and energy demand of dance movement occurring through one year of dance training. This knowledge will add to the previous body of research and help us to understand how to best prepare dancers to cope with the physical demands of dance training and performance.

Testing Procedures: Data will be collected at three time-points throughout the academic year: October, February, and July. At each of the three time-points you will be asked to complete two separate tests.

Firstly, you will be asked to complete a short dance movement sequence while measurements of your energy expenditure are undertaken. The measurements will require you to wear a portable gas analyser, which consists of a strap containing the analyser that fits around the upper torso and a face mask. This equipment will not restrict your movement or breathing and weighs around 1Kg only. To allow readings of heart rate a Polar heart rate monitor will also be worn around the torso throughout. At the end of the sequence you will also be asked to provide a blood lactate sample to assess the concentration of lactic acid. This involves a small pin-prick in the ear lobe with a contained lancet and collection of a very small amount of blood. The test is not painful and will not leave a wound. The sequence will be filmed for marking by expert technique teachers to enable a basic assessment of technical skill and quality of movement.

You will additionally be asked to undertake a maximal treadmill laboratory test to determine your individual lactate threshold and maximal oxygen uptake (VO_2max). The test involves you running on a treadmill, where the intensity will be increased every 3 minutes until you feel you are unable to continue, i.e. you have reached exhaustion. You will be required to wear the portable metamax gas analyser and a heart rate monitor throughout this test and blood lactate measurements will be taken at the end of each test stage.

The testing will take place in the dance science laboratory and studios at the dance faculty. You may ask questions at any time during the data collection.

Expected Benefits:
The maximal oxygen uptake and lactate threshold tests are considered *gold standard* fitness tests and usually cost around £150 to undertake within a specialist testing facility. The results of the test will provide you with an in-depth assessment of your current cardiovascular fitness level and the changes in your fitness throughout the year.

By completing measurements during dance activity you will gain a deeper understanding of the demand placed on your body during your training through calculation of the total energy it takes you to complete the task. This gives an indication of the economy of your movement and also the development in your skill and technique throughout the year.

Possible Risks/ Discomfort:
You will be asked to undertake a maximal test which is designed to push your body to its maximal capacity and is therefore strenuous and exhaustive. However, this is a recognised and validated test, widely used within sport and exercise research. You may pull out from any part of the study at any time without giving notice or reason. If you are experiencing pain or discomfort you should stop and inform the researcher. You will be given opportunity to warm-up prior to all data collection to minimise potential injury risks.

Clothing:
For the maximal test in the laboratory you will be asked to wear running shoes/ trainers and comfortable clothing appropriate for undertaking physical activity.

Formality: The Trinity Laban Research Ethics Committee has reviewed and approved this project. Feedback will be given to all participants as soon as possible upon completion of data analysis. All data collected will remain confidential and used only for the purposes of this research study. Data will be stored on a hard-drive and back up on a USB device. Both will be password protected. Your identity will remain anonymous in all data and documents. Any video footage collected by the researcher for the purposes of data analysis will be destroyed following completion of the study.

Voluntary Participation: Your participation in this study is completely voluntary. You may stop participation at any time with no negative consequences. You also have the right to refuse any component part of the measurement, including blood lactate sampling.

Contact Information: If you have any questions, comments, or require additional information please contact Sarah Beck (Tel: [redacted]; email: [redacted]).
If there is an aspect of the study which concerns you, you may make a complaint via the researchers lead supervisor, Emma Redding (Tel: [redacted]; email: [redacted])

Authorization: I have read this document and the study has been fully explained to me. I have had all of my questions adequately answered. I volunteer to participate in this study. I declare that I have no known injuries or cardiopulmonary problems, and have not received serious medical treatment within three months prior to my participation in this study.

Participant's name (please print): _______________________________

Participant's signature: _______________________ Date:___/___/___.

Participant Information Sheet - MA

Study Title: Energy cost of dance activity and physiological adaptations to training and performance in different skill levels of dancers across one training year.

Investigator: Sarah C Beck **Tel:** [redacted] **Email:** [redacted]

You are invited to participate in a study for an MPhil/PhD student at Trinity Laban that involves longitudinal tracking of physiological adaptation over one training year (academic year) under two separate investigations. Firstly, monitoring changes in aerobic fitness and energy demand of a simple dance movement phrase in both first year undergraduate dance students and Transitions dance company members throughout the year. Secondly, monitoring changes in aerobic fitness and energy demand of performance repertoire in Transitions dance company members throughout their touring period.

Objective: The main aim of this study is to describe changes in aerobic fitness and energy demand of dance movement occurring through dance training and performance. This knowledge will add to the previous body of research and help us to understand how to best prepare dancers to cope with the physical demands of dance training and performance.

Testing Procedures: Data will be collected under two separate investigations. You are invited to take part in both sets of measurements, but have the choice to participate in just one if you wish. The first investigation will involve testing at three time-points throughout the academic year: October, February, and July. At each of the time-points you will be asked to complete two separate tests (1&2) as detailed below. The second investigation will involve testing a three time-points throughout your touring period: February, April, and July. At each of the time-points you will be asked to complete two separate tests (1&3). If you volunteer to participate in both sets of measurements you will complete the following tests at each time-point; 1 & 2 in October; 1, 2, & 3 in February; 1 & 3 in April; and 1, 2, & 3 in July.

1) You will be asked to undertake a maximal treadmill laboratory test to determine your individual lactate threshold and maximal oxygen uptake (VO_2max). The test involves you running on a treadmill, where the intensity will be increased every 3 minutes until you feel you are unable to continue, i.e. you have reached exhaustion. The measurements will require you to wear a portable gas analyser, which consists of a strap containing the analyser that fits around the upper torso and a face mask. This equipment will not restrict your movement or breathing and weighs around 1Kg only. To allow readings of heart rate a Polar heart rate monitor will also be worn around the torso throughout. At the end of each test stage you will also be asked to provide a blood lactate sample to assess the concentration of lactic acid. This involves a small pin-prick in the ear lobe with a contained lancet and collection of a very small amount of blood. The test is not painful and will not leave a wound.

2) You will be asked to complete a short dance movement sequence while measurements of your energy expenditure are undertaken. You will be required to wear the portable metamax gas analyser and a heart rate monitor throughout this test and a blood lactate measurement will be taken at the end of the sequence. The sequence will be filmed for marking by expert technique teachers to enable a basic assessment of technical skill and quality of movement.

3) You will be asked to perform a pre-selected section of your current performance repertoire while measurements of your energy expenditure are undertaken. As with the other measurements, you will be required to wear the portable metamax gas analyser

and a heart rate monitor throughout this test and a blood lactate measurement will be taken at the end of the piece.

The testing will take place in the dance science laboratory and studios at the dance faculty. You may ask questions at any time during the data collection.

Expected Benefits:
The maximal oxygen uptake and lactate threshold tests are considered *gold standard* fitness tests and usually cost around £150 to undertake within a specialist testing facility. The results of the test will provide you with an in-depth assessment of your current cardiovascular fitness level and changes in your fitness throughout the year.

By completing measurements during dance activity you will gain a deeper understanding of the demand placed on your body during your training and performance through calculation of the total energy it takes you to complete the tasks. This gives an indication of the economy of your movement and also the development in your skill, technique and performance throughout the year.

Possible Risks/ Discomfort:
You will be asked to undertake a maximal test which is designed to push your body to its maximal capacity and is therefore strenuous and exhaustive. However, this is a recognised and validated test, widely used within sport and exercise research. You may pull out from any part of the study at any time without giving notice or reason. If you are experiencing pain or discomfort you should stop and inform the researcher. You will be given opportunity to warm-up prior to all data collection to minimise potential injury risks.

Clothing:
For the maximal test in the laboratory you will be asked to wear running shoes/ trainers and comfortable clothing appropriate for undertaking physical activity.

Formality: The Trinity Laban Research Ethics Committee has reviewed and approved this project. Feedback will be given to all participants as soon as possible upon completion of data analysis. All data collected will remain confidential and used only for the purposes of this research study. Data will be stored on a hard-drive and back up on a USB device. Both will be password protected. Your identity will remain anonymous in all data and documents. Any video footage collected by the researcher for the purposes of data analysis will be destroyed following completion of the study.

Voluntary Participation: Your participation in this study is completely voluntary. You may stop participation at any time with no negative consequences. You also have the right to refuse any component part of the measurement, including blood lactate sampling.
Contact Information: If you have any questions, comments, or require additional information please contact Sarah Beck (Tel: [redacted]; email: [redacted]).
If there is an aspect of the study which concerns you, you may make a complaint via the researchers lead supervisor, Emma Redding (Tel: [redacted]; email: [redacted])

Authorization: I have read this document and the study has been fully explained to me. I have had all of my questions adequately answered. I volunteer to participate in this study. I declare that I have no known injuries or cardiopulmonary problems, and have not received serious medical treatment within three months prior to my participation in this study.

Participant’s name (please print): ________________________________
Participant’s signature: _______________________ Date:___/___/____.

Participant Consent Form

This information will be treated, as confidential and only those involved in the activity will have access to it.

Name (please print):

Participant ID number:

Title of Study: Energy cost of dance activity and physiological adaptations to training and performance in different skill levels of dancers across one training year.

Please read the following statements carefully. Please sign only when you have agreed with the statements and when you have had any relevant questions answered.

By signing this form I confirm that:

- I am willing to take part in this study.
- I have read and understood the information sheet related to this study.
- The test(s) and procedures have been fully explained to me. I am clear about the nature, purpose and potential benefits of my participation in the study.
- I am aware there may be possible risks involved in this test and these risks have been explained to me. I understand that every effort will be made to minimise these risks based on information that I have provided and observations carried out by the tester throughout the test(s).
- I have/will inform the person conducting the test(s) about any medical condition I am currently suffering from or have suffered from which may affect or be affected by the test(s).
- I am free to withdraw from the test(s) at any time without necessarily giving a reason.

➢ Selected data may be used for other dance research projects approved by an official Ethics Committee. All data will remain anonymous. By signing this consent form you agree to have your data used anonymously in subsequent projects.

➢ Anonymous group average data may be provided upon request to technique teachers and/or heads of studies in order for them to be able to evaluate the training programme on which you are enrolled.

Your participation in this investigation and all data collected from the above testing procedures will remain strictly confidential. Only the researchers involved in the study will have access to your information and the information will not be accessible to any other member of staff. In compliance with the Data Protection Act (1998) and the Freedom of Information (2000), you will be able to access all information collected upon the completion of the study.

Signature:________________________________ Date:___/___/___.

MODIFIED MEDICAL PAR-Q and CONSENT FORM

Please read the following carefully and answer as accurately as possible.

	Yes	No
1. Have you ever suffered from low blood pressure?	……	……
2. Have you ever been prescribed a long-term course of steroids or anything to thin your blood?	……	……
3. Has your doctor ever said you have heart trouble?	……	……
4. Do you suffer frequently from chest pains?	……	……
5. Do you often feel faint or have dizzy spells?	……	……
6. Has a doctor ever said you have epilepsy?	……	……
7. Has a doctor ever said you have high blood pressure?	……	……
8. Has a doctor ever said you have diabetes?	……	……
9. Has a doctor ever said you have asthma?	……	……
10. Do you have a bone, joint or muscular problem which may be aggravated by exercise?	……	……
11. Do you have any form of injury?	……	……
12. Are you currently taking any prescription medications?	……	……
13. Have you suffered from a viral illness in the last 2 weeks?	……	……

14. Is there anything in your past medical history that you have not mentioned so far on this questionnaire (conditions, diseases)? Please give details:

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Adapted from Chisholm, D.M., Collins, M.I., Davenport, W., Gruber, N. & Kulack, L.L. 1975. PAR-Q validation report. British Columbia Medical Journal, 17.

	YES	NO
Have you eaten within the last hour?		
Have you consumed alcohol within the last 24 hours?		
Have you performed exhaustive exercise within the last 48 hours?		

If you have answered YES to any of the above questions, please inform the researcher.

2.2. Risk Assessment Evaluation and Consent Form for Blood Lactate Testing

<u>**Risk Assessment Evaluation and Consent Form for Blood Lactate Testing**</u>

Dance Science Staff or Students involved in Blood Lactate Testing- Trinity Laban Dance Science Department 2011-12

All University employees and students who might be at risk of occupational exposure to Hepatitis B, C and HIV will be categorised into the following groups: Please select the appropriate **Risk** category from below:

High-Risk - To include individuals who, as part of their normal duties would be expected to experience frequent direct exposure to blood or other potentially contaminated human tissue or fluids; and where an acute contamination incident may not be immediately noticed. This would include those clinical academic staff involved in invasive or exposure prone procedures, forensic pathologists and dentists. (Exposure prone procedures are those where the worker´s gloved hands may be in contact with sharp instruments, needle tips and sharp tissues inside an open body cavity, wound or confined anatomical space, and where the hands and fingertips are not completely visible at all times.)

Please tick appropriate box-

Moderate-Risk - Activities where there is a risk of contamination on a regular basis, but safe systems of work (including use of suitable and appropriate personal protective equipment where necessary), should normally provide adequate protection against Hepatitis `B´. Contamination incidents are isolated and recognisable. Includes academic medical staff not carrying out invasive or exposure prone procedures; laboratory technicians in pathology and haematology departments etc.

Please tick appropriate box-

Low-Risk - Work where there is occasional risk of exposure, but this is not a regular feature of employment. Potential contamination incidents are isolated and recognisable. Includes security staff, porters, university safety officers and domestic staff in areas where Hepatitis B is a significant hazard.

Please tick appropriate box-

No Normal Risk - No potential for contamination in normal course of employment would include administrative, clerical and kitchen staff, most non-clinical academics.

Please tick appropriate box-

Has your doctor immunised you for Hepatitis B and/or C? Yes / No (please circle) If yes please provide details of date and place.

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Are you currently infected with blood related diseases, including Hepatitis B or C or HIV? **Yes / No** (Please Circle)

Overall Risk Assessment for Tester: **High / Moderate / Low / None** (Please Circle)

All data collected during your time at Laban will remain strictly confidential. Only the head researcher involved in this study will have access to your information and the information will not be accessible to any other member of staff. In compliance with the Data Protection Act (1998) and the Freedom of Information (2000), you are able to access all data collected at any time.

I have read the ‘Risk Assessment and Consent Form’ and I fully understand the risk of taking blood samples and incident management procedures. **Yes/ No**. I consent to participate as a tester in these tests. **Yes / No**

Tester Name (please

print):____________________________Date:_____________Signature:___________________

Researcher Name (please

print):____________________________Date:_____________Signature:___________________

2.3. Information sheet, informed consent, and Medical Par-Q for chapters 4, 7, and 8

Participant Information Sheet

Study Title: Energy demand of contemporary dance repertoire and the relevance of cardiorespiratory fitness in dance performance

Investigator: Sarah C Beck **Tel:** [redacted] **Email:** [redacted]

You are invited to participate in a study for a PhD student at Trinity Laban that involves measurement of cardiorespiratory fitness levels and your metabolic response to performing repertoire under two separate investigations.

Objective: The first investigation aims to examine the cardiorespiratory demands placed upon contemporary dancers during performance of specific repertoire. The second investigation aims to practically question the relevance of examining cardiorespiratory fitness levels in dancers and document the relationship between various markers of cardiorespiratory fitness and dance performance competence. This knowledge will add to the previous body of research and help us to understand how to best prepare dancers to cope with the physical demands of dance performance.

Testing Procedures: You will be asked to complete two separate tests as detailed below. Please be aware that you may ask questions at any time before, during, or after the data collection.

1) You will be asked to perform a pre-selected section of your current performance repertoire while measurements of your energy expenditure are undertaken. This will require you to wear a portable gas analyser, which consists of a strap containing the analyser that fits around the upper torso and a face mask. This equipment will not restrict your movement or breathing and weighs around 1Kg only. To allow readings of heart rate a Polar heart rate monitor will also be worn around the torso throughout. The measurement will also be filmed, purely for data analysis purposes. The footage will not be shared with anyone outside of this research project and will be destroyed following completion of the project.

2) You will additionally be asked to undertake a maximal treadmill laboratory test to determine your individual anaerobic threshold and maximal oxygen uptake (VO_2max). The test involves you running on a treadmill, where the intensity will be increased every minute until you feel you are unable to continue, i.e. you have reached exhaustion. As with the other measurements, you will be required to wear the portable metamax gas analyser and a heart rate monitor throughout this test. This test will need to be conducted in the Dance Science Laboratory at Trinity Laban Conservatoire of Music and Dance, London. This can take place at any time convenient to you and will take approximately 45 minutes of your time. If this is not possible you will still be able to take part in part 1 of the testing.

Expected Benefits:
The maximal oxygen uptake and anaerobic threshold tests are considered *gold standard* fitness tests and usually cost around £150 to undertake within a specialist testing facility. The results of the test will provide you with an in-depth assessment of your current cardiovascular fitness level. By completing measurements during performance of dance repertoire you will gain a deeper understanding of the demand placed on your body during performance through calculation of the total energy it takes you to complete this task. You will be given detailed feedback on all measurements you undertake.

Possible Risks/ Discomfort:
You will be asked to undertake a maximal test which is designed to push your body to its maximal capacity and is therefore strenuous and exhaustive. However, this is a recognised and validated test, widely used within sport and exercise research. You may pull out from any part of the study at any time without giving notice or reason. If you are experiencing pain or discomfort you should stop and inform the researcher. You will be given opportunity to warm-up prior to all data collection to minimise potential injury risks.

Clothing:
For the maximal test in the laboratory you will be asked to wear running shoes/ trainers and comfortable clothing appropriate for undertaking physical activity.

Formality: The Trinity Laban Research Ethics Committee has reviewed and approved this project. Feedback will be given to all participants as soon as possible upon completion of data analysis. All data collected will remain confidential and used only for the purposes of this research study. Data will be stored on a hard-drive and back up on a USB device. Both will be password protected. Your identity will remain anonymous in all data and documents. Any video footage collected by the researcher for the purposes of data analysis will be destroyed following completion of the study.

Voluntary Participation: Your participation in this study is completely voluntary. You may stop participation at any time with no negative consequences. You also have the right to refuse any component part of the measurement.

Contact Information: If you have any questions, comments, or require additional information please contact Sarah Beck (Tel: [redacted]; email: [redacted]).
If there is an aspect of the study which concerns you, you may make a complaint via the researchers lead supervisor, Emma Redding (Tel: [redacted]; email: [redacted])

Authorization: I have read this document and the study has been fully explained to me. I have had all of my questions adequately answered. I volunteer to participate in this study. I declare that I have no known injuries or cardiopulmonary problems, and have not received serious medical treatment within three months prior to my participation in this study.

Participant's name (please print): ________________________________

Participant's signature: _______________________   Date:___/___/___.

Participant Consent Form

This information will be treated, as confidential and only those involved in the activity will have access to it.

Name (please print):

Participant ID number:

Title of Study: Energy demand of contemporary dance repertoire and the relevance of cardiorespiratory fitness in dance performance.

Please read the following statements carefully. Please sign only when you have agreed with the statements and when you have had any relevant questions answered.

By signing this form I confirm that:

- I am willing to take part in this study.
- I have read and understood the information sheet related to this study.
- The test(s) and procedures have been fully explained to me. I am clear about the nature, purpose and potential benefits of my participation in the study.
- I am aware there may be possible risks involved in this test and these risks have been explained to me. I understand that every effort will be made to minimise these risks based on information that I have provided and observations carried out by the tester throughout the test(s).
- I have/will inform the person conducting the test(s) about any medical condition I am currently suffering from or have suffered from which may affect or be affected by the test(s).
- I am free to withdraw from the test(s) at any time without necessarily giving a reason.

➢ Selected data may be used for other dance research projects approved by an official Ethics Committee. All data will remain anonymous. By signing this consent form you agree to have your data used anonymously in subsequent projects.

➢ Anonymous group average data may be provided upon request to company/ tutoring staff, including (but not limited to) rehearsal directors. By signing this consent form you agree to have your data used anonymously in such reports.

Your participation in this investigation and all data collected from the above testing procedures will remain strictly confidential. Only the researchers involved in the study will have access to your information and the information will not be accessible to any other member of staff. In compliance with the Data Protection Act (1998) and the Freedom of Information (2000), you will be able to access all information collected upon the completion of the study.

Signature:________________________________ Date:___/___/___.

MODIFIED MEDICAL PAR-Q and CONSENT FORM

Please read the following carefully and answer as accurately as possible.

	Yes	No
3. Have you ever suffered from low blood pressure?	……	……
4. Have you ever been prescribed a long-term course of steroids or anything to thin your blood?	……	……
3. Has your doctor ever said you have heart trouble?	……	……
4. Do you suffer frequently from chest pains?	……	……
5. Do you often feel faint or have dizzy spells?	……	……
6. Has a doctor ever said you have epilepsy?	……	……
7. Has a doctor ever said you have high blood pressure?	……	……
8. Has a doctor ever said you have diabetes?	……	……
9. Has a doctor ever said you have asthma?	……	……
11. Do you have a bone, joint or muscular problem which may be aggravated by exercise?	……	……
11. Do you have any form of injury?	……	……
12. Are you currently taking any prescription medications?	……	……
13. Have you suffered from a viral illness in the last 2 weeks?	……	……

14. Is there anything in your past medical history that you have not mentioned so far on this questionnaire (conditions, diseases)? Please give details:

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Adapted from Chisholm, D.M., Collins, M.I., Davenport, W., Gruber, N. & Kulack, L.L. 1975. PAR-Q validation report. British Columbia Medical Journal, 17.

	YES	NO
Have you eaten within the last hour?		
Have you consumed alcohol within the last 24 hours?		
Have you performed exhaustive exercise within the last 48 hours?		

If you have answered YES to any of the above questions, please inform the researcher.

3. List of Publications and Presentations

Publications

Under review in Journal of Strength and Conditioning Research... Beck, S., Wyon, M.A., & Redding., E. Changes in energy demand of dance activity and cardiorespiratory fitness during one year of vocational contemporary dance training.

Beck, S., Redding, E., & Wyon, M.A. (2015). Methodological considerations for documenting the energy demand of dance activity: a review. *Frontiers in Psychology: Performance Science*. *6*: 568.

Presentations

Needham-Beck, S., Redding, E., & Wyon, M. (2016). Determining the cardiorespiratory demand of contemporary dance repertoire. International Association for Dance Medicine and Science 26th Annual Conference, Hong Kong

Needham-Beck, S. (2016). Cardiorespiratory demands and training adaptation in contemporary dance performance. Brazil-UK Dance Medicine and Science Network, Gioania, Goias, Brazil (invited presentation)

Needham-Beck, S. (2016). Cardiorespiratory fitness testing in dance populations. Brazil-UK Dance Medicine and Science Network, Gioania, Goias, Brazil (invited presentation)

Needham-Beck, S. (2016). The cardiorespiratory demands of contemporary dance performance. Dance Medicine and Science Research Workshop, Wolverhampton, UK (invited presentation)

Redding, E., & Beck, S. (2015). Physiological preparation for the demands of choreography. DANscienCE Festival, Brisbane, Australia (invited presentation)

Redding, E., Aujla, I., Beck, S., De'Ath, S., Nordin-Bates, S., Quin, E., & Rafferty, S. (2015). Dancer Aerobic Fitness Across Ten Years. International Symposium on Performance Science, Kyoto, Japan

Redding, E., Aujla, I., Beck, S., De'Ath, S., Nordin-Bates, S., Quin, E., & Rafferty, S. (2015). Dancer Aerobic Fitness: A Decade Later. International Association for Dance Medicine and Science 25th Annual Meeting, Pittsburgh, USA

Quin, E., Redding, E., & Beck, S. (2015). Physiological preparation for the demands of choreography. The future: new ideas, new inspirations, Dance UK Industry Wide Conference, London, UK (invited presentation)

Beck, S., Redding E., & Wyon, M. (2014). Investigating changes in energy system utilization during a year of contemporary dance training. International Association for Dance Medicine and Science 24th Annual Meeting, Basel, Switzerland