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**Testing and Training for Physical Fitness in Contemporary
Dance: Investigations**

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**This thesis is submitted in fulfilment of the qualification for
Doctor of Philosophy (PhD) by Prior Publication**

**School of Community and Health Sciences, Department of
Applied Biological Sciences**

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London.**

January, 2009

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**CONTACT DETAILS AND SIGNATURES IN APPENDICES
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Declaration

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Abstract

Dance training has developed eclectically to serve the different approaches to dance performance and making, however there is a discrepancy between the physiological demands of training and dance performance. It is no longer acceptable to train contemporary dancers without due regard for physiological concerns if they are to be prepared appropriately to meet the demands of current choreographic work.

This doctoral thesis contains six published studies (chapter 3), five of which have been published as papers in peer reviewed academic journals and one as an abstract in a peer reviewed academic journal. The main thrust of each of the studies falls under the umbrella investigations of dance specific ways of assessing and training for physical fitness in contemporary dance. More specifically, the aims of the progressive research were: to investigate the physiological demands of dance training and performance; to assess the role of supplementary fitness training in dance; to examine new dance specific methods of testing and training dancers.

The thesis also comprises a supporting document (chapters 1, 2, 4, 5, 6) which places the work in its overall context, articulates the coherence and contemporary relevance of the work and critically evaluates its application to, and implications for, the broader dance context. The relationship between each study and how the six studies address an overarching question about the appropriateness of today's contemporary dance training is considered and some recommendations proffered. Specific limitations of each study and of the studies collectively, are articulated with recommendations for where future research efforts might be focused. Application of the research from the

educator and researcher's perspective is suggested, and the significance of the work is highlighted.

1.0 Introduction

The purpose of this chapter is to introduce the potential for the application of dance science to dance training. It will provide a brief account of key factors in the development of the contemporary dance genre using mainly an Anglo-American frame of reference. This will offer context for discussion of current training methods and their ‘fitness for purpose;’ and justification for the research submitted in this thesis. The original impetus for the research together with the research aims will be presented. An introduction to each research study will then follow.

1.1 Application of dance science

Teaching and training methods in dance have typically evolved from tradition and personal experiences; they have remained until very recently, relatively uninfluenced by the movement and exercise sciences. In recent decades, science has become a major contributor to advances in sport training and performance, evidenced by the number of sport science journals and applied sport science journals such as the *Journal of Strength and Conditioning Research* and the *International Journal of Sport Science & Coaching*. Developments in dance training and performance have not been comparable. Dancers view themselves as artists, not as athletes, yet the highly trained physical skills and movement vocabulary through which they communicate their ideas in choreographic work share much in common with those of athletes. Independent dance artist Gill Clarke stated, in her keynote speech at the Dance UK *Healthier Dancer Conference*, 2008:

“Dancers are the medium through which our art speaks – even in reconstructions or existing repertoire they are the active agents of translation of the work into the here and now. They are the expressive tools, the meaning makers, as if the musical instrument as well as the player. They are not machines, nor athletes – although extraordinary virtuosity might be one of their means of expression. They are imaginative artists. What we see in performance is not their physical bodies, but their ‘selves’ – their imaginations and intentions and wills and desires in disciplined motion” (Appendix 8.1).

Artistic expression is the primary focus of the dancer’s engagement with training.

Dancers and their teachers may be reluctant, therefore, to acknowledge the potential application of exercise science to their work. Indeed, there is some evidence of resistance to approaches in dance teaching and training which engage with research that might challenge previous practices. Donna Krasnow wrote that,

“[An] aspect that may inhibit dance educators from looking to the research to develop teaching methodology is the perpetuation of the tradition, as it has existed for many years. Most people in the profession have a strong belief in the past and the successes of past training methods, and fear that the power of the process will be lost” (Krasnow, 2005: p5).

Dancers are influenced by their teachers, and training methods have been passed down – dancer, teacher, dancer - with little critical scrutiny of the basis of traditional or established methodologies and practices. What has pervaded is the belief that past practice has brought success; however, the measures for success have not been investigated or qualified. Unlike sport, the goals for dance are less measurable, however, until dance performance can be quantified more systematically, the potential for arguing the benefits of a particular method(s) of training cannot be alleged with confidence.

There are additional factors which arguably have further militated against dance teachers engaging with scientific research. In particular, the historic location (in statutory education in England) of dance as a curriculum subject within Physical Education¹. Rightly in the author's view, dance teachers in schools, and the National Dance Teachers Association² have developed arguments for dance in the curriculum as artistic and creative engagement, rather than as physical activity *per se*. Since the 1990s, the reducing hours dedicated to dance in the curriculum and other general curriculum-related issues, have led to a strengthening of the arguments for curriculum dance experience to focus on the creative and imaginative development of the child.

Directions of thinking that stress the potential application of exercise science to dance have understandably been met with some resistance or lack of interest from dance educators and those involved in the training of professional dancers.

Krasnow's view underlines this position,

"Another aspect to consider is an unspoken bias that science ruins art in some way. Some teachers feel that artistic expression implies remaining completely in that passionate, non-logical state of being that is sometimes referred to as right-brain thinking." (Krasnow, 2005: p5).

Creativity and artistry should not and never will be led by science; however a greater understanding of how the physiological, psychological and biomechanical aspects of dance may lead to the development of better training techniques and healthier dancers must inform those engaged in the creative, artistic and training process. In 1990, sport scientist, Craig Sharp stated that,

¹ In 85 per cent of schools, delivery of curriculum dance is led by the school PE department (Youth Sports Trust, March 2008)

² The National Dance Teachers Association (NDTA) is a membership organisation led by a team of teachers and dance education professionals. It works to ensure that all young people in the UK have access to high quality dance education in schools.

“Dancers are, in fact, among the supreme all-round athletes in our society, and as such are well worth a look at physiologically” (Sharp, 1990: p15)

Almost twenty years on, Sharp’s comment has resonance: debate continues within the dance profession about the extent to which science can contribute to dance training and performance. In the last two decades, however, organisations and researchers have led initiatives to ensure that issues concerning dancers’ health are at the forefront of debates about dance training and performance. Some of these initiatives will be discussed later in this chapter.

It is important to appreciate developments in the contemporary dance art form itself, shifts in choreographic processes, and the historical context within which contemporary dance training and performance is located. Such an understanding will illuminate current dance training methodologies, enable us to challenge the appropriateness of certain teaching approaches, and consider how scientific approaches might support the achievement for the dancer of optimum health and performance.

1.2 Developments in dance training

The most familiar of dance techniques is arguably classical ballet. Classical dancers training to professional level are selected against criteria relating to body type, particular physical characteristics and capacities, and executant skills that can be developed to master a highly codified dance technique. The training has developed to fit perceived demands, based in the pedagogy of the technique that has evolved from the ballet masters onwards. Developments within the classical technique in the 20th century have been led largely by virtuosic demands and artistically motivated

challenges to conventions rather than being generated from any external perspectives such as the scientific.

The emergence of modernism in dance in America towards the end of the 19th century, continuing in America and Europe through the 20th century, led to the development of new aesthetic values in dance, to what became known as modern dance, and latterly in the UK as contemporary dance³. Isadora Duncan and Loïe Fuller were the first exponents in America of a kind of dancing that rejected the values of classicism, departing from the ideals of representation that were fundamental to classical ballet, and which in Europe had resulted in some cases, to a debasement of the technique and a trivialising of its use (Mc Donagh, 1970). Duncan and Fuller attempted to return to the originary nature of dance and to the integrity of movement itself. A guiding principle became 'truth to nature' and 'the natural', "... rejecting the formal aspects and rationality that inhere in the principles of classicism" (Bartrip, 1985, p14). Duncan's approach advocated a natural, liberating and individual way of moving as an extension of the inner self and the emotions. She stated: "I would like to no longer dance to anything but the rhythm of my soul" (Morrison Brown, 1980: p9-10). Training became less about the body and its capacity to express ideas and more about developing the capacity of the dancer to express the self and its response to and interaction with the natural world. Duncan's dancers, for example, would learn dance through executing basic human movements such as skipping and turning - 'natural' movements - bringing awareness to the use of breath in these activities (Mc Donagh, 1970).

³ The terms 'modern dance' and 'contemporary dance' are often used interchangeably. In this context, 'modern' and 'contemporary' are synonymous – 'modern' applies in the US, 'contemporary' applies in the UK.

For later dance artists, human experience became the subject of their work. Martha Graham, for example, exploited what she considered to be eternal and universal themes of mankind. In her rejection of the classical ballet tradition, she searched for an alternative framework to give voice to what was essentially her “dance-as-expression” thesis. She developed a technique, grounded in her choreographic work that would enable her to express the inner realities of the self⁴. Graham insisted that her dancers undertake her bespoke technical training, sets of exercises she derived from her choreographic work, preparing the body for the ‘contraction’ and ‘release’ patterns of her choreography which used the themes of classical mythology as a vehicle for expression of the ‘true’ (inner reality of the self) (Foster, 1997). Graham, together with other artists such as Doris Humphrey, Charles Wiedman, Hanya Holm, represented the establishment of (an essentially American) modern dance: Graham and Humphrey in particular, developed codified techniques to support the training of dancers for their choreography (in the case of Humphrey, the technique developed around particular movement principles and characteristics, and is arguably less prescribed in terms of its movement vocabulary).

A significant change emerges in the development of modern dance from the late 1940s in the work of Merce Cunningham. Duncan, Fuller and Graham, though very different in their exposition of ideas, had all been concerned with the dance itself, the dance language or movement vocabulary with which dance ideas are given expression (Bartrip, 1985: p8). Cunningham, on the other hand, can be seen to have been searching for a set of intrinsic properties which ground dance in a theory of kinesics (Bartrip, 1985: p8). This emerges as,

⁴ Graham’s pre-occupation with the inner self is consistent with widening acceptance during the 1940s of the theories of Jung and Freud, and acknowledgement of the significance of the unconscious mind.

“(a) critically different (approach) to emotion and cognition: ...Cunningham’s philosophy for dance inheres in a theory that places cognition before emotion, there is no set of pre-constituted images or symbols embodied in the dance tradition, and no external referent...movement itself is intrinsically expressive, it offers itself as the expression of itself....(Cunningham) inaugurated a modern tradition for dance; ...his approach to the medium itself and to dance as a process of making establishes a new concept for the modern” (Bartrip, 1985: p9).

McDonagh articulates this in the following terms:

“The assertion of the individual as the dominant focus of choreographic interest had reached a point which no one could ignore ... The dancers began to examine the basics of their craft in highly personal terms” (McDonagh, 1970: p50).

This essentially modernist theory prefigured the emergence of a variety of approaches to dance making (choreography), the movement vocabulary that could be used for dance, and dance training. A new dance avant-garde heralded itself⁵, the underlying principle of which was the reduction of movement to its essential features:

“For the new generation of choreographers that emerged in the 1960s and 1970s with the Judson Dance Theatre and Grand Union, movement’s essence was its capacity to display only those features essential to complete a given action” (Bartrip, 1985: p9).

Often employing mundane, everyday movement, the complexity of the work lay in the effort required to sustain performance to ensure the appearance of the ‘natural’ phrasing of everyday movement. The developments in modern dance post-1970s are significant not only for the way in which they changed expectations for what dance could be about, but also for the way in which they proposed an alternative relationship with the body, the dancing body, dance technique, and the function and purpose of dance technique. These debates were primarily of a philosophical nature, and were

⁵ There is no debate included here about the modernist/postmodernist distinctions that began to emerge at this time. Such distinctions require the full force of academic argument and such concerns are not the subject of this thesis.

seminal in developing aesthetic values in modern dance. The role of the dancing body in the communication of ideas, and the artifice of performance were questioned, as was the function of dance technique in the development of the dance artist.

The emergence in America of Contact Improvisation Technique developed by Steve Paxton, Nancy Stark Smith, Lisa Nelson and others in the early 1970s, trained dancers for performance through a series of unstructured practice sessions that involved weight sharing improvisation 'jams' (Foster, 1997). These sessions were themselves the technical training for the choreographic output that emerged. For Yvonne Rainer too, improvisational processes constituted a form of training for her choreographic work, focussing on the use of mundane, everyday movement: for Rainer, "...movement itself became like an object, something to be examined coolly without psychological, social or even formal motives" (Banes, 1980: p43).

Concurrent with the above developments in America in the 1960s and 70s, the formation by Robin Howard in 1967 of the London Contemporary Dance Group (afterwards renamed London Contemporary Dance Theatre) and the Contemporary Dance Trust in London marked the introduction of modern dance – contemporary dance - in the UK. It saw a new development of the Graham technique, led by Robert Cohan who pioneered the teaching of contemporary dance technique in the UK and was responsible for developing a significant repertory for London Contemporary Dance Theatre in the 1970s and 80s. His influence through residencies across the UK was considerable, and many dance artists and teachers emerged to develop the contemporary dance genre in their own very different directions (e.g. Siobhan Davies, Richard Alston, Darshan Singh Bhuller) (Sweeney, 2000).

New contemporary dance styles began to emerge, and, as was the case in America, developments in contemporary dance in other parts of the world were not homogenous. The development of physical theatre companies in Europe such as Ultima Vez and Tanztheater Wuppertal provided an opportunity for dancers to engage with a fusion of contemporary dance, pedestrian movement, text, theatre, film. Furthermore, the influences of dance from parts of Asia have resulted in companies such as Shobana Jeyasingh Dance Company and Akram Khan Company which celebrate cultural diversity through a synthesis of cultural dance styles. Khan notes the way in which his collaboration with Jonathon Burrows stipulated new physiological demands. He explains how this collaboration “was pivotal in his coming to understand the manner in which the two genres, Kathak and Contemporary, were generating new information in his muscles”.

(http://www.akramkhancompany.net/html/akram_akram.htm)

In no sense can one speak of any one dance technique or approach to the body that characterises contemporary dance teaching and training. Rather, a variety of approaches emerges from the 1970s onwards not only in America and the UK but also in Europe and Asia. An overarching feature is evident, however: what has been characterised by Bartrip (1985) as Cunningham’s theory of kinesis – the primacy of the movement itself, the idea that movement itself is intrinsically expressive – dominates, harnessed in different forms. Dance training developed eclectically to serve the different approaches to dance performance and making. Foster reflects this in her concept of the ‘The Hired Body’ (Foster, 1997), arguing that dancers hone their technical skills not for one particular choreographer but rather for any dance maker

who chooses to work with them. In other words, 'the body available for hire', so to speak, must have a range of technical skills and a capacity to respond to differing choreographic demands. Possible negative connotations of Foster's concept of the 'body for hire' are far outweighed by the enhancing qualities embraced within the interrogation of the physiological body that became the focus of the somatic approaches⁶ to dance training that emerged through the 1990s and onwards. Ownership and understanding of one's dancing body from within is what characterises many of the artistic and technical developments in contemporary dance during this period.

From the 1990s onwards, then, the focus on the kinaesthetic takes another direction in the development of release based-techniques which adopt a somatic approach to learning: these have emerged out of a concern for understanding the physiology of the body and its motor-sensory integration system, and the desire to learn how to learn from within the self. Release based techniques⁷, individually developed by dance-artist teachers who develop personalised dance styles based in fundamental anatomical and physiological principles (Hackney, 1998), require time in class to be devoted to reflection and memory consolidation (Batson, 2006: p100) in order for movement patterning and re-patterning to take place. By definition, the physiological intensity of release-based technique which requires a larger rest-to-activity ratio; is

⁶ Soma is a Greek word meaning "living body". Hanna (1988) states: "This living, self sensing, internalised perception of oneself is radically different from the externalised perception of what we call "a body" in an objectified form.

⁷ 'Release' is the term applied to dance technique that gives primacy to the internalised perception of oneself. Hanna's (1998) concept of the soma is central, emphasising the body's natural alignments and movements. Operating within these common principles, 'release' as technique and as teaching method is specific to the person teaching it and to the person dancing it. In itself, release technique is not passed on as a technical vocabulary, or dance form, as is the case with vocabulary-based codified techniques, but rather, it is an approach to moving and creating dance.

lower than in other contemporary dance techniques which focus on a particular movement vocabulary, dance style or codified technique.

Modern /contemporary dance techniques had previously been characterised in the main particular movement principles and/or a specific movement vocabulary. Dancers trained in a technique to prepare for choreography that utilised that particular technique. Indeed Foster claims that not only was the dancer trained exclusively for that technique but each choreographic work was designed exclusive of others (Foster, 1997). No longer can it be claimed that dancers in training will work exclusively for one choreographer in one contemporary dance style, however. Dancers may, for example, work with choreographers as diverse as Russell Maliphant, Hofesh Schechter, Wayne McGregor, Athina Vahla, Shobana Jeyasingh. The development of release-based techniques reflects the artistic concerns of many 'independent choreographers' whose work exists alongside that of other dance makers who require dancers with executant skills in the vocabulary-based, codified techniques. Today's contemporary dancer must be able to move between these differing demands.

1.3 Today's dance training

Contemporary dance⁸ in the 20th century consisted of "choreographic experimentation with eclectic vocabularies and with new interdisciplinary genres of performance" (Foster, 1997: p253). At Dance UK's Healthier Dancer Conference (1990), describing how contemporary choreographers are literally making new movement vocabulary as they work, Bannerman and Mason (1990) posed the question as to how

⁸ The term 'contemporary dance' and 'contemporary dance training' will be used hereafter to refer to the forms of modern dance that developed in the UK and Europe.

dancers could train effectively for companies as diverse as DV8, Rambert Dance Company, The Cholmondeleys:

“...perhaps we have not yet adapted our training programmes to suit the needs of today’s dancers” (Bannerman & Mason, 1990: p11).

Foster describes ‘independent choreographers’ who do not require dancers to train in a particular technique but to train in several techniques. Today’s dancer is required to have the strength and flexibility necessary in ballet, the athleticism of contact improvisation enabling the dancer to fall and recover and support the weight of others, the articulated torso of a Graham dancer and the agility of a Duncan dancer (Foster, 1997).

Independent dance artist, Gill Clarke (2007) commented,

“What is required of dancers has changed. Dancers of all kinds need to be open and adaptable; the diversity of influences on new work is growing continuously. There is no single movement vocabulary or narrow set of skills that we can teach them that will serve all their needs” (Appendix 8.1).

It can be argued that through a significant proportion of the 20th century, the cardiovascular requirements of choreographic work were met during the technical training and subsequent rehearsals of that work: the technique itself and the subsequent rehearsals prepared the dancer for the physiological energy demands of the performance. Today’s dancer cannot be so confident of the relationship between training and performance. The range of choreographic demands made upon contemporary dance artists (and indeed classical ballet dancers also) make it necessary to address dancers’ fitness for purpose. These factors give rise to the inquiry into dancers’ cardiorespiratory fitness, the role of fitness training within dance

and the need for a more systematic approach to measuring the impact of current training regimens on today's dancers.

Dancers spend between two to six hours per day, six to seven days per week for eight to ten years creating the 'dancing body' (Foster, 1997). The full time period of intensive vocational contemporary dance training is five full days per week usually lasting for three years. The majority of professional dancers in the UK have undertaken their training at vocational dance schools where the contact time for the student is more intensive than within university dance settings, although the professional performance arena numbers some graduates from university dance programmes. The primary focus of dance training in the professional training schools is the development of technical skill and artistry, taught through exercises and choreographed phrases and combinations in a daily technique class. Technique classes take up much of the practical contact time in dance training (Laban BA Hone Dance Theatre, Programme Specification 2008).

A typical technique class starts with a 'warm-up phase' which includes: a series of choreographed exercises aimed at improving coordination, alignment and dance specific movement skills such as balance, tilts, body part articulations and extensions; a 'centre phase' that includes longer choreographed movement sequences to develop memory, ability to pick up movement sequences as well as musicality and the use of dynamic intonation. Finally, there is normally a 'travelling phrase' consisting of choreographed combinations of movement designed to improve spatial skills, capacity to link together different kinds of movement, interpretative skills and usually including steps of elevation. The functional physiological development of dancers,

such as their muscular power or cardiovascular stamina, would rarely be of greater concern to the dance teacher than their students' development of technical skills (Krasnow & Chatfield, 1996). Such physiological improvements are not precluded as an outcome of the technique class, but can occur only as a consequence of something else taught within the class which is repeated over time.

The growth in somatic techniques such as Alexander Technique, Mind Body Centring⁹™ (Hackney, 1998) and Feldenkrais Method¹⁰® as supplementary training practices for dancers has highlighted the importance of encouraging a particular approach to learning through the use of imagery, proprioception and kinaesthetic awareness in dance to enhance balance, spatial awareness and other dance skills (Olsen, 2004). While the scientific research to support the use of such techniques is as yet undeveloped, many dance training programmes now include supplementary conditioning classes such as Pilates and other somatic based classes that aim to develop greater body awareness and postural alignment. The majority of dance training remains heavily skill focused, however (George et al 1996; Fitt et al 1998; Santillano, 2007; Brodie & Lobel, 2004).

Dance is a high skill based activity where tremendous demands are placed on the dancer in terms of joint range of motion, coordination and balance. Dancers are required to jump, perform fast explosive movements, balance, and turn, at the same time giving due attention to flow, suspension and many other qualities. They are expected to be expressive through their bodies, above all to communicate to an audience. In preparation for performance, dancers must be able to recall series' of

⁹ Body-Mind Centring denotes a patented system of movement therapy created by Bonnie Bainbridge Cohen.

¹⁰ *Feldenkrais Method*® is the registered trademark of the Feldenkrais Guild UK Ltd.

intricate, complicated and coordinated movement vocabulary and phrases. It is to be expected then, that a large part of dance training will be devoted to technical training, as defined above, where the specific focus is on skill acquisition rather than on general physiological development, notwithstanding the fact that supplementary classes may well be included to enhance training.

Changes in the demands of contemporary dance choreography has resulted in a ‘blurring’ of techniques so that no longer does one technique serve one choreographer or choreographic genre. Today’s contemporary dancers will have eclectic demands placed upon them, no one training regimen is likely to prepare them adequately for optimum performance in the different dance styles and demands they will encounter. There is a need to consider the general physiological development of the dancer who is likely to operate within a portfolio career profile, where s/he will work with many choreographers.

It is a challenge for exercise scientists to work alongside dancers, dance educators and choreographers, but not impossible, given that they share common goals: the pursuit of expression through the moving physical body. Important for exercise scientists to take account of, is that while the dancer may recognise him or herself as an elite athlete as well as artist, notions of faster, further, higher, longer are not normally the motivating factors for a dancer, as they are for the athlete, though they may well be for particular choreographers. Dance educators and trainers, on the other hand, need to recognise that significant physical demands are placed on the dancer, and that science knowledge and its application can enhance the training process and optimise dancers’ performance potential. Sharp proposes that,

“Dance, of course, consists of enormously much more than a superb physiology. Dancers must be highly co-ordinated, have an excellent musicality, pass through orthopaedic assessments, be of the right temperament in psychological terms, be adequately motivated, be of appropriate appearance and physical type in terms of body proportion and above all else they must have the creative talent to dance. There is, though, a factor which sports competitors use and dancers, on the whole, do not and that is laboratory fitness testing” (Sharp, 1990: p18).

1.4 Interface of sport and dance science

A primary goal for dance educators is to enhance dance training in order to support dancers in maximising their potential. The common element between dance and sport is perhaps that “both require endless physical training in order to achieve peak performance and culminate in concentrated, often risk-involving expenditures of physical energy” (Solomon, 1990: pXV). Compared with sport, dance as competitive performance is a relatively new concept. However, dance as a physical activity has much in common with sport; hence it has the potential to make use of principles established in the more advanced areas of exercise physiology and their application to training. In sport, for example, the issue of quality over quantity has been addressed, while in dance, this matter has only recently been given serious consideration. Bompa’s (1999) concepts of fatigue and overtraining in sport have recently been addressed for dance by Batson (2006) and others. Batson identifies the importance of a somatic “rest to activity ratio” to allow for memory consolidation and help the dancer process proprioceptive input and refine it “in the service of motor control” (Batson, 2006: p100).

It is important that findings in sport are acknowledged with due critical consideration by dance practitioners: there are essential differences between dance and sport especially with regards to performance criteria. The success of the dancer and the

impact of his/her training are measured not through quantitative measures such as jump height or the speed at which a movement can be completed, but through the audience and choreographer's subjective evaluation. Nevertheless, 'performance' is what is being evaluated in both sport and dance: the pursuit of excellence is a goal for both but with different processes and end products. Concepts from sport such as optimal psychological and biomechanical functioning and performance optimisation can be applied to dance. While in sport, records are being broken and limits are being stretched, in contemporary dance, choreographers strive for both the new and extreme in their works, indeed some demanding physiological extremes.

Dance science is a relatively new but rapidly growing area of research and study. Its aim is to investigate ways of enhancing dance training and optimising dancer potential. Recognising the dancer as athlete and artist, investigating the dancer through physiological, biomechanical and psychological perspectives, dance scientists strive to optimise the dancer's potential as an elite performer. The International Association of Dance Medicine and Science (IADMS), founded in 1990, and the first UK Healthier Dancer conference held in 1990, marked a commitment to investigating how better to support dancer health. The seminal text by Exercise Physiologists Yiannis Koutedakis and Craig Sharp, *The Fit and Healthy Dancer*, (1999) provided dancers and dance educators with the first science informed book about dancers' fitness, and offered essential recommendations for enhancing training as well as generating debate within the dance world about the role of fitness in dance. Subsequently, several Masters Degrees in Dance Science have been developed for dancers and dance educators, enabling them to increase their knowledge and understanding of the human body in dance from a scientific perspective. A

commitment to ensuring that the dance profession is populated by better informed dancers, teachers and choreographers is evident. Dance UK's¹¹ Healthier Dancer Programme (developed in 1990) and the outcome of its national inquiries into dancers' injuries has provided a greater understanding of the aetiology of injuries from which physiotherapists, physical therapists and physicians have benefitted.

The profiling of dancer health since the 1990s by Dance UK, IADMS and other organisations has brought about greater awareness of dance health issues. This has led to a better educated generation of dancers (Krasnow & Chatfield, 1996). Krasnow and Chatfield (1996: p162) observed that, "as dance became its own academic discipline, aspects of dance science were integrated into the curricular visions; most dance departments offer some sort of dance science options for their students". Much remains to be done, however. The two national inquiries into dancers' injury and health undertaken by Dance UK (1992 and 2002), have generated important data. In 1992, the enquiry found that 83% of dancers are injured within a 12 month period. In 2002, ten years on, the situation had not changed (Laws, 2005). Findings show that the prevalence of injuries in dance is higher than in many sport activities: for example, over 80% of dancers are injured each year compared to 15-25% of participants in rugby and football (Orchard & Seward, 2002). The cost to the subsidised dance sector in lost time due to injury is approximately 1 million pounds (Laws, 2005). The cost for treatment of these injuries is a further £900,000 per year (Laws, 2005). When reporting perceived causes of injury, dancers continue to cite 'fatigue' and 'overwork' as the most common alongside 'repetitive movements' (Laws, 2005). While there are several stages of fatigue ranging from acute to chronic

¹¹ Dance UK is the UK's national organisation for dance, set up to advocate for and promote the needs of dance.

which can be remedied in various ways, physical fatigue can be defined as ‘the inability to maintain a given power output’ (Edwards, 1982). In *The Fit and Healthy Dancer* (1999), Koutedakis and Sharp define fatigue as,

“the inability to generate or maintain a particular rate of physical work, as in especially fast, or long, or repeated dance or practice sequences” (Koutedakis & Sharp, 1999: p171).

It is known that a greater cardiorespiratory fitness capacity will enhance endurance and that dancers who are less fatigued show improved physical fitness (Koutedakis et al 1999). This indicates that dancers with better physical fitness will not feel as fatigued during rehearsals. This view has yet to be examined directly and verified.

It is anticipated that with the emergence of Dance Science as a growing field of research and study, and the number of interested medical practitioners, future dancers will be healthier dancers, dancing for longer and experiencing less injury.

1.5 The research

1.5.1 Impetus to undertake the research

A person’s experiential or instinctive comprehension of a phenomenon can sometimes precede their scientific understanding of it. As a professional dancer, I started to become interested in developing my physical stamina before fully understanding my reasons. There seemed to be a disjunction between my dance training as a student, in other words, the way in which I was prepared for the dance profession, and the physiological demands of performing as a dancer. This led to my participation in

regular fitness classes in gymnasiums, swimming, running and subsequently undertaking fitness and personal training qualifications. I was interested in why my improved physical stamina was assisting my dance performance, but I was in search of a dance specific method of improving stamina rather than relying on training regimes developed in sport and in gymnasiums by non dancers. This led me to undertake a Masters Degree in Sports Science, stimulating me to pursue my research interests, post-graduation. At this time, debates were emerging regarding whether dancers were fit enough: Dance UK's national inquiries into dancers' health and injury (Brinson & Dick 1992; Laws 2005) culminated in recommendations for the dance profession, included in which was an identified need to address dancers' physical fitness. While it was not the aim of the inquiries to uncover a link between injury and cardio-respiratory fitness, these surveys indicated that the greatest perceived cause of injury is fatigue and that improved cardiorespiratory fitness might therefore help reduce injury.

This doctoral thesis contains six studies, five of which have been published as papers in peer reviewed academic journals and one as an abstract in a peer reviewed academic journal. The findings of each study formed the impetus for subsequent research. The main thrust of each of the studies falls under the umbrella investigations of dance specific ways of measuring and training for fitness in contemporary dance. The aims of the progressive research are discussed below:

1.5.2 Research aims

- To investigate the physiological demands of dance training and performance
- To assess the role of supplementary fitness training in dance
- To examine new dance specific methods of testing and training dancers

The studies explicated in this thesis submitted for a PhD degree by prior publication are:

Study 1: Validity of using heart rate as a predictor of oxygen consumption in dance. Journal of Dance Medicine and Science, 8(3), 2004.

Study 2: Development, reliability and validity of a multistage dance specific aerobic fitness test. Journal of Dance Medicine and Science, 7(3), 2003.

Study 3: Physiological monitoring of cardio-respiratory adaptations during rehearsal and performance of contemporary dance. Journal of Strength and Conditioning Research, 19(3), 2005.

Study 4: Development of a High Intensity Dance Performance Fitness Test. Journal of Dance Medicine and Science, 13(1), 2009.

Study 5: When art meets science: An action research approach to improving professional dance teaching and learning using scientific methods. International Journal of Learning, 13, 2006. This paper won an International Award for Excellence in the area of Literacy and Education.

Study 6: The effect of a one year dance specific fitness training programme on undergraduate modern dance students; An experimental study. International Association of Dance Medicine and Science, 16th Annual Meeting, USA (published in conference proceedings and Abstract published in Journal of Dance Medicine and Science, 11(1), 2007.

1.5.3 Study 1, *Validity of using heart rate as a predictor of oxygen consumption in dance.*

An understanding of the energy requirements of dance is important in order to develop effective dance training programmes (Redding & Wyon, 2003). Much

research prior to this study had attempted to measure the physiological demands of dance using Douglas bag equipment¹² (Cohen et al 1982a; Schantz & Astrand, 1984). This earlier research noted that the equipment restricted the dancers' movement and the Douglas bag capacity limited the testing time available. Only mean results were reported and in addition, this earlier research noted that the oxygen uptake (VO_2) values were estimated from dance heart rates (HR) on the basis that the linear relationship between HR and VO_2 established in laboratory tests (treadmill or cycle ergometer) holds true for dance. However, because of the intermittent and random movement patterns of dance, it has been difficult to measure accurately energy expenditure during the activity itself (Bot & Hollander, 2000). Study one submitted in this thesis (Redding et al 2004), was an investigation into the extent to which the linear relationship between heart rate and oxygen uptake established during steady state exercise can be used to predict exercise intensity in dance. The findings of this study (study one) were that the use of steady state treadmill running to generate a HR- VO_2 relationship for the prediction of oxygen consumption during dance is questionable. The recommendation from these findings of study one was that dance specific methods of measuring dance and dancers is advised, calling into question the efficacy of the methodologies used in previous research to determine the physiological demands of dancing and the physiological capacities of dancers (Cohen et al 1982a; Schantz & Astrand, 1984; Dahlstrom et al 1996).

1.5.4 Study 2, *Development, reliability and validity of a multistage dance specific aerobic fitness test.*

¹² Douglas bag equipment comprises a polyvinyl chloride (or other leak-proof material) bag of typically 100–150 litre capacity. After collection of the expired air, the volume of the expired air in the bag is measured and a sample is analysed to determine oxygen and/or carbon dioxide concentrations.

Study two was the development of a dance specific multi-stage aerobic fitness test (Wyon et al 2003). Such a fitness test was the first of its kind and serves as a response to the call for more activity-specific methods of evaluating physiological capabilities as found in study one (Redding et al 2004) and also supported by Welsh (2003) who wrote more generally about the need for specificity in measuring capabilities in dance. The test consists of five stages of progressively demanding dance sequences. Each of the five stages is 4 min in duration and as the test continues, each stage becomes increasingly difficult in intensity (not in terms of choreographic demands). The movement material developed for each stage is representative of contemporary dance and consists of pliés in parallel and 1st positions; lunges with an opposition coordinated arm; and circular springs with various oppositional arm patterns; jumps and springs (Appendix 8.2). Stage three is equivalent to the mean O₂ demands of dance class and stage five is equivalent to the mean O₂ demands of performance. The technical level of each stage is kept as simple as possible to reduce the effect of movement economy so that the emphasis is physiologically based rather than skill orientated. There are several applications of the findings of this study for the dance world. They include the monitoring of progress across time through the measurement of heart rate at each of the stages during the year; the setting of a target stage attainment for an individual's readiness to undertake class or performance after injury and/or setting specific aerobic capabilities for dancers or choreographers post holiday period. Currently, the Dance Aerobic Fitness Test (DAFT) (Wyon et al 2003) is being used by dance schools in the UK and overseas, for example at Central School of Ballet, Bird College, the Australian Ballet School, Laban, and by dance companies such as Transitions Dance Company and Birmingham Royal Ballet.

1.5.5 Study 3, *Physiological monitoring of cardiorespiratory adaptations during rehearsal and performance of contemporary dance.*

Much of dance physiology research has examined the physiological status (fitness levels) of dancers. Few studies have attempted to measure the physiological characteristics of dance itself and the energy systems required in dancing (Cohen et al 1982a; Schantz & Astrand, 1984). The majority of existing studies were undertaken within the classical ballet dance genre. Information about the physiological demands of dancing is valuable in prescribing appropriate training programmes for dancers. Previous research indicates a difference between the intensity at which classical ballet dance training (class) is undertaken and the intensity at which classical ballet dance performance is undertaken (Cohen et al 1982a; Schantz & Astrand, 1984).

The extent to which such a physiological discrepancy between training and performance exists in contemporary dance had not been investigated until the time of the research presented in this thesis. Study three was an investigation to determine whether such a discrepancy between training and performance holds true for contemporary dance (Wyon et al 2005). The workload of the warm up section of a dance class and most rehearsals is below the minimum requirement of intensity to elicit a positive aerobic training effect (Pollock et al 1998 cited in Balady et al 2000). Although the centre section of a class may be similar in intensity to performance, the work to rest ratios are such that different energy systems are being stressed. The Dance Aerobic Fitness Test (Study two) (Wyon et al 2003) was used in the third study to assess physiological changes across a rehearsal and performance period. The aim of this study was to examine whether improvements occurred in dancers' cardiorespiratory fitness across a rehearsal and performance season. Findings of this study show that dancers are not adequately physiologically prepared to perform to the

same degree to which their technical skills are developed and that supplemental training is required to bridge this gap to better prepare dancers for performance. The Dance Aerobic Fitness Test (Wyon et al 2003) provided a means to measure changes in fitness in an objective way across the rehearsal and performance period as it stood outside the dance repertoire that was being learned and practised.

1.5.6 Study 4, *Development of a High Intensity Dance Performance Fitness Test.*

Dance is an intermittent activity that utilises both the aerobic and anaerobic energy systems (Chatfield et al 1990; Cohen et al 1982b; Dahlstrom et al 1996; Novak et al 1978; Rimmer et al 1994; Wyon et al 2004). While the DAFT responded to the need to monitor aerobic capabilities among dancers, it did not address the fact that dance uses both aerobic and anaerobic energy systems (Chatfield et al 1990; Cohen et al 1982b; Dahlstrom et al 1996; Novak et al 1976; Rimmer et al 1994; Wyon et al 2004). In order to ensure that appropriate physiological improvements occur through training, it is important that dance scientists and educators monitor not only dancers' aerobic fitness levels but also their capacity to dance at high intensities where the demand for adenosine triphosphate (ATP) can not be met solely through aerobic glycolysis and the proportion of energy derived from anaerobic pathways increases. Following the development of the DAFT (Wyon et al 2004), the investigations for study four were a logical progression. Study four was the development of a dance specific high intensity fitness test protocol. The test consists of jumps in parallel and 1st position; rolls to the floor; weight transference from feet to hands and back to feet; circular springs with an arm pattern and a parallel jump forward in space using an arm swing (Appendix 8.3). The phrase is completed three times within one minute and then the one minute movement phrase is again repeated after two minutes of rest. The sequence occurs four times. As with the DAFT (study two), the emphasis of the high

intensity dance fitness test is physiologically based rather than skill oriented, reducing the effect of movement economy through practice. Findings indicate that the high intensity dance specific test is a reliable and valid means of assessing and monitoring cardiovascular fitness of dancers. The test allows dancers to be assessed in an environment with which they are familiar (the studio) using a mode of exercise that is relevant (dance) and is of an adequate intensity to be representative of performance.

1.5.7 Study 5, *When art meets science: An action research approach to improving professional dance teaching and learning using scientific methods.*

Screening in dance is used both to identify potential problems at an early stage, and to develop prevention and/or rehabilitation strategies for individuals (Liederbach, 1997).

Dance screening developed as a response to the high injury rates among dancers (Laws, 2005). Methods to identify injury risk have therefore been mainly biomechanical and orthopaedic. Profiling gathers descriptive information about the status of a performing artist and/or to observe changes to their status across time (Chatfield et al 1990). Study five was the development of an interdisciplinary screening and profiling programme which was adopted by Laban¹³ and implemented within its undergraduate training programme. Laban was one of the first dance training institutions to pilot such a comprehensive screening programme and Laban is now considered a leader in the field of dance medicine and science because of this work (Redding et al 2005).

The dance students at Laban undertake an extensive interdisciplinary screening programme, designed to measure the parameters associated with quality performance

¹³ Laban is one of the leading contemporary dance conservatoires in the UK and in the international dance training arena. In paper five submitted in this thesis (chapter three) the reference to Laban as the largest dance conservatoire is based on the space allocation to students pursuing a contemporary dance major and also the number of students pursuing a contemporary dance major (380 FTE).

and well-being. The programme, embedded within the undergraduate training at Laban, assumes features of an action research approach¹⁴. This approach is a cyclical process that involves evaluation, reflection and implementation, thereby informing the curriculum across its research period. The screening process provides biomechanical, physiological and psychological information which is analysed and interpreted by a multidisciplinary team of dance science researchers including psychologists, physiologists and physiotherapists. On a continual basis, findings from the work are not only shared with each individual student at a private consultation but group information about the students is shared with dance teachers. Importantly, findings inform the development of the curriculum and changes are made accordingly and as appropriate. For example, early findings showed that dance students across year one of their studies were not improving aspects of their physical fitness. Consequently, a dance specific fitness training programme was integrated into the weekly training schedule at Laban which demonstrates how results were applied and an action research approach followed. Rarely do dancers in vocational training receive such specific, detailed information about their performance strengths and weaknesses, and rarely is dance training directly informed by systematic observation and evaluation in this way.

¹⁴ Research is longitudinal in design and situation-specific to Laban. Therefore between each stage of testing, methods of dance training and methods of measurement evolve, often as a result of evaluating data and also to ensure that the project continues to focus on pertinent issues. Consequently, this research does not fall into the category of typical experimental research. Many of the features of the approach adopt some of the characteristics of 'action research' (AR). AR is a method commonly used in education, health and more recently sport (Gilbourne, 1999) to evaluate and improve practice. The AR framework takes into account knowledge and methods already in place at the setting, termed craft knowledge (McFee, 1993 cited in Gilbourne, 2001). The AR cycle involves creating or redefining the way in which practice operates to overcome problems and improve practice (Carr & Kemmis, 1986).

1.5.8 Study 6, *The effect of a one year dance specific fitness training programme on undergraduate modern dance students: An experimental study.*

Debate has been evolving over the last two decades about what is an appropriate level of physical fitness for dancers. Research has shown that both professional and student dancers are no fitter than non endurance athletes (Chatfield et al 1990; Cohen et al 1982b; Dahlstrom et al 1996; Novak et al 1976; Rimmer et al 1994) and that they show limited cardiac function and structure changes during training as compared to age matched controls (Whyte et al 2003).

The idea of supplementary fitness training has consequently been debated albeit untested longitudinally with large groups of dancers. One previous study, entitled, *Breathless!: Results of a long term study of an integrated endurance training in professional dancers* (Wanke, 2001) assessed the effect of an integrated endurance training programme for ballet dancers (n=16) across a ballet season and found positive results. The purpose of this final study (study six) was to undertake longitudinal experimental research into the effect of a one-year dance specific fitness programme among undergraduate contemporary dance students undertaking full time vocational training. The fitness training programme consisted of weekly 90 min sessions across one academic year. The programme was progressive in that it developed every 4-6 weeks. Each period involved a series of exercises devised to focus on an appropriate balance of the components of physical fitness (Koutedakis & Sharp, 1999). The content of the sessions also addressed principles of periodisation and specificity (Bompa, 1999). Findings show that dance specific fitness training can improve aerobic power and serve as a useful supplementary tool to dance training.

1.6 Summary

Dance choreographers producing work today are placing new physiological demands on their dancers. Training regimens must match these demands. In the last 15-20 years, there has been a shift in thinking about the value for dance of scientific principles from the exercise and movement sciences. While there is still much work to be done, the research submitted in this thesis exemplifies new knowledge and understanding required to develop more effective and relevant training for the next generation of dancers.

This chapter has provided a brief account of key factors in the development of the contemporary dance genre to offer both context for discussion of current training methods and their ‘fitness for purpose;’ and justification for the research submitted in this thesis. While the overview of developments in contemporary dance presented in this chapter has adopted a mainly Anglo-American frame of reference, it is proposed that developments in dance in Europe and Asia, and indeed in other countries such as Australia and Canada where there are vibrant and diverse contemporary dance cultures, are comparable. And similarly, concerns are being raised by those responsible for contemporary dance training from within these different cultures. There is the potential, therefore for disseminating the research in this thesis to an audience worldwide. The original impetus for the research aims has been presented, followed by an introduction to each research study.

Chapter two that follows will introduce the physiological theory underpinning energy transfer and the various pathways in which energy is re-synthesised for biological work. It will provide a review of literature that has measured the cardiorespiratory

capabilities of dancers and the physiological characteristics of dance. The chapter will then address the need for dance specific fitness training as part of today's dance training regimen.

2.0 Introduction and literature review

The purpose of this chapter is to introduce the physiological theory underpinning energy transfer and the various pathways in which energy is re-synthesised for biological work. It reviews previous research that has measured the cardiorespiratory capabilities of dancers and the physiological characteristics of dance. The challenge is two fold: to test dancers using the various standardised measuring techniques that have been used to date; and measuring dance itself - a multi-directional transitory and diverse physical activity the many physiological demands of which are yet to be determined. Finally, the need for dance specific fitness training as part of today's dance training regimen will be proposed.

An understanding of the metabolism of exercise has implications for the training of sport and physical activity. Knowledge of the metabolic factors associated with a decrease in performance and of the various ways in which metabolism can affect optimal performance is vital to those interested in training.

2.1 Introduction

2.1.1 Classification of skeletal muscle

In order to explain fully metabolism and energy transfer in exercise, consideration should be given to muscle fibre types, the fuels that are utilised by the various fibre types and the complex changes and interactions that occur in order to affect physical activity. Muscles differ with regards to their physiological capabilities and metabolic properties, however, because of the variations in muscle fibres within any one muscle, it is more appropriate to classify the fibre composition within muscles. The division of human muscle fibres is characterised by physiological and metabolic distinctions.

Broadly speaking, there are at least three types of muscle fibres: Type I, Type IIa and IIb (Saltin et al 1977). Type I fibres are known as slow twitch fibres: the duration to maximum twitch/contraction is longer than Type II fibres' time to maximum contraction. Type I fibres have a greater oxidative capacity, low glycolytic capacity and high content of triacylglycerol. Fatigue resistant, they can utilise their ability to oxidise fatty acids. Conversely, the rapid transmission of the action potential across the fibre membrane of Type II fibres allows rapid contractions to occur. Type II fibres are innervated by larger motor neurons and the way in which the cross-bridges of the actin and myosin filaments in myofibrils interact also makes for a shorter contraction-relaxation cycle. These physiological characteristics provide the speed for a sprinter and the larger motor units contribute to a greater power output. Type II fibres are further divided into Type IIa and IIb. Type IIa fibre types have a high oxidative capacity like Type I fibres however they also have a high glycolytic capacity (degradation of glycogen). Type IIb fibres have high glycolytic but low oxidative capacities (Table 1).

Property	Type I (slow twitch)	Type IIa (fast twitch-oxidative)	Type IIb (slow twitch-glycolytic)
Speed of contraction	Slow	Fast	Fast
Glycolytic capacity	Low	Moderate	High
Oxidative capacity	High	Moderate	Low
Glycogen store	Moderate-high	Moderate-high	Moderate-high
Triacylglycerol store	High	Moderate	Low
Capillary supply	Good	Moderate	Poor

Table 1. Characterisation of human muscle fibre types (Saltin et al 1977 cited in Newsholme 1983: p213).

Elite male and female distance runners have 90-99% slow twitch Type I fibres in the gastrocnemius calf muscle whereas elite sprinters have approx 25% in the gastrocnemius muscle (Costill et al 1976). The question as to whether there is an optimal fibre type composition for dancers is debatable given that dance consists of activity that probably utilises all fibre types to varying degrees.

Although the actual number of fibre types in any one muscle may be fixed, research has shown that through training, and particularly strength training, the capabilities of fibres can be enhanced (Shephard, 1978). Controversy exists as to whether the fibre type composition of a given muscle can change through either training or prolonged rest. It is generally accepted that fibre type composition is determined genetically, however some research has shown that anaerobic training can convert the functional capacity of Type I fibres into Type II (Jansson et al 1978). Snow & Guy (1980) found that muscles of the greyhound, which have been bred over hundreds of years, contain a high percentage of Type II fibres (in some muscles the percentage is greater than 95%) as compared to the mongrel at 69%, which suggests a conversion training effect. Furthermore, it has been found that immobilisation due to injury can lead to a change in fibre type composition with the reverse effect post returning to training (Eriksson, 1981, 1982).

2.1.2 Energy transfer

The body needs a constant supply of energy for cellular metabolism (Marieb, 2009). The breakdown of the compound adenosine triphosphate (ATP) releases the energy needed for all cellular work. The adenosine molecule is attached to the phosphate molecules through high energy bonds. The enzyme ATPase breaks down one of these

bonds to form adenosine diphosphate (ADP) and phosphate (Pi) which releases energy for cellular work (Figure 1).

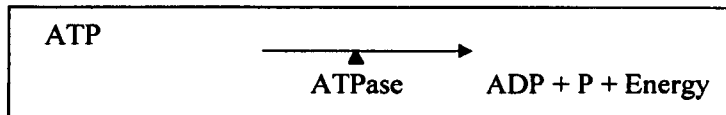


Figure 1. The catabolic breakdown of adenosine triphosphate (ATP) to adenosine diphosphate (ADP) and Pi by the enzyme ATPase.

The human body stores approximately 85 g of ATP which is enough for only the first few seconds of maximal exercise (< 4 sec). There are limited stores of ATP available in the body, and there are a number of other processes through which ATP is re-synthesised. There are three important energy systems for physical activity: two do not require oxygen (ATP-CP and glycolytic/lactate system); one system requires oxygen (aerobic system).

As exercise intensity increases, so does the demand for energy, and this increase in ATP demand can be several hundred-fold. The predominant methods called upon to replenish ATP stores change according to ATP demand.

2.1.3 ATP-CP system

Muscle tissue contains phosphagens also known as creatine phosphate (CP). These phosphagens are described as energy rich compounds because the phosphate group is catalysed by creatine kinase (CP hydrolysis) in a reaction with equilibrium constant (ATP-CP). A small amount of CP is stored in the body and this system can supply energy for immediate use at high exercise intensities (< 10 sec). This system produces energy for very fast and explosive movements such as jumps and sprints and is available for almost immediate use (Hultman & Sjoholm, 1983).

2.1.4 Anaerobic glycolysis

Anaerobic metabolism is used to re-synthesise ATP for a slightly longer duration than the ATP-CP system (< 2 min as opposed to < 10 sec). The re-synthesis of ATP occurs within the cytoplasm of the cell through a process called glycolysis - the anaerobic breakdown of glycogen (Figure 2) - and is more specifically called upon when the muscle's demand for oxygen cannot be met as intensity increases from moderate to high and when the ATP-CP system is depleted at maximal intensities up to 180 sec. Glycolysis is a much more complex process than ATP-CP system as it involves a series of complex enzymatic reactions.

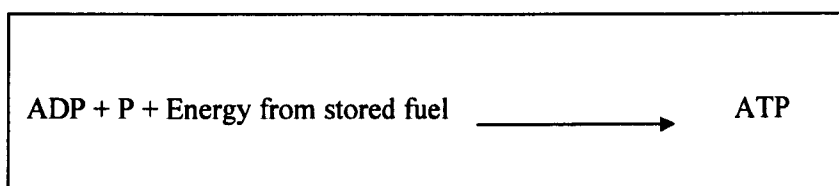


Figure 2. The re-synthesis of ATP through the breakdown of stored fuel to join ADP and Pi.

One of the end-products of the lactic acid system is pyruvate and protons hydrogen (H^+). An accumulation of H^+ reduces pyruvate to lactate (LA). In the right conditions, pyruvate can be broken down and used to assist energy production in other parts of the body, assisting aerobic glycolysis. The resulting H^+ from anaerobic glycolysis is carried by molecules: nicotinamide adenine dinucleotide (NAD^+). The NAD^+ is reduced to $NADH$ which take the H^+ to the mitochondria to be combined with oxygen to form water (Astrand et al 1986). At moderate intensities, the production and removal of LA is even and turns over effectively. Indeed, LA is considered useful in that it aids the dissociation of oxygen from haemoglobin thereby enhancing aerobic metabolism (Brooks, 1985).

However, when there is insufficient oxygen available for this process, pyruvate accepts the excess H^+ forming lactic acid, hence the term Lactic Acid System and eventually Lactate (LA) and H^+ . Some of the protons are buffered both intra-and extra-cellularly by various buffers including the carbonic acid/hydrogencarbonate system so as to prevent a pH imbalance of the blood (Sahlin, 1978) and subsequent muscle fatigue. As the demand for energy remains high, the subsequent accumulation of protons leads to subsequent blood acidosis and fatigue, limiting long term high power output performance. The normal amount of lactic acid in the blood is 1 to 2 millimoles/litre of blood, however as an accumulation occurs, this amount rises. An onset of blood lactate accumulation (OBLA) is noted at 2 to 4 millimoles/litre of blood (Astrand et al 1986).

It is often assumed that lactate ion is responsible for muscle fatigue yet high power output can be maintained in the presence of high concentrations of lactate so long as the pH remains constant (Newsholme, 1983). It is the intracellular accumulation of protons that is responsible for fatigue because of the subsequent decrease in pH below 7.0 (Hermansen, 1979). The way in which this increase in proton concentration leads to peripheral fatigue is not clear, however there are a number of possible explanations. A decrease in pH has been shown to increase the Ca^{2+} binding capacity of the sarcoplasmic reticulum reducing the contractile processes (Nakamura & Schwartz, 1972). Another view is that the decrease in pH can affect glycolytic enzymatic activity, thereby reducing the rate of ATP production (Newsholme, 1983). More recently, the 'central governor' theory suggests that fatigue is not a peripheral (muscular) but a central (CNS) phenomenon i.e that maximal capacities in physical

activity are controlled by the brain and that the extent of skeletal muscle recruitment is modified by a continuously altering pacing strategy (Noakes, 2005).

2.1.5 Aerobic system

During rest, it is likely that ATP is predominantly generated by aerobic metabolism (oxidation of glucose, fatty acids etc) occurring within the mitochondria of the muscle cells. The oxidative energy pathway is the most complex energy providing process involving a large number of reactions and specialised enzymes. At rest, the ATP demand is low and even a muscle with relatively poor blood supply can provide sufficient fuel and oxygen. Aerobic metabolism is sometimes referred to as the 'pay as you go' system since the rate of demand for ATP can be adequately met by its supply at low to moderate intensities. During aerobic metabolism, the complete oxidation of one molecule of glucose through glycolysis, the Krebs cycle and electron transport chain produces 38 molecules of ATP. If glycogen is used as the oxidising substrate then 39 molecules are produced (Table 2) as the first process of phosphorylation uses P_i rather than ATP (Newsholme, 1983).

The aerobic system cannot produce large amounts of energy quickly; however it can produce energy for long periods of time so long as adequate oxygen is available. The metabolism of carbohydrates, as opposed to fat, using pyruvate from glycolysis as fuel can produce energy at a slightly faster rate. At the other end of the spectrum from the ATP-CP system, is the aerobic metabolism of fats which can provide energy for long durations but at lower intensities.

If exercise intensity increases and the demand for oxygen can no longer be met using the aerobic energy system, the major pathway through which ATP is generated alters

so that ATP re-synthesis can continue. A rise in blood lactate above 4 mmol is an indirect 'indicator' that the demands for energy can no longer be met solely by aerobic pathways and the contribution of the anaerobic glycolytic system has increased.

2.1.6 Energy yield

The yield from anaerobic glycolysis is low compared with the yield from aerobic metabolism. Anaerobic glycolysis produces 2-3 molecules of ATP per molecule of substrate as opposed to the 38 to 39 molecules of ATP per molecule of substrate produced by the aerobic system (Table 2). However the anaerobic pathways can generate ATP much more quickly and are therefore useful for sudden explosive movements.

Fuel	Conditions	ATP yield (mol) per mol of fuel utilised
Glucose	Aerobic, complete oxidation	38
Glucose	Anaerobic, conversion to lactate	2
Glycogen	Aerobic, complete oxidation	39
Glycogen	Anaerobic, conversion to lactate	3

Table 2. Yield of ATP from various fuels under aerobic and anaerobic conditions (Newsholme 1983: p208).

2.1.7 Energy continuum

The body's choice of energy system is dependent upon the duration and intensity of exercise undertaken. Although an increase in energy demand can be sudden and substantial at the initiation of exercise, the required increase of blood flow (vasodilation) can take several minutes (Rowell, 1974). During this initial period, ATP must be generated from phosphocreatine and glycogen. Notwithstanding this, with the exception of high explosive intensity exercise lasting less than 10 seconds, all

exercise periods employ all energy systems to varying degrees (see Figure 3). For instance, the time taken to sprint the 400 m race is more than four-fold the time to complete the 100 m sprint. At the 2008 Beijing Olympics, the 100 m race was completed in 9.69 sec compared to the 43.75 sec for the 400 m race (The official Beijing Olympic website: 2008) demonstrating that maximum power output cannot be sustained across even relatively short periods of time and that the demand for ATP is met by a combination of processes. Conversely, while the aerobic energy system is useful for long duration low to moderate intensity exercise, it becomes no longer the sole provider of energy as intensity continues to rise.

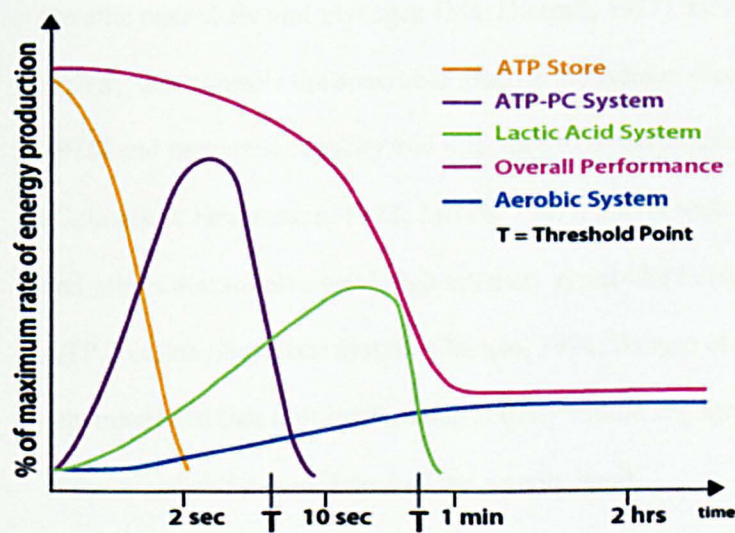


Figure 3. The percentage of maximum rate of energy production over time (Fox & Matthews, 1981).

Essentially the energy systems constitute a continuum from high-energy phosphates supplying the energy at one end (very short duration) to energy being produced aerobically (sustained duration) at the other. With the exception of specific

performance events such as the 100 m race or a power weight lifting event, most physical activity utilises all energy systems. It is therefore vital for anyone involved in the education and training of athletes and physical performers such as dancers, to understand the inter-relationships of all energy systems and the concept of the energy continuum.

2.1.8 Training and adaptations

In order to elicit physiological adaptations and improve performance for any athlete or physical performer, it is necessary to design programmes that address factors such as specificity, individuality, type of training, intensity, duration and frequency, ensuring an appropriate overload. Strength training and sprint, power-type work has shown various adaptations including increased levels of anaerobic substrate such as ATP, creatine phosphate and glycogen (MacDougall, 1977), increased levels of enzymatic activity that controls the anaerobic glucose breakdown (Jacobs, 1987; Thorstensson, 1976) and increased capacity and tolerance to blood lactate during all-out exercise (Gollnick & Hermansen, 1973; Jacobs, 1987). Sports such as football, weightlifting and others that involve brief high intensity sprint-like burst activities depend upon the ATP creatine phosphate system (Bangso, 1994; Bangso et al 2006). It is recommended that training for such activity should engage the specific muscle groups at the speed and power output of the activity itself.

Aerobic submaximal-type exercise can stimulate a variety of metabolic adaptations such as: enhanced mitochondria; enhanced ability to achieve a high aerobic capacity without significant lactate build-up (Seals, 1984); increased aerobic enzyme activity (Holloszy, 1988); enhanced lipid and carbohydrate (Riviere, 1989; Holloszy, 1988) and enhanced Type I muscle fibres. The physiological adaptations associated with

aerobic submaximal-type exercise include increased size and thickness of the left ventricular heart cavity (Mitchell, 1994); decreased resting and submaximal heart rate; increased stroke volume and cardiac output and an increased oxygen extraction (Magel, 1978; Rowell, 1994).

Activities such as marathon running rely heavily on the aerobic system to generate ATP. It is recommended that training for such activity should provide sufficient overload of the cardiovascular system to stimulate increases in stroke volume and cardiac output. Exercises should work those muscle groups specific to the chosen activity. The concept of specificity is equally applicable to aerobic training as it is to anaerobic training in that runners should run, swimmers should swim and so on so that both the intensity and mode of activity is specific to the athlete. Interval (exercise-rest) training (Daniels & Scardinia, 1984), continuous (long, slow, distance) training and fartlek (varying intensity bouts) training are common methods for improving aerobic fitness (Balady et al 2000).

2.2 Literature Review

2.2.1 Physiological demands of dance

The physiological classification of dance is an area of contention, primarily because dancers are more likely to see themselves as artists rather than athletes. In this sense, the physiological training is only a symptom of a primary requirement; the search for the aesthetic and little research exists in this area (Krasnow & Chatfield, 1996). Most previous research agrees that dance is an intermittent activity that utilises both the aerobic and anaerobic energy systems (Novak et al 1978; Cohen et al 1982a,b; Chatfield et al 1999; Rimmer et al 1994; Wyon et al 2004). Dance is 'transitory', meaning that its exercise intensity may move from moderate to high to moderate to low activity in a non steady state fashion (Cohen et al 1982a; Schantz & Astrand, 1984).

It is therefore likely that the energy systems that are called upon to generate ATP are continually changing to meet such varying demands. Dance may be considered as physiologically demanding not only in terms of extreme joint ranges of motion that are achieved but also with regards to the high intensity jumps and lifts observed in performance. However, there appears to be a discrepancy in the intensity level of training when compared to performance (Cohen et al 1982a; Schantz & Astrand, 1984; Wyon et al 2004). What has been shown in classical ballet, is that the cardiorespiratory demands of dance rehearsal and performance are high (Rimmer et al 1994), whereas 'class' has remained relatively the same for decades. Conversely, performance has changed at a relatively faster rate, both physiologically and within the diversity of the technical skills required (Bannerman & Mason, 1990). Findings

such as these may account for the recent debate about whether dancers are as fit as they could be (Koutedakis & Jamurtas, 2004).

Adaptability is a prerequisite for a dancer to cope with the diverse physical, technical and mental demands of today's dance. As discussed in the previous chapter, while it could be assumed that the aim of the training class (known as the technique class) in dance is to hone technical skills, the extent to which physiologically it prepares dancers in terms of physical fitness stamina is contentious. The findings of the previously cited research undertaken on classical ballet dancers cannot be assumed as transferable to other genres. There was a need for research that investigates whether the same physiological discrepancy between class, rehearsal and performance found in classical ballet holds true for other genres such as contemporary dance. The author of this thesis measured oxygen uptake during modern dance class, rehearsal and performance and noted a difference between the intensity of class, rehearsal and performance (Wyon et al 2004), hence the justification for study three (Wyon et al 2005) submitted in this thesis.

2.2.2 Physical fitness of dancers

Dancers' fitness has been at the forefront of debate in recent years and within that debate, the role of cardiorespiratory fitness in particular, has been discussed. Previous research has examined the physical fitness status of professional and pre-professional ballet dancers (Chatfield et al 1990; Cohen et al 1982; Dahlstrom et al 1996), Novak et al 1978; Rimmer et al 1994). Findings show that female ballet dancers' cardiovascular fitness measured through the maximal oxygen uptake test ranges from 39.1 ml.kg.min (Brinson & Dick, 1996) to 51 ml.kg.min (Schantz & Astrand, 1984) with the range for male ballet dancers being 50.5 ml.kg.min (Rimmer et al 1994) to

59.3 ml.kg.min (Mostardi et al 1983). Ballet dancers' cardiovascular capabilities are slightly higher than untrained females and males at 38 ml.kg.min and 42 ml.kg.min respectively (Koutedakis & Sharp, 1999) but either equal to or lower than other sports athletes such as footballers (Heller et al 1993; Jensson & Larsson, 1993) and squash players (Chin et al 1995). The cardiovascular capabilities of modern dancers as measured through a maximal oxygen uptake test have been found to be 43.5 ml.kg.min and 55.7 ml.kg.min respectively (Brinson & Dick, 1996). While Whyte et al (2003) did not measure the cardiovascular capabilities of modern dancers using a maximal oxygen uptake test, they observed their cardiovascular functioning and structure and found that modern dancers' left ventricular thickness was comparable to age matched controls, thereby resembling non-endurance athletes. It should be noted however, that the modern dancers used in Whyte's study were students. A similar study by Cohen et al (1981c) found professional dancers to have greater volume and thickness measurements of left ventricular mass compared to age matched controls. Given that in ballet, the intensity of performance is higher than in training, the same may hold true for modern dancers in that students are not exposed to the performance opportunities of professionals and are therefore arguably less physically fit.

Debate continues regarding the optimal levels of fitness for dancers, indicating a need for further research into both the demands of training and performance across genres and the cardiovascular fitness capabilities of dancers working in different genres. Dahlstrom et al (1996) examined the physiological demands of four different dance genres: modern, jazz, ballet and character during class. The method used was HR telemetry and analysis shows percentage of time spent above certain HR bands. The limitation of this study is that this method does not allow comparison with other

previous studies. Furthermore, the HR values appeared unusually high, possibly due to the small sample size and alterations in the structure of class to accommodate the testing.

There has been related research into the relationship between areas of health, injury risk and optimal performance, however a significant proportion of this research has again focussed on classical ballet (Wilmerding et al 2005; Kadel et al 1992; Calabrese et al 1983) with limited research in contemporary dance and other genres (Laws, 2005; Irvine, 2008). For example, the body composition and body mass index (BMI) of ballet dancers has been reported to be lower than the normal population (Kadel et al 1992; Wilmerding et al 2005); female dancers are more likely to suffer from menstrual dysfunction than the normal population (Kadel et al 1992; Chartrand & Chatfield, 2005) and dancers are more likely to smoke. Dancers who smoke are more likely than non smokers to suffer bone, neck, shoulder, lower back, groin and hip injuries (Laws, 2005). The two national enquiries into dancers' health and injury led by Dance UK further highlighted the need for a greater awareness among dance educators of the role of health education and of supplementary fitness training in dance (Brinson & Dick, 1992; Laws, 2005). Alongside the growing interest in the healthier dancer, Koutedakis & Sharp (1999) initiated the fitness debate within the wider dance community through their seminal publication 'Fit and Healthy Dancer' which provides information for dancers and dance educators about the need for supplementary fitness training in dance.

The more recent of the two enquiries into dancers' health and injury identified menstrual health, smoking, sleep disturbances and body composition as factors

relating to injury and fatigue. The enquiry also cited low fitness as a perceived contributor towards fatigue and therefore injury (Laws, 2005). These descriptive studies provide a useful 'snap shot' picture of the current health and injury status of dancers and the potential links between these variables. There is a need however, for more longitudinal research which examines dancers' profiles across time, the effect of certain training regimens and choreography on these profiles and the impact of health education. Study five (Redding & Quested 2006) submitted in this thesis initiates such research through its development of a longitudinal interdisciplinary screening programme.

While it might be assumed that dance rehearsals could provide all the training required for the particular choreographic work in progress, funding restrictions are such that rehearsal periods are often too short to allow the time required for the necessary physiological adaptations to occur. The largest perceived cause of injury in dance is fatigue (Brinson & Dick, 1996; Laws, 2005). It is therefore important to improve the aerobic capacities of dancers in order to delay the onset of fatigue which may mean extending rehearsal periods or, supplementing the technique classes in support of the choreography. Wanke's study, *Breathless!: Results of a long term study of an integrated endurance training in professional dancers* assessed the effect of an integrated endurance training programme for ballet dancers (n=16) across a ballet season and found positive results. There is a need however, for more longitudinal studies with larger groups (Wanke, 2001). Study six submitted in this thesis (Rafferty et al 2007) addressed this need through the investigation of the effect of a one year dance specific fitness training intervention for full-time vocational contemporary dance students.

2.2.3 Methods for evaluating the energy demands of dance

Previous research has attempted to measure the energy demands of ballet dance class, rehearsal and performance (Schantz & Astrand 1984; Cohen et al 1982b). These two studies used Douglas bags or other balloon type equipment as the main method of gas analysis to measure the energy demands of classical ballet but noted problems with potential movement restriction as well as the fact that the data provided were only a mean value of the workload which would not take into account variations within dance sequences. Other studies (Cohen et al 1982a; Rimmer et al 1994; Dahlstrom et al 1996) used heart rate monitors via telemetry, which overcame the problem of movement restriction, however HR alone is rarely used to determine exercise intensity because of the psychological and physiological factors beyond the exercise itself that influence it (Dishman et al 2000).

Heart rate does not always depend on work output nor is it closely correlated with cardiac output; particularly in sports with large and sudden variations in speed and work rate like dance (Bot & Hollander, 2000). Dance consists of isometric contractions as well as transitory activity of varying intensities. Isometric contractions tend to depend upon anaerobic metabolism because of the pressure of the contraction on blood vessels which cause a decrease in blood flow and subsequent hypoxia (Edwards et al 1972). In severe isometric contractions, lactate concentration can increase to as much as 30 mM. The method of using HR as a way of estimating work intensity in non-steady state exercise seems therefore somewhat limited.

Field tests have been created in sports which use prediction equations to estimate oxygen uptake (VO_2) from “performance” predictor heart rate. Conversion formulas

and prediction equations are not direct measurements of VO_2 and therefore have greater potential for containing prediction errors (Alexander, 1991). Such tests can be more activity specific however, and in this sense might claim validity (McArdle et al 1978; Pechar et al 1974; Wilmore et al 1980).

Dance is considered a non-steady state activity (Schantz & Astrand, 1984; Cohen et al 1982a,b; Rimmer et al 1994; Dahlstrom et al 1996). Dance movement sequences can consist of fast jerky movements, off-balance turns, twists and falls to the floor and include the use of props and the necessity to negotiate/relate to other people.

Movement patterns within dance can be diverse, ranging from the multi-directional to the static and therefore comparison to either steady state or incremental exercise on a treadmill has to be challenged. Although the indirect method of predicting VO_2 from HR has been noted as reliable during steady state activity (Astrand & Rodahl 1988; Rodahl et al 1974), until study one submitted in this thesis (Redding et al 2004), it was unknown as to whether the same holds true for non-steady state dance. Study one assessed the validity of using the HR/ VO_2 relationship established through a treadmill or cycle test as a method of predicting VO_2 in dance.

2.2.4 Methods for evaluating aerobic and anaerobic fitness

In sport and exercise science, aerobic power is tested using sub-maximal or maximal graded exercise tests (GXT). Oxygen uptake (VO_2) is measured as an indicator of aerobic power and VO_2 peak either sub-maximally or maximally is recorded.

Ergometer treadmills and ergometer stationary cycles are commonly used in these tests. Sub-maximal tests have the ability to *estimate* maximal aerobic power without

having to exercise maximally and are often used within the health industry to measure physical fitness (Astrand & Ryming 1954; Storer et al 1990).

Anaerobic fitness is often measured using supra-maximal tests such as the Wingate Anaerobic Test (WAnT) usually involving a cycle ergometer (Chatfield et al 1990; Rimmer et al 1994). While the WAnT is a recognised standard laboratory test, the cycle ergometer is a non impact mode of exercise that utilises specific muscle groups repeatedly, something that is unfamiliar to dancers. The vertical jump height assessment (VJH) may provide both a valid and relevant method of measuring power. Several dance studies have investigated the dancer's anaerobic capabilities using the WAnT, possibly because it measures power in watts (unlike the jump height tests) and is a standardised and recognised test also used for comparisons across studies (Rimmer et al 1994; Chatfield et al 1990; Rafferty et al 2007). Quin et al (2008) investigated methods of measuring dancer's lower limb power and more specifically, the relationship between the vertical jump height (VJH) test and the Wingate Anaerobic bike Test (WAnT). Not surprisingly, results reported a positive relationship ($r= 0.54$, $n=492$, $p=0.00$) between the WAnT and the VJH suggesting that both the VJH and WAnT are valid methods of measuring dancers' lower limb power measures. However the VJH may be more applicable to dancers since jumping occurs in their training regimens and in choreographed work.

Many physiological measurements taken from sports are undertaken within standardised conditions in laboratory settings and not in the field. This is to help ensure that they remain valid, reliable and objective. While laboratory tests are more likely to yield accurate results, they may be less representative; and field tests, while

more relevant and specific, are potentially less accurate because there is less control of the environment and of the research variables (Welsh, 2003). The concept of specificity in this context refers to a method of assessment designed to allow athletes to be tested in an environment to which they are accustomed. The question arises therefore, as to the relevance of laboratory tests with regard to specificity: the debate between laboratory and field-testing is on going (Kenneth et al 2004; Ceci & Hassmen, 1991).

Physiological tests applied to a specific activity do not always have the ability to indicate performance capabilities in another physical activity. For example, individuals trained in cycling show greater improvements when tested on a bike than on a treadmill (Pechar et al 1974). Sport that is characterised by cyclic and constant work rates is more likely to show a greater correlation (Alexander, 1991). Research has shown that little improvements are observed when aerobic capacity is measured during dissimilar exercise, yet improvements to training can be significant when both the training and test exercise are the same (Magel, 1975). It would be unlikely, for example, to test a swimmer on a cycle ergometer or treadmill (McArdle et al 1978; Pechar et al 1974; Wilmore et al 1980). Runners undertaking a VO_2 max test on a cycle ergometer and treadmill could have a variance in their maximal scores of between 5-10% (Bijker et al 2002), indicating further that reliability is undermined unless training activity and test are matched.

Cycling is non weight bearing and is therefore unlike dance. Although treadmill running is weight bearing as is the case with dance, it is a form of exercise less familiar to dancers than dancing. The muscles used and the percentage of muscles

working in both cycling and treadmill running are likely to be different from those utilised within the movement patterning in dance genres. Movement vocabulary in classical ballet and also in some contemporary dance styles tends to involve lateral rotation of the hip – ‘turn-out’ - whereas running and cycling utilises a more parallel leg/hip position. It has been shown in certain sports that the concept of specificity of local changes holds true, whereby the overload of specific muscle groups enhances performance and aerobic power at the local level of the trained muscles (Holloszy, 1984; Gregg, 1989; Roca 1989).

An additional problem in dance with both maximal and supra-maximal tests is that working maximally is not common for dancers. The maximal push that is required of test participants to yield accurate results may not occur: the high skill factor and the fact that the choreographer (not the dancer) usually decides the intensity by virtue of the choreography, means that these tests have limited potential (Chatfield et al 1990).

The development of more precise methods of evaluating highly specific sport activities has been of interest to many sport scientists. It has led to the development of activity specific modes of testing such as kayak ergometers and swimming flumes. An activity specific devised test should comprise a mode of exercise that is representative of the activity in question. Consideration should also be given to environmental conditions in order to ensure that the test participants are performing within a known environment (for example, the dance studio).

An understanding of the energy requirements of dance and of the physiological status of dancers can be helpful in the development of more effective and appropriate tests

and training programmes for dancers. As previously argued, dancers are required to be both aerobically and anaerobically fit. The nature of dance, however, is transitory and intermittent in terms of work output, and this has made it difficult to measure accurately these parameters within a dance specific setting (Schantz & Astrand, 1984; Wyon et al 2000).

There was therefore a need to develop dance specific tests to measure the aerobic and anaerobic fitness of dancers within the dancing environment. Such tests should comprise dance movement material, rather than running or cycling, for example. Spatial considerations such as directional changes and the use of floor, work to rest ratios and body part usage are also important; it is necessary to simulate the energy sources used in the activity in question, particularly in the activity's performance/competition state. Study two (Wyon et al 2003) and study four (Redding et al 2009) responded to this call for dance specific ways of measuring dancer capabilities through the development of the first dance specific aerobic fitness test and the first dance specific high intensity fitness test.

There is now more highly sophisticated data collection equipment available for field environments: for example, the miniaturised low weight telemetric gas analysers developed by Cosmed (Italy) and Metamax (Germany) which record heart rate, ventilation and oxygen uptake and also carbon dioxide production. Given that dance is considered to be a non-steady state by nature (Novak et al 1978; Cohen 1982; Chatfield et al 1990; Rimmer et al 1994; Wyon et al 2004; Whyte et al 2003) and uses the body solely as its medium, it would seem inappropriate to devise any kind of ergometer equipment as a means of measuring the aerobic power of dancers. The

most recently developed telemetric portable gas analysis equipment is arguably more suitable for dance since it allows researchers to measure energy demands of dancing 'in the field'. This was used to develop the fitness tests for dancers in study two (Wyon et al 2003) and four (Redding et al 2009), and used to measure the energy demands of modern dance class, rehearsal and performance (Wyon et al 2004) and the respiratory responses to modern dance classes (Wyon et al 2002).

2.2.5 Monitoring and profiling dancers

Dance science research indicates the value of identifying the physiological demands of dance, in order that the performance and well-being of dancers can be better understood and promoted. Indeed, the mission of the International Association for Dance Medicine and Science (IADMS) is to enhance the health, well-being, training, and performance of dancers by cultivating educational, medical, and scientific excellence.

The emergence of dance science has prompted the initiation of comprehensive screening and profiling programmes now undertaken in many vocational dance schools such as Laban, London; Arts Educational School, Tring; Theater school, Amsterdam School of the Arts (Laws, 2005). Initially, screening and profiling programmes were established as a response to the high injury rates among dancers and were focused on screening for injury risk factors. Until the screening and profiling programme developed in study five, assessments were primarily biomechanical and orthopaedic (Liederbach, 1997; Plastino, 1990). The aim of such screening was to identify potential problems at an early stage, and develop prevention and/or rehabilitation strategies (Liederbach, 1997). More recently, there has been a drive for such programmes to include physiological and psychological profiling as

well as the biomechanical and orthopaedic screening for injury risk in order to gain a fuller profile of each dancer (Redding et al 2005). In addition to the information provided from screening, profiling gathers descriptive information about the status of dancers and/or changes that may occur to their status across time (Chatfield et al 1990).

Although relatively new in the field of science, dance science research is now reaching the public domain and there is a shift in thinking about how best to train dancers (e.g. Laws, 2007; Dance UK, 2006; Rist, 2001; Clarkson & Skrinar 1988; Dance UK, 2006; Laws, 2007; Rist, 2001). Research in the last few years indicates the practical value of developing an effective screening and profiling programme for dancers (Hamilton et al 2006; Redding et al, 2005; Chisholm, 2003; Rist, 2001; Liederbach, 1997; Molnar & Esterson, 1997; Plastino, 1997; Siev-Ner et al 1997, Solomon, 1997; Molnar, 1995). Research to date has in the main been short-term and focused primarily on professional or pre-professional populations. It has also typically focused on one topic area (e.g. physiology, biomechanics, or psychology). It is clear that while dance science evidences some clear directions for further research, it is not yet at a stage where sufficient information is available to support the issuing of any guidelines for substantial changes to dance training practices.

Evidence is available to specify that psychological, physiological, and biomechanical parameters interact in the health, injury, and performance of dancers (e.g. Laws, 2005; Brinson & Dick, 1996); however there is a shortage of studies employing an interdisciplinary and/or longitudinal approach. A need for interdisciplinary screening and profiling programmes in dance was therefore identified. Study five (Redding et al

2006) addressed this, offering an action research interdisciplinary screening and profiling programme.

2.3 Summary

Dance research that has attempted to measure work outputs in class, rehearsal and performance has in many cases failed to consider the appropriateness of the methods used to measure physiological parameters. The problems highlighted above indicate that the HR/VO₂ relationship established via a GXT may not allow for the accurate estimation of VO₂ in dance, however further research is required to substantiate this view. The use of a GXT that utilises ergometers to measure a dancer's physical fitness is not ideal. The exercise mode used in a dance fitness test needs to be weight-bearing to match the characteristics of dance activity: this prohibits the use of rowing or cycle ergometers. A dance specific weight bearing GXT protocol would be the most relevant method of providing information about dancers' aerobic and anaerobic capabilities. Such field assessments must be tested for validity and reliability, as previously discussed.

An improved understanding of the energy requirements of dance and of the aerobic power of dancers will help in the development of more effective and appropriate training programmes for dancers. Initially this requires the development of suitable testing methodologies that evidence validity, reliability and sensitivity. Dance science research acknowledges the need for dance specific tests whilst recognising the reliability of standardised laboratory protocols.

Research over the last two decades has examined the physical fitness status of professional and student dancers (Chatfield et al 1990; Cohen et al 1982; Dahlstrom et

al 1996; Novak et al 1978; Rimmer et al 1994). While the majority of the research has focused on classical ballet, there are a number of physiological discrepancies between training and performance. It is necessary to determine whether the discrepancy in exercise intensity between class, rehearsal and performance found within classical ballet holds true for other dance genres: the efficacy of applying these previous findings to other dance genres is questionable, as previously argued. One contemporary dance study found a difference between the intensity of the warm up phase of class and the centre phase of class (Wyon et al 2002). Until the publication of the studies presented within this thesis, discrepancies claimed between class and performance were essentially anecdotal assumptions. It is proposed that the evidence now available supporting the existence of such discrepancy offers justification for the use of supplementary fitness conditioning in contemporary dance training.

The author has identified areas of research requiring investigation as follows:

- the validity of using heart rate as a predictor of oxygen consumption in dance
- the physiological demands of class, rehearsal and performance in contemporary dance
- the development of dance specific tests for measuring the aerobic and anaerobic fitness of dancers
- the effect of a fitness intervention longitudinally within a dance training regimen
- the development of an interdisciplinary screening and profiling programme for dancers

The following chapter comprises the six published studies that address many of the issues highlighted in this chapter and most specifically the investigations delineated above. All six studies have been published in peer reviewed academic journals either as full papers (studies one, two, three, four and five) or as an Abstract (study six). All

six studies have also been accepted for presentations at various international dance education, dance medicine and dance science conferences such as the International Association for Dance Medicine and Science Annual Meetings and the International Learning Conference. Study five, published in the International Journal of Learning won the 2006 award for Excellence in the area of Literacy and Education.

Validity of Using Heart Rate as a Predictor of Oxygen Consumption in Dance

Emma Redding, M.Sc., Matthew Wyon, Ph.D., Jeremy Shearman, Ph.D., and Lance Doggart, Ph.D.

Abstract

The validity of predicting oxygen uptake (VO_2) from heart rate (HR) was examined in 19 professional modern dancers of both genders ranging in age from 21 to 29 years. The subjects were measured on two occasions; once during a multi-stage graded treadmill test and again during their usual modern dance class. The data showed significant differences during both the treadmill test or dance class at lower intensities of less than $20 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ ($p \leq 0.03$) and paradoxically no significant differences between the relationships at intensities greater than $20 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. However results also identified large individual variability and when taken into account the great variability, it would seem unacceptable to predict the VO_2 from HR values in dance, based on the HR- VO_2 relationship established from a progressive treadmill protocol. Furthermore, given that dance is a non-steady-state activity and is executed at low to moderate intensities with occasional anaerobic bursts, it seems unlikely that the HR- VO_2 relationship established from a steady-state laboratory test can be relied upon as a predictor of VO_2 in dance.

An understanding of the energy requirements of dance can help in the development of more effective and appropriate training pro-

grams for dancers. However because of the intermittent and random movement pattern of dance, it has been difficult to accurately measure energy expenditure during the activity itself. Attempts at measuring the energy requirements of dance in previous studies have either involved the use of Douglas bag equipment^{1,2} where movement restriction was noted or they have assumed oxygen uptake (VO_2) values from dance heart rates (HR) on the basis that the linear relationship between HR and VO_2 ^{3,4} established in laboratory tests (treadmill or cycle ergometer) holds true for dance.^{1,5} Dance is considered a non-steady-state activity^{6,7} and, although the indirect method of predicting VO_2 from HR has been noted as reliable during steady-state activities,^{3,8} the extent to which the relationship can be relied upon in non-steady-state conditions is questionable.⁸⁻¹⁰

The degree to which HR and VO_2 are related during activities that involve different muscle groups and changing work intensities is far from established. In 1995, Lothian and Farrally¹¹ found that heart rate gave a

close estimate of VO_2 during intermittent exercise, while in 1996, Bernard and colleagues⁸ suggested that the method can be depended upon during non-steady-state conditions providing that individual subject relationships are used. Dance can consist of fast jerky movements, off-balance turns, twists, and falls to the floor. Dance is multi-directional and involves the use and coordination of different muscle groups at varying times. No previous research has established the validity of this method of work rate prediction in dance. The aim of the current study was to investigate the validity of the use of HR in estimating VO_2 in dance from the HR- VO_2 relationship established in a steady-state laboratory test.

Methods

Nineteen professional dancers ($n = 19$; male 7, female 12) from two professional modern dance companies took part in the investigation (Table 1). Subjects completed the necessary consent and PAR-Q forms and were allowed time to become familiar with the equipment and protocols before the testing.

Initially, the dancers carried out the dance test, which was followed by the treadmill test. The dance test consisted of a technique class, which was familiar to the dancers. The class lasted 90 minutes and took place in the usual studio. The teachers were asked to conduct a normal class at

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Table 1 Subject Characteristics

Gender	Age (yr)	Height (cm)	Weight (kg)	BMI
Female (n = 12)	25 ± 4.0	166 ± 2.4	55.8 ± 1.3	20
Male (n = 7)	25 ± 4.4	173 ± 2.6	69.7 ± 2.0	23

an appropriate level to the dancers' abilities. Thirty minutes before the start of the class, the volunteer dancers were fitted with a heart rate monitor and the Cosmed K⁴b² telemetric gas analyzer (Cosmed, Italy) so as to prevent interference with his or her warm-up routine and for the purposes of familiarization (Fig. 1). The dancer was told that the apparatus could be removed at any stage either to drink water or to terminate the test, however no subject asked for the equipment to be taken off during the tests. The class consisted of exercises that were typical of those normally performed at the advanced to professional level. The emphasis at the beginning of the class was on postural alignment, balance, and control. Movements were more static in nature compared with those during the second half of the class. The second half of the class consisted of more dynamic movement phrases that included more directional changes in space. Movements such as lunges and rolls to the floor, jumps, and springs were also executed.

On the same day, the dancers carried out a progressive graded test on a motor-driven treadmill using the same portable gas analyzer. The dancers expressed concern about running, as was the case in a previous study¹² and the treadmill protocol was modified



Figure 1 Dancer wearing the heart rate monitor and the Cosmed K⁴b² telemetric gas analyzer (Cosmed, Italy).

as a result. There were six three-minute stages of a constant speed of 6.4 km·hr⁻¹ and at each stage intensity was increased by a gradient increase of 3% starting at 0% (Table 2). The protocol was previously used by Mostardi and colleagues¹² with professional ballet dancers in 1983.

Statistical Analysis

Pearson's Product correlation test was used to assess the relationship between heart rate and oxygen consumption during dance and the progressive treadmill test for the whole group. A 2-way Analysis of Variance (ANOVA) was used to determine whether there was a significant difference between each stage for both protocols. Although mean differences are important (paired t-test), variation between individual scores must also be considered. In 2001, Atkinson and Nevill¹³ suggested the use of limits of agreement (LOA), which take into account both the mean differences and the variability. The LOA calculation was used to determine the amount of agreement between HR in dance and HR in treadmill protocol at six arbitrary VO₂ settings (10, 20, 30, 40, 50, and 60 ml·kg⁻¹·min⁻¹).

Results

The correlation between heart rate and oxygen consumption during class was $r = 0.792$; $n = 2807$; $p < 0.001$ and during progressive treadmill work $r = 0.822$; $n = 1004$; $p < 0.001$. Figures 2 and 3 indicate the line of best fit

Table 2 Treadmill Protocol

Time (min)	Speed (km·hr ⁻¹)	Gradient (%)
0-3	6.4	0
3-6	6.4	3
6-9	6.4	6
9-12	6.4	9
12-15	6.4	12
15-18	6.4	15

for heart rate and oxygen consumption during class and treadmill work respectively.

The standard error of estimate for the prediction of oxygen consumption from heart rate data during dance was ± 5.904 ml·kg⁻¹·min⁻¹ and for treadmill work ± 8.437 ml·kg⁻¹·min⁻¹. The analysis of oxygen consumption at specific heart rates between class and treadmill work noted a number of significant differences. Significant differences were noted at 120 b·min⁻¹ ($t = -2.046$; $df = 17$; $p = 0.05$), 130 b·min⁻¹ ($t = -2.539$; $df = 17$; $p \leq 0.05$), 140 b·min⁻¹ ($t = -2.833$; $df = 17$; $p \leq 0.01$), 150 b·min⁻¹ ($t = -2.948$; $df = 17$; $p \leq 0.01$), 160 b·min⁻¹ ($t = -2.744$; $df = 17$; $p \leq 0.01$), and 170 b·min⁻¹ ($t = -2.909$; $df = 17$; $p \leq 0.01$).

The 2-way ANOVA and Tukey post-hoc analysis showed significant differences between all five HR stages and all five VO₂ stages for both protocols ($p < 0.05$). Table 3 shows the mean and standard deviation values for the subjects during both the class and treadmill protocols.

Table 5 shows the amount of agreement between HR values from the dance protocol with HR values from the treadmill protocol.

Results suggest that there could be at least 30 b·min⁻¹ difference between the two protocols at any VO₂ value. At VO₂ 10 ml·kg⁻¹·min⁻¹, the mean difference between the subjects for both protocols was 6 b·min⁻¹. The standard deviation for the difference of these mean scores was ± 16.056 but the limits of agreement was 31.47 ($5.79 \times 1.96 = 31.47$). For a complete analysis, the mean difference is 5.79 ± 31.47 b·min⁻¹. This suggests that for both protocols at VO₂ 10 ml·kg⁻¹·min⁻¹, a subject's HR could potentially vary by up to 31 b·min⁻¹. The agreement limit increases as intensity increases up to a variability of 49 b·min⁻¹ at a VO₂ 60 ml·kg⁻¹·min⁻¹.

Although there was no significant difference between the data sets, the level of agreement is unacceptable. For example, at VO₂ 10 ml·kg⁻¹·min⁻¹, the mean difference between the two sets of data is approximately 5.79 b·min⁻¹ with a SD of approximately 16 b·min⁻¹.

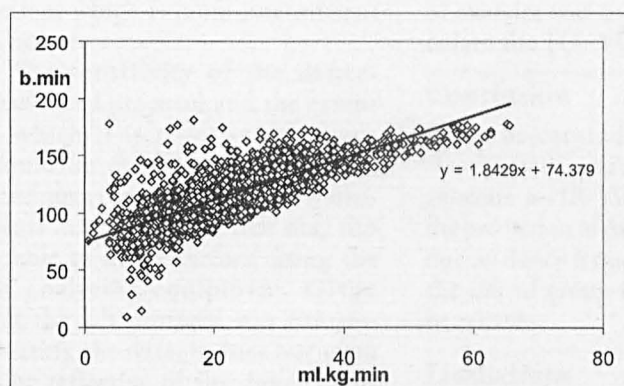


Figure 2 The HR-VO₂ relationship during dance protocol.

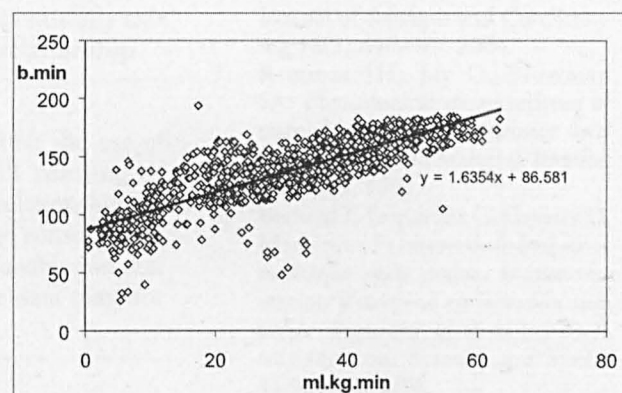


Figure 3 The HR-VO₂ relationship during progressive treadmill protocol.

suggesting that there is too much variability between the two protocols. In most cases, the HR values appear to be underestimated during the dancing.

Discussion

The aim of this study was to assess whether HR from dance (non-

steady-state) could be used to predict VO₂ from data established in a lab test (steady state).

The results of the present study imply that the prediction of oxygen consumption from heart rates during dance is unreliable when a group-wise HR-VO₂ relationship during

progressive exercise is used. Statistical analysis highlighted significant individual variances in the group data when examining the relationships of the predicted heart rates and arbitrarily given VO₂ values between dance and treadmill work. These findings support research by Bot and Hollander,⁹ who recommended that individual regression lines should be used, rather than group-wise regression lines, during non-steady-state exercise. In other words, it may be possible to use HR values established during a treadmill protocol to predict VO₂ in dance only if individual data is obtained. This suggestion is also supported by previous studies.^{8,11}

The present study assessed the HR-VO₂ relationships during two weight-bearing activities because such activity (treadmill running) is considered to produce a closer relationship than that found between weight-bearing (dance) and non-weight-bearing (i.e., cycle ergometer) activities. It appears however, that the extent to which work intensities change during an activity should also be considered when developing a lab protocol for dance. In other words, the lab protocol should more closely mimic the changing intermittent nature of dance. The findings of Bernard⁸ would suggest that the steadier the state of an activity, in terms of its intensity, the greater the relationship between HR and VO₂ will be. It appears likely that the warm-up section of class may have a stronger HR-VO₂ relationship than the center

Table 3 Mean and Standard Deviation Values for the Subjects During Both the Class and Treadmill Protocols

Oxygen uptake (VO ₂) (ml·kg ⁻¹ ·min ⁻¹)	Class mean HR (b·min ⁻¹)	Treadmill mean HR (b·min ⁻¹)
10	91.4 ± 9.9	97.2 ± 12.9
20	113.4 ± 8.8	117.8 ± 14.4
30	135.2 ± 10.9	138.5 ± 17.7
40	157.2 ± 15.0	159.1 ± 22.1
50	179.2 ± 19.8	179.8 ± 27.0
60	201.1 ± 25.0	200.4 ± 32.2

Table 4 Paired t test Differences Between Class and Treadmill Protocols at Varying Intensities

VO ₂ (ml·kg ⁻¹ ·min ⁻¹)	t value	Significance
10	-1.57	0.13
20	-1.27	0.22
30	-0.86	0.40
40	-0.44	0.67
50	-0.11	0.91
60	0.13	0.89

Table 5 Limits of Agreement Between Class and Treadmill Protocol

VO ₂ (ml·kg ⁻¹ ·min ⁻¹)	LOA	SD
10	5.79 ± 31.47	16.056
20	4.47 ± 30.17	15.395
30	3.2 ± 31.85	16.249
40	1.8 ± 36.1	18.421
50	0.6 ± 42.12	21.493
60	0.7 ± 49.33	25.166

section, which is more intermittent in nature.

The sensitivity of the dance-class-based protocol and the extent to which it is reflective of dance should be considered, bearing in mind that there are intricate movements in a dance class that may not be able to be performed using the gas analyzing equipment. Given that the lab protocol was over-estimating the data, it does not seem to be reflective of the dance class. It might be that the lab protocol was too dependent on gross movement, whereas the class incorporates intricate movement.

The physiological mechanisms attributed to the reliability of the HR-VO₂ relationship during steady-state versus non-steady-state exercise may relate to the changes in stroke volume during recovery immediately after exercise or sudden decrease in exercise intensity.¹⁴ In order to maintain cardiac output, the heart rate remains high because of the decrease in stroke volume. Therefore the HR-VO₂ relationship during non-steady-state exercise cannot mimic the relationship in steady-state exercise as the oxygen consumption is reduced due to a decrease in exercise intensity while the HR remains high.

Future research efforts might re-examine this study using a non-steady-state lab protocol such as the Dance Aerobic Fitness Test (DAFT) developed by Wyon and Redding¹⁵ so that the intermittent nature of dance is more closely mimicked. This idea was supported by Lothian and Farrally¹¹ who suggested that individual estimation of oxygen consumption was possible from heart rate data when a similar form

of exercise was used to initially calculate the HR-VO₂ relationship.

Conclusion

It can be concluded that the use of steady-state treadmill running to generate a HR-VO₂ relationship for the prediction of oxygen consumption during dance is questionable and that the use of group-wise data may not be reliable.

Limitations

The main limitation with this study is the number of subjects used. Ideally a greater number would be required to examine this relationship more closely. As mentioned previously, it might be that the lab protocol used in this study was too steady state in nature to produce a close enough HR-VO₂ relationship for use in dancing which is more intermittent.

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Development, Reliability, and Validity of a Multistage Dance Specific Aerobic Fitness Test (DAFT)

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Abstract

The aim of this study was to design a multi-stage dance-specific aerobic field-test that would indicate whether a dancer had the cardiorespiratory capabilities to cope with the demands of dance class and performance. The test consisted of five progressively demanding dance sequences. The technical level of each stage was kept as simple as possible to reduce the effect of economy of movement so that the emphasis of the test was physiologically based rather than skill orientated. The reliability of the stage workloads was measured via oxygen uptake and heart rate using a telemetric gas analyzer. After an initial familiarization trial, subjects ($n = 56$: 24 males and 32 females) undertook the test twice within 48 hours. The results showed significant differences in oxygen requirement and heart rates between stages ($F [4, 172] = 803.522$; $p < 0.001$) and gender ($p < 0.01$). The HR- $\dot{V}O_2$ relationship for the test was $r = 0.94$; $n = 3336$; $p < 0.001$ and the SEE was ± 4.506 . Reliability of the DAFT

was calculated by determining the coefficient of variation (CV) expressed as a percentage and the percentage change in the mean between trials ($\% \Delta \text{mean}$). CV ranged between 1.4 and 6.0 and $\% \Delta \text{mean}$ between 0.2 and 6.3 for the stages. The use of dance specific moves and specific levels of the test equating to the mean oxygen demands of class and performance confirmed that logical validity had been achieved. Possible applications to the dance world are the monitoring of heart rate at each of the stages during the year; setting of a target stage attainment for an individual's readiness to undertake class or performance after injury and/or, setting specific aerobic capabilities for dancers post-holiday or for guest artists (below a specific mean heart rate during a designated stage).

There is a problem when administering a "maximal" test to dancers.¹ Dance is non-competitive and dancers do not need to strive against others during

performance. Consequently, the intensity of the performance is set by the choreographer and the concept of "gritting your teeth" for the final push is not found within the environment of dance, probably due to the high skill factor required. Chatfield and colleagues¹ suggested that this has led to problems during physiological testing which require the participants to exert themselves maximally. Previous studies have reported that dancers' have achieved maximal oxygen uptake ranges of between 39 to 51 $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ for females and 48 to 59 $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ for males during laboratory tests.¹⁻¹⁰ Maximal exertion within a simplistic movement form (running or cycling) is alien to the dancer as the choreography during a performance generally determines maximal effort. Additionally, the result could be affected by the specificity of the tests used with regards to dance. Dancers experience mechanical problems when running and walking due to highly developed turn-out and limited dorsiflexion capabilities of the ankle, and physiotherapists often actively discourage running as an activity, though this has not been demonstrated scientifically.

Direct measurement of the physiological cost of dance has until now proven difficult due to the limitations of apparatus available to researchers. Schantz and Astrand⁹ used Douglas bags as the method of gas collection but

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noted problems with potential movement restriction (even in classical ballet) and the fact that the data provided were only a mean value of the workload. Other studies used heart rate monitors during dance, which overcame the problem of movement restriction.^{2,6,8} The aforementioned studies indirectly calculated the oxygen requirement of dance by comparing the heart rates gained during class with those from a maximal oxygen uptake treadmill (or in some cases cycle) test. This method is also open to question as it assumes that the HR-VO₂ relationship during dance is the same as that for treadmill or cycle work. The results from Redding and colleague's¹² study indicated the flaw in this method, the HR-VO₂ relationship in dance and treadmill work produced predicted oxygen consumptions from heart rates that were significantly different. The movement patterns within dance are very diverse, ranging from multi-directional to the static holds. The physiological demands are considered to be high intensity, intermittent exercise in nature and to produce a HR-VO₂ relationship ($r = 0.79$), less than that seen in steady state or incremental exercise ($r = 0.82$; $r = 0.87 - 1.00$).¹¹

Oxygen uptake during performance and class ranges between 10 to 60 ml·kg⁻¹·min⁻¹ for both ballet^{2,8,9,13,14} and contemporary dance.¹⁵ The results from Wyon and associates¹⁵ noted significant differences between the physiological demands of contemporary dance class and performance. The mean oxygen requirement of class for males and females was 22.06 ± 5.86 ml·kg⁻¹·min⁻¹ and 17.42 ± 2.75 respectively. While the mean requirements for performance were also low, they were significantly

greater at 24.85 ± 5.83 ml·kg⁻¹·min⁻¹ and 23.34 ± 3.83 ml·kg⁻¹·min⁻¹ respectively. The main differences between class and performance were the periods spent at high intensities with performances requiring a significantly greater time (minutes) above 35 ml·kg⁻¹·min⁻¹ and 160 b·min⁻¹ than class.

Aims

Field-testing allows those without access to laboratory equipment the ability to measure base fitness levels and training adaptations. However, the newness of dance science means that appropriate and specific field tests have not been developed. The aim of the present study was to produce a continuous incremental five-stage aerobic fitness test that used dance specific movements. The test was to have specific stages that corresponded to the mean oxygen requirement of dance class and dance performance. The movement sequence of each stage was designed so that both novice and elite dancers of the same gender would work at the same relative oxygen requirement. The test was designed to be able to observe changes in a dancer's aerobic fitness by their ability to dance at a higher stage or by recording lower heart rates during each stage during a repeat test thereby indicating an improvement in their aerobic power.

Method

Development of the Test

The development of the test proved to be difficult as the investigators wanted an initial dance sequence that could be elaborated on to gain the increased intensities required for the subsequent test stages. The aim was to add only one to two variations per test level so that the

learning of the test was not a factor of its function. This was achieved by real-time reviewing of data from a telemetric gas analyzer and adapting the dance movements so that they fell within a 5 ml·kg⁻¹·min⁻¹ bandwidth.

The final test was designed around a 16-beat sequence. It was established that each stage should be 4 minutes in length and that the oxygen requirements of each stage would be within a 5 ml·kg⁻¹·min⁻¹ bandwidth. This enabled physiological steady state to be achieved even though the movement patterns that the dancer carried out were diverse. Intensity was increased at each stage either in terms of tempo, the size of movements or the inclusion of additional movements (Table 1). The movements were kept simple with regard to skill to allow novice and elite dancers to use the same test, thereby reducing the affect of movement economy. Dancers were eliminated from the test if: 1. They were behind the beat or, 2. Movements became compromised (e.g., arms and hands not held properly, feet not pointed). A telemetric gas analyzer (Cosmed K4 b², Italy) was used to measure oxygen consumption and heart rate during the test to allow reliability analysis.

Reliability, Validity, and HR-VO₂ Analysis

Fifty-six contemporary dancers (Table 2) undertook the test wearing the telemetric gas analyzer on two occasions, with not more than 48 hours between the tests. Each subject signed a consent form and PAR-Q and undertook a familiarization trial to learn the dance sequences 2 hours before starting the trial. Their skill level was also recorded as ei-

Table 1 Dance Aerobic Fitness Test

Stage	Tempo (b·min ⁻¹)	Movement
1	68	5 steps, lunge and recover. 4 sets of 2 pliés with 90° turn between each set. Repeat for 4 minutes.
2	78	5 steps, lunge and recover. 3 spring hops in a circle. 4 sets of 2 pliés with 90° turn between each set, arms moving between first and second position. Repeat for 4 minutes.
3	78	5 steps, lunge and recover. 3 spring hops in a circle include arm movements. 4 sets of hop plié with 90° turn between each set, arms moving between first and second position. Repeat for 4 minutes.
4	94	5 steps, lunge and recover. 3 spring hops in a circle include arm movements. 4 sets of hop, hop with 90° turn between each set, arms moving between first and second position. Repeat for 4 minutes.
5	108	5 springs, lunge and recover. 3 spring hops in a circle include arm movements. 4 sets of hop, hop with 90° turn between each set, arms moving between first and second position. Repeat for 4 minutes.

Table 2 Subject Data

Gender	Level	N	Years Dancing	Age (years)	Height (cm)	Weight (kg)
Female	Novice	13	1.4 ± 0.9	20 ± 1.2	1.63 ± 0.1	53.6 ± 4.6
	Elite	19	6.7 ± 2.3	23 ± 3.2	1.66 ± 0.1	51.2 ± 3.8
Male	Novice	8	1.1 ± 0.4	20 ± 2.8	1.75 ± 0.1	66.2 ± 7.2
	Elite	16	5.9 ± 3.1	24 ± 4.1	1.74 ± 0.2	67.9 ± 6.8

ther novice (presently in full-time training) or elite (graduate dance student or professional dancer). Mean relative oxygen uptake and heart rate were calculated for each stage. The HR-VO₂ data were plotted.

Statistical Analysis

A repeated measures ANOVA with within-subject repeated contrasts was used to analyze and detect a main effect for the relationship between the stages. To detect significant differences between gender and skill level for each individual stage, a factorial MANOVA was performed. Reliability of the test was calculated by determining the coefficient of variation (CV) and the percentage change in the mean between trials (%Δmean) as suggested by Hopkins and coworkers¹⁶; this is variation on the Bland-Altman test for reliability. The validity of the test was assessed logically.^{17,18} The similarity between the mean oxygen requirements of dance class and performance and specific stages of the test was used for logical validity. Another aspect of logical validity was the termination criteria of the test. The moves

chosen for the test were assessed as to their relevance to modern dancers. The "termination criteria" for the test were when pointed feet and arms in specific positions could not be maintained. Linear regression analysis was used to assess the HR-VO₂ relationship for the whole test and to calculate the standard error of the estimate.

Results

Test Stage Data

The oxygen consumption for each stage is depicted in Table 3. Repeated Measures ANOVA detected significant differences between the stages, ($F [4, 172] = 803.522$; $p < 0.001$). There was a significant difference between genders at each stage ($p < 0.01$) but no significant difference between skill levels was observed at each stage. Figure 1 provides an example of the test for a male and female subject.

Test Reliability

The variables measured were mean oxygen consumption ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) and heart rate ($\text{b} \cdot \text{min}^{-1}$) for each stage (Table 4). The acceptable percentage

change in the coefficient of variation was set at 5% between the trials.

HR-VO₂ Relationship

Group-wise linear regression analysis noted that the HR-VO₂ relationship for the test was strong, $r = 0.91$; $n = 4462$; $p < 0.001$; and $\text{SEE} \pm 5.6 \text{ b} \cdot \text{min}^{-1}$ (Fig. 2).

Discussion

Hopkins and coworkers¹⁶ suggested that one method of testing reliability was by analyzing the changes in the coefficient of variation between the trials, expressed as a percentage of change (a variation on the Bland-Altman method). They went on to note that the percentage changes below 5% between trials were considered to be reliable. As can be seen in Table 4, the percentage changes in the coefficient of variation for heart rates are all within this designated limit. The reliability for relative oxygen uptake is outside the 5% upper limit for stages 1 and 2, though it drops within the designated zone for the subsequent three stages. This may be due to the slow pace of the movement and the limited limb action seen in stages 1 and 2.

Validity for the test was assessed logically,^{17,18} this refers to the concept that the test is valid by definition. The aim of the test was to be able determine whether a dancer could cope with the cardiorespiratory demands of class and performance. These criteria were met with stage 3 having a similar mean oxygen demand as a dance class ($20 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$).^{2,9,15} Performance demands were more difficult to quantify, as the mean oxygen demand is very similar to that of class, though Wyon and associates¹⁵ noted the work-to-rest ratio during performance indicated a greater reliance on the aerobic system to supply the energy demands of the high intensity dance periods than that seen in class that was more reliant on the ATP-CP system. The study by Wyon and associates also noted that not only were the dance periods longer during performance than class but were also at a higher oxygen demand (30 to $60 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$). There were a number of reasons for limiting the test to an

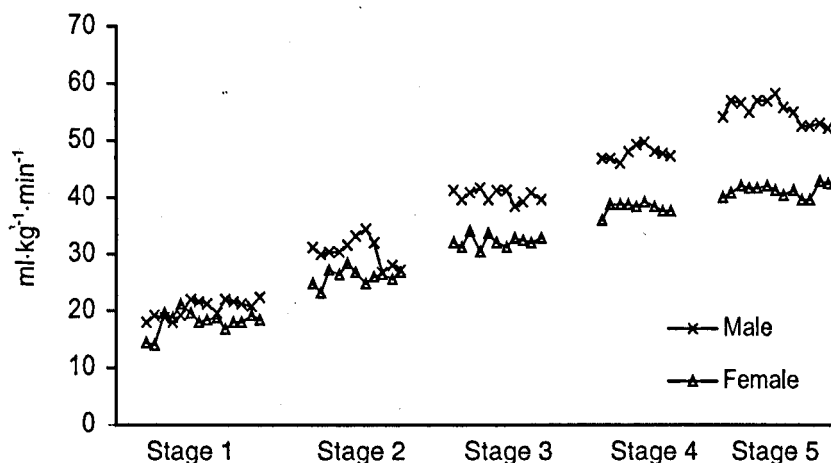


Figure 1 Representative oxygen uptake for a male and female dancer during the five stages of the test.

Table 3 Oxygen Uptake Requirements for Each Stage of the Test for Trials I and II

	Mean Relative Oxygen Uptake (ml·kg ⁻¹ ·min ⁻¹)				
	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Males					
Test I	21.7 ± 2.4	30.2 ± 3.7	39.7 ± 3.9	48.5 ± 3.6	55.7 ± 4.1
Test II	22.8 ± 2.4	32.2 ± 3.3	42.1 ± 2.5	50.3 ± 2.9	56.0 ± 3.5
Females					
Test I	19.7 ± 2.4	27.1 ± 3.6	34.1 ± 3.9	40.7 ± 4.4	46.0 ± 3.5
Test II	20.5 ± 2.3	28.1 ± 3.7	34.9 ± 3.8	41.6 ± 4.3	45.6 ± 4.5

Table 4 Stage Reliability

	Heart Rate		Relative Oxygen Uptake	
	CV (%)	%Δmean	CV (%)	%Δmean
Stage 1	2.7	0.2	5.5	6.3
Stage 2	3.5	1.3	6.0	6.2
Stage 3	2.6	3.3	3.5	5.1
Stage 4	1.7	1.6	1.4	3.3
Stage 5	1.5	0.6	3.6	0.7

oxygen uptake range of 46 ml·kg⁻¹·min⁻¹ for female dancers and 55 ml·kg⁻¹·min⁻¹ for male dancers. The maximal oxygen uptakes are within the ranges previously reported for dancers,¹⁻¹⁰ and although the peak oxygen requirements of dance performances are noted to exceed the oxygen requirements of the test,^{9,13,15} the actual time the dancer is working at the higher intensity during a performance is very short. Moreover, there has been no research to date suggesting possible optimal VO₂max for dancers, perhaps due to the diverse nature of dance performance. It was

decided by the authors that the oxygen requirement of the fifth stage of the test should be similar to that reported for maximal oxygen uptakes of other non-endurance sports.¹⁹

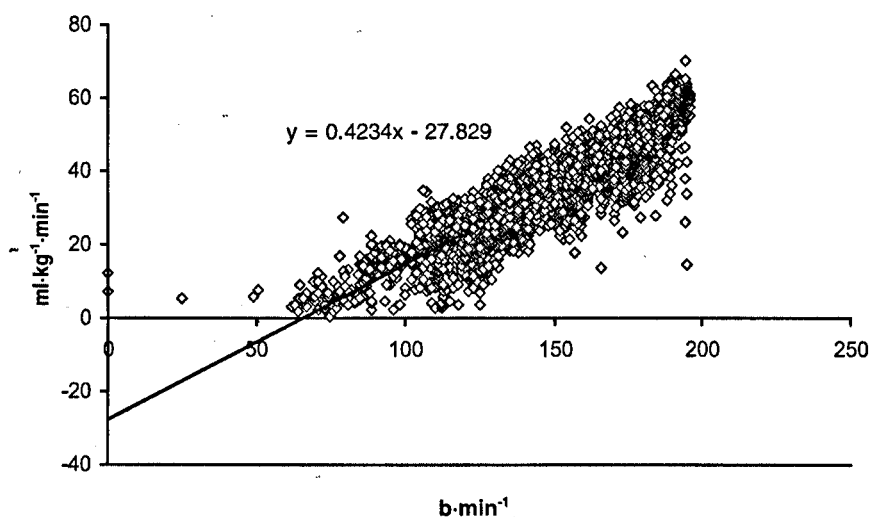
The HR-VO₂ relationship for the test ($r = 0.912$) was stronger than that seen during other dance activities (e.g., class and performance) ($r = 0.792$),²⁰ similar to that seen during progressive intensity exercise tests,^{11,21} but less than seen in steady state exercise ($r = 0.95$ to 0.99).^{22,23} Possible reasons for this could be due to the length of time at each stage (4 minutes) and the small fluctuation in workload

during each stage (5 ml·kg⁻¹·min⁻¹). The low standard error of estimate (± 5.6 ml·kg⁻¹·min⁻¹) and the high correlation between heart rate and oxygen consumption allow for reasonably accurate prediction of oxygen consumption from heart rate data; thereby increasing the efficacy of the test as a field method for monitoring work intensities and changes in aerobic fitness levels. This was demonstrated by Redding and Wyon²⁴ who monitored two dance companies over a period of time comparing physiological adaptation from class and performance.

The stages increase by approximately 7 ml·kg⁻¹·min⁻¹ for females and 8 ml·kg⁻¹·min⁻¹ for males, providing clear separation of each stage. The aim of the study was to devise a test that measured aerobic fitness rather than skill, and this was achieved as there were no significant differences observed between novice and elite dancers in any of the stages. The decision to emphasize physiological parameters rather than skill was due to the fact that dance training tends to emphasize skill and technique, perhaps to the detriment of the relevant physiological parameters of fitness. One of the main reported causes of injury within the dance world is a reduced level of physical fitness.^{10,25,26} A test of this type will help provide reliable and relevant information regarding the aerobic fitness levels of dancers, which may thereby help reduce injury risk.

The use of submaximal aerobic fitness tests to predict maximal oxygen uptakes must be viewed with caution. At high relative workloads, the HR-VO₂ relationship changes from the linear seen at submaximal intensities; therefore the use of linear regression to calculate VO₂ max by plotting submaximal heart rates against known workloads will cause an over prediction of the value. This was the reason that the test was designed so that two stages had similar oxygen requirements as that seen for the two main aspects of dance – performance and class.

There are a number of possible applications of the test to the dance

**Figure 2** HR-VO₂ relationship for the test.

world. These could include setting specific stage targets to be met at the start of training and at the commencement of rehearsals or performances. The specific targets would need to be set by artistic directors, physiotherapists, teachers, or choreographers. For example, the mean oxygen requirement for dance class is 17 ml·kg⁻¹·min⁻¹ for females and 21 ml·kg⁻¹·min⁻¹ for males and approximately 85% of the class are below the oxygen requirement of stage three (34 ml·kg⁻¹·min⁻¹ and 39 ml·kg⁻¹·min⁻¹, respectively). Therefore a pre-requisite for dancers returning from holiday might be to reach level three, which would imply that they had the physiological capability to cope with class. Due to the simplistic nature of the dance movements during the test, it is ideal in determining whether a dancer is physiologically ready to return to class or performing after injury without the added complication of skill. The use of the test to predict maximal oxygen uptake has been highlighted, but further research is needed to examine this ability.

Limitations

The main limitation for the study is the low number of subjects. This is very apparent for the issue of validity. The other limitations are concerned with the administration of the test; presently its designers have only taught the test to subjects and possible differences in the physiological parameters have not been monitored when others teach the movements to subjects. The effects of learning the sequences from video and the use of the subjective test termination criteria have not been examined and further research is needed to examine whether the error is increased.

Conclusion

The test has shown to be a reliable and valid field test capable of measuring a dancer's physiological ability to cope with the aerobic demands of class and performance. The null hypotheses that stated there would be no significant dif-

ference between stages for mean oxygen consumption and heart rate; between genders for mean oxygen consumption for each stage; or in oxygen consumption between dancers' ability levels can be rejected.

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PHYSIOLOGICAL MONITORING OF CARDIORESPIRATORY ADAPTATIONS DURING REHEARSAL AND PERFORMANCE OF CONTEMPORARY DANCE

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ABSTRACT. Wyon, M., and E. Redding. Physiological monitoring of cardiorespiratory adaptations during rehearsal and performance of contemporary dance. *J. Strength Cond. Res.* 19(3):611–614. 2005.—Previous research has shown that dance class and rehearsal stress different cardiorespiratory energy systems than dance performance. The aim of the present study was to monitor the physiological parameters of a number of dancers during a 12-week rehearsal period and an 8-week performance schedule. Seventeen dancers (8 men and 9 women) from 2 companies undertook the multistage dance specific aerobic fitness test before the rehearsal period, before the performance period, and after the performance period. Heart rate data were collected throughout the test; the mean heart rate during stage 5 and blood lactate levels were measured at the end of the test. No significant changes in heart rate or lactate parameters were noted between the prerehearsal and preperformance tests, but significant decreases during the preperformance and postperformance tests were shown in both parameters ($p < 0.01$ and $p < 0.01$, respectively), which suggests an increase in the subjects' aerobic capacities during the performance period. Implications from the present study suggest that dancers are not adequately physiologically prepared to perform to the same degree to which their skills are honed. The study suggests that supplemental training is required to bridge this physical gap and better prepare the dancer for performance.

KEY WORDS. energy systems, dance companies, performance preparation

INTRODUCTION

ist (17) has suggested that the gap between the physical demands of class and performance is widening. Wyon and Redding (22) later noted that dance performance caused a significantly greater mean heart rate and oxygen consumption than reported for dance class and rehearsal. The workload of the class warm-up section and most rehearsals is below the work intensity required to elicit an aerobic training effect (1). The mean workload of the class center section is similar to that seen during performances, but its exercise-to-rest ratio implies that the adenosine triphosphate-creatine phosphate system receives the greatest stimulus during the work periods, whereas in performance the exercise-to-rest ratio allows greater emphasis on the aerobic and lactate metabolic systems (22). The findings of Wyon and Redding confer with previous research that shows that the center phase of a dance class is an intermittent "multiple sprint" form of exercise that does not place significant stress on the aerobic system (4, 6, 16, 19). The warm-up phase is more continuous in na-

ture, although at too low an intensity to elicit a training effect. Dance performance can also be classified as high-intensity interval exercise (5, 19); the exercise intensity is similar to that of the center phase of the dance class, although the exercise-to-rest ratios differ and indicate that greater stress is placed on the aerobic energy system due to longer exercise and shorter rest periods (21).

The aims of the present study were to examine whether the data reported in the cross-sectional analysis by Wyon and Redding (22) of the cardiorespiratory demands of individual classes, rehearsals, and performances validated the predicted cardiorespiratory changes in the dancers during an extended period that encompassed performance (8 weeks) and normal daily company routine (class or class and rehearsal; 12 weeks). Company 1 had cardiovascular training equipment for the dancers to use. The use of the equipment was not prescribed, and the dancers set their own programs if they used the equipment. The study also therefore assessed whether the provision of cardiovascular equipment was enough to help prepare dancers for the increased demands of performance.

METHODS

Experimental Approach to the Problem

The team used an observational approach that consisted of 3 testing periods to monitor any observable adaptations in the variables under examination.

Subjects

Twenty-two subjects from 2 professional contemporary dance companies volunteered for the study; their descriptive data are given in Table 1. Company 1 promoted aerobic training for its dancers. This company had rowing and cycle ergometers and step machines for the dancers to use, but had made no time or guidance provision for the supplemental training. All the subjects from that company reported that they used these machines but not regularly. All subjects had been taking dance class on a regular basis for the preceding 1–2 weeks and were free of injury during this time. Anecdotal discussions noted that only 2 of the 22 subjects smoked. During the testing period, there was a dropout rate of 23% ($n = 5$). The data from the subjects who left the study were excluded from the statistical analyses. The University of Surrey Roehampton gave ethical approval for the research. Written

TABLE 1. Descriptive statistics for the subjects.*

Company	Sex	Age (y)	Height (cm)	Weight (kg)
1	Female (<i>n</i> = 6)	23 ± 5.57	1.64 ± 4.91	51.7 ± 3.79
	Male (<i>n</i> = 4)	22 ± 3.0	1.77 ± 3.40	66.7 ± 4.26
2	Female (<i>n</i> = 3)	23 ± 1.73	1.66 ± 7.93	55.7 ± 3.51
	Male (<i>n</i> = 4)	22 ± 1.25	1.76 ± 5.71	66.3 ± 8.50

* Data are mean ± SD.

TABLE 2. Mean parameter data for prerehearsal, preperformance, and post-performance tests.*

Company	Test	Mean HR (b·min ⁻¹)	Maximum HR (%)	Blood lactate (Mmol·L ⁻¹)
1 (<i>n</i> = 10)	Prerehearsal	167 ± 10.65	84.7 ± 4.89	2.2 ± 0.92
	Preperformance	166 ± 10.55	84.1 ± 4.99	2.1 ± 0.90
	Postperformance	155 ± 12.86	77.9 ± 6.18	1.5 ± 0.77
2 (<i>n</i> = 7)	Prerehearsal	190 ± 3.07	96.3 ± 1.96	3.4 ± 1.12
	Preperformance	189 ± 4.19	95.8 ± 2.23	3.4 ± 1.15
	Postperformance	179 ± 4.76	91.8 ± 3.17	2.8 ± 1.09

* Data are mean ± SD. HR = heart rate.

consent was gained from both the dancers and their respective companies before testing started.

Protocol

Descriptive data (age, height, and weight) were collected at the beginning of the study, and skinfold measurements were taken before and after the performance period. Skinfold thickness measurements (in millimeters) were taken at 5 sites: biceps, triceps, suprailiac, subscapular, and medial calf.

The monitoring of cardiorespiratory changes was performed with the multistage dance aerobic fitness test (14). The test is continuous, with 5 steady-state stages of increasing intensity, each 4 minutes long. Before each test, each subject underwent a familiarization process and was introduced to the tempo of each stage by use of a metronome. Before the start of the test, the subjects were fitted with a Polar heart rate monitor and watch (Polar Accurrex; Polar, Finland). Each subject was informed of the test termination criteria (20) and that they would be given 2 warnings before being asked to stop dancing. The mean heart rate of the subject's last stage was calculated from the downloaded heart rate data. The mean heart rate of the last stage was calculated as a percentage of the subject's age-predicted maximum [(end heart rate/220 - age) × 100]. A blood lactate sample was taken 1 minute after the test cessation using a Lactate-Pro (Arkay, Japan) following the British Association of Sport and Exercise Sciences procedures.

Each subject was tested 3 times during the testing period, at the same time of the day and generally on the same day of the week, but company timetables sometimes made this schedule impossible. The initial test was performed 1–2 weeks after the return from company break and 2–3 weeks before the start of rehearsals. The second test occurred the week before the start of performing (week 12), each company being involved with a 2-month performance period, and was fitted in around the companies' schedules. The last test took place the week following the end of the respective tours (week 20). Feedback was provided to each of the subjects on their individual data.

Statistical Analyses

All data were entered into the SPSS version 10 statistical analysis software program (SPSS Inc, Chicago, IL). Means and SDs were calculated for all variables. A repeated-measures analysis of variance (ANOVA) between-subjects design, using difference contrasts, was used to monitor changes in mean heart rate, percentage of maximum heart rate, and blood lactate data collected during stage 5. The α level was set at 0.95.

RESULTS

The repeated-measures ANOVA, using difference contrasts, compared prerehearsal with preperformance test results and pre- with post-performance test results. The descriptive statistics of the companies during the study period are given in Table 2. Groupwise analysis noted no significant differences between the prerehearsal and preperformance test results for mean heart rate ($p > 0.05$), percentage of maximum heart rate ($p < 0.05$), and blood lactate values ($p < 0.05$).

Significant decreases were found between the pre- and postperformance test results for mean heart rate ($F_{1,12} = 149.606$; $p < 0.01$), maximum heart rate percent ($F_{1,12} = 40.878$; $p < 0.01$), and blood lactate ($F_{1,12} = 12.093$; $p < 0.01$). Mean skinfold preperformance data (36.35 ± 9.74 mm) were not significantly different from the postperformance data (35.54 ± 9.68 mm) ($t = 1.106$, $df = 13$, $p = 0.307$). The changes in the companies' mean values can be seen in Figures 1–3. Between-subject analysis noted that company 1 had significantly lower data values than company 2 for mean heart rate ($F_{1,12} = 5653.926$; $p < 0.01$), maximum heart rate percent ($F_{1,12} = 6303.412$; $p < 0.01$), and blood lactate ($F_{1,12} = 98.166$; $p < 0.01$).

DISCUSSION

The mean data given in Table 2 indicate that subjects from company 1 had greater aerobic capacities than those from company 2, because their mean heart rates for stage 5 were at a lower relative percentage, in relationship to age-predicted maximum heart rate, than those for company 2. This could be due to the availability and promo-

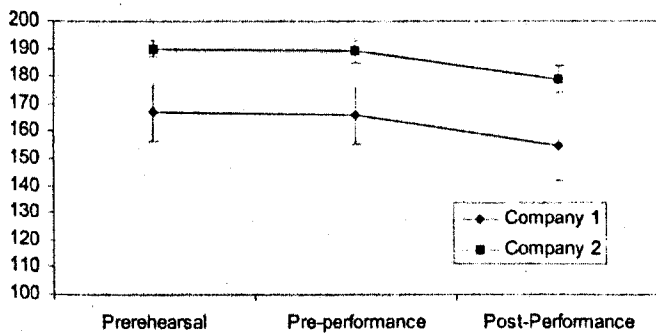


FIGURE 1. Changes in mean heart rate of dance specific aerobic fitness test stage 5 over time.

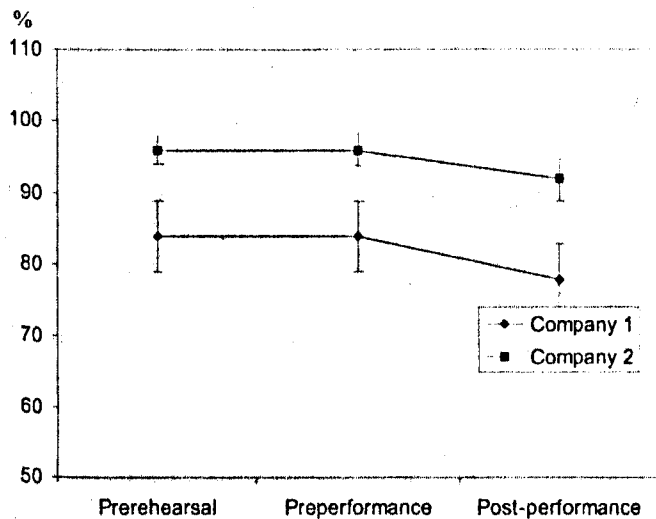


FIGURE 2. Changes in mean maximum heart rate percent of dance specific aerobic fitness test stage 5 over time.

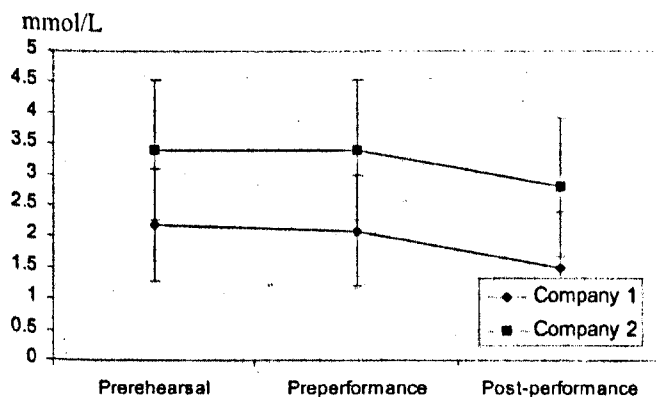


FIGURE 3. Changes in mean blood lactate values of dance specific aerobic fitness test stage 5 over time.

tion of aerobic fitness by the management in company 1. Neither company showed changes in aerobic fitness during the first period (prerehearsal to preperformance), as illustrated by heart rate and blood lactate data (Figures 1-3). The subjects in company 1 were able to complete the test at a lower relative workload than the company 2 subjects. This is illustrated by the lower blood lactate values shown in company 1 during the initial period. The lack of change in these parameters confirms the sugges-

tions of Wyon and Redding (22), who hypothesized that the metabolic stresses placed on the dancer from class and rehearsal were not enough to develop the dancers' aerobic capacities. This phase of performance preparation is characterized by a daily class of approximately 90 minutes and rehearsal sessions that last between 60 and 180 minutes. The warm-up phase of class and most rehearsals are at a low exercise intensity, and only the center section of the dance class is at a high enough intensity to develop the aerobic system, although the exercise-to-rest ratio demonstrates that the actual exercise time is insufficient to stress the aerobic system enough for adaptation to occur. The exercise intensity of the rehearsal process increases to that seen within performance, but this is generally in the last week of rehearsals and too late to have a physiological benefit for the proceeding performance period. This is in contrast with findings by Rimmer et al. (16) and Dahlstrom et al. (6), who suggested that adequate time, during class and rehearsal, is spent within the aerobic training heart rate zones to stimulate a moderate aerobic training effect. The difference in findings could be due to differences in data analysis. They monitored heart rates during class and calculated time spent at specific heart rate bands. This does not take into account work-to-rest ratios; therefore, elevated heart rates from recovery periods were also included in the overall analysis. This would increase the supposed time spent within the aerobic training zone but not the actual exercise time within the zone, which is the stressor that causes adaptation (2).

The performance period is characterized by daily class (90 minutes), a short rehearsal (60-90 minutes), and the performance (approximately 60 minutes). During performance no dancer is on the stage all the time, although the exercise-to-rest ratio indicates more time dancing than resting. The performance period showed significant decreases in the heart rate parameters and blood lactate levels, indicating improvements of the subjects' aerobic capacities. This confirms the findings reported previously by Wyon and Redding, which indicated that the work intensities and exercise-to-rest ratios noted during performance were at a level to cause aerobic system adaptation. The amount of daily exercise that the individual performs decreases during the performance period, which would suggest that the main influence on any cardiorespiratory adaptations is due to changes in exercise intensity and the exercise-to-rest ratio. The results from the present study were also reinforced from the dancers, who commented that they felt it took 2 weeks of performing before they felt physically capable of "performing fully." The lack of change in skinfold measurements is not surprising due to the low levels of body fat of dancers (3, 12, 13). Because of the lack of specified competitive periods or seasons as seen within the sporting world, which allows athletes to carry more fat during noncompetitive periods and then "strip-down" for competition, dancers often perform year-round, with only short periods off to rehearse the next piece. The culture and environment of the dance world also place pressure on the dancer to maintain low levels of body fat throughout the year, often to the detriment of their health (3, 7-12, 15, 17, 18). The present study did not monitor other fitness components, such as power, strength, or muscular endurance, so one cannot comment on whether similar changes in these parameters might occur during the performance period as were seen for aer-

obic fitness. In conclusion, class and rehearsal did not prepare the dancers in this study adequately for the performance period. The provision of cardiovascular equipment, though beneficial, is not sufficient in itself, and the 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.

PRACTICAL APPLICATIONS

The findings from the present study suggest the need to start applying training science within the dance world. Currently, the emphasis is mostly on the skill acquisition and perfection required to perform. The development of the dancer's physicality is thereby a by-product of the skill acquisition. An enhancement of the aerobic system is required, most likely at the prerehearsal stage, to allow the dancer the physiological capability to cope with the stresses during performance.

The use of heart rate monitors as the sole means of measuring time spent within specific training zones during current dance training exaggerates the actual training time. We suggest the use of training impulse (2) within an interval-based program as a means of monitoring the training effect of dance-based activity. The provision of cardiovascular equipment and a reliance on the dancer's motivation to perform self-administered training do not always provide adequate training stimuli to benefit the dancer during performance periods. Dance company management needs to schedule supplemental training into their timetables to reduce the potential onset of overtraining. We also suggest that these sessions are scheduled at the end of a dancer's training day so that fatigue does not affect skills-based sessions, rehearsals, and allows the dancer an extended period to warm down without the need to rush off for the next rehearsal.

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The Development of a High Intensity Dance Performance Fitness Test

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Abstract

While there is currently a validated dance-specific exercise method of measuring aerobic fitness, no such test has been developed to measure high intensity capabilities in dance. The purpose of this study was to initiate an intermittent high intensity dance-specific fitness test. The test was designed to be able to observe changes in heart rate (HR), thereby allowing for a measurement of physical fitness at high intensities. Sixteen professional dancers (4 males and 12 females) volunteered to take part in this study. The fitness test protocol consists of movements that are representative of contemporary dance, and contains exercise and rest periods that mimic the intermittent nature of dance. The participants performed four trials. The physiological variables measured were HR ($\text{b}\cdot\text{min}^{-1}$) for each one minute bout of the four minute test for all trials, oxygen uptake (VO_2) throughout the test, and end blood lactate (BLa $\text{mmol}\cdot\text{L}^{-1}$) for each trial. In addition, five of the participants undertook a maximal oxygen uptake treadmill test, and the scores obtained were compared with those from the dance test. Results show HR consistency across each one minute bout of the test and across each of the four trials of testing for all participants, indicating that the test is reliable. There was good reliability

between bouts of each trial (typical error as % of CV = 1.5), intraclass " r " = 0.8, and good reliability between the four trials (typical error as % of CV = 2.1), intraclass " r " = 0.82. There were no significant differences between the maximal VO_2 and BLa scores established in the treadmill and dance tests, demonstrating validity. Thus, the results of this study indicate that the high intensity dance-specific test is a reliable and valid means of assessing and monitoring the cardiovascular fitness of dancers. The test allows dancers to be assessed within an environment that they are accustomed to (the studio), using a mode of exercise that is relevant (dance), and it is of adequate intensity to be representative of performance.

Regular monitoring of adaptations from any training regimen is advisable so that the effect of that training can be measured and modified as necessary. In dance training, the monitoring of skill and technical improvements often prevails over other concerns; thus, dancers' physiological development and preparation for performance has been somewhat overlooked.

There have been previous attempts at measuring the energy demands of

dance and the fitness status of dancers.¹⁻⁷ A rise in blood lactate (BLa) above $4 \text{ mmol}\cdot\text{L}^{-1}$ is an indicator that ATP demand cannot be met solely by aerobic glycolysis and that the proportion of energy derived from anaerobic pathways has increased. Previous research has noted BLa values of $10 \text{ mmol}\cdot\text{L}^{-1}$ during dance performance.² Another method for measuring exercise intensity is via heart rate and oxygen uptake recordings. Cohen and colleagues noted peak HR values of $184 \text{ b}\cdot\text{min}^{-1}$ and a mean HR of $169 \text{ b}\cdot\text{min}^{-1}$ during dance performance.¹ The same investigators found that dancers perform at 90% of their maximum HR for short amounts of time. Wyon and colleagues noted that the mean oxygen demand and heart rate of dance performance was significantly greater than that seen during rehearsal and class.⁶ Though the dance class reached the same aerobic intensities as performance ($55+ \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$), significantly less time was spent there, and rehearsals rarely exposed the dancer to these intensities. Dance appears to be an intermittent activity that utilizes both the aerobic and anaerobic energy systems.²⁻⁷ In order to ensure that appropriate physiological improvements occur, it is therefore important that dance scientists and educators monitor both the demands of dance performance and dancers' aerobic and anaerobic fitness levels.

Much of the early research in

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these areas, however, has involved either the use of Douglas Bag equipment to measure oxygen demands, or researchers have estimated oxygen uptake (VO_2) values from dance heart rates (HR). Both techniques have drawbacks: in the former, movement restriction was noted by the dancers during their dancing,^{3,8} and in the latter, extrapolation of oxygen uptake was based on the principle that the linear relationship between HR and VO_2 established during a steady state lab test holds true for dance. Dance is considered a non-steady-state activity,^{2,7} and although the indirect method of predicting VO_2 from HR has been noted as reliable during steady-state activity,^{9,10} the opposite is true for dance.¹¹ This finding led to the development of the Dance Aerobic Fitness Test (DAFT),¹² which is now used by several dance companies and schools to monitor changes in aerobic capabilities across time. To date there is no validated high intensity dance-specific fitness test available that can provide a way of evaluating the ability to dance at the higher intensities representative of stage performance—those that utilize the anaerobic energy systems.

The development of more specific and precise methods of evaluating performance is of interest to many sports scientists. Most physiological monitoring has been undertaken within standardized conditions such as laboratory settings, rather than “in the field.” This is to ensure that the tests remain valid, reliable, and objective. However, questions often arise as to the relevance of such tests with regard to specificity. The debate between laboratory and field-testing is on-going; while laboratory tests are more likely to yield accurate results, they may be less representative, and while field tests are more relevant and specific, they have the potential of being less accurate. This predicament has led to the development of activity-specific measuring tools like kayak ergometers and swimming flumes, as well as the invention of the telemetric gas analyzer, which is lightweight, portable, and non-

restrictive.

Dancers’ anaerobic fitness has been previously measured using the Wingate Anaerobic Test (WAnT), usually involving a cycle ergometer.^{4,5} While this is a recognized standard laboratory test, it does not use a mode of exercise that is familiar to dancers. First, dancers are not used to working to volitional exhaustion (probably due to the high skill factor in dance and the fact that choreographers set the intensity by virtue of the choreography).⁴ Second, the cycle ergometer is a non-impact mode of exercise that uses specific muscle groups repeatedly, which is again something unfamiliar to dancers. The concept of specificity should be acknowledged, whereby methods of assessment are designed to allow athletes to be tested in an environment with which they are familiar. Today it would be almost unheard of, for example, to test a swimmer on a cycle ergometer or treadmill.

Dance science is a relatively new area of research, and there is a need for more research into dance-specific field tests. The Research Committee and the Standard Measures Consensus Initiative of the International Association for Dance Medicine and Science has been advocating standardized techniques for measuring dancer capabilities. The aim of the present study was to develop an intermittent high intensity dance-specific fitness test. The test was designed to facilitate observation of changes in HR and in the qualitative performance of movement material across time, thereby identifying any physiological developments at high intensities. This research is descriptive in design and based on the following hypotheses:

- There should be reliability in HR between each bout and between each trial of the fitness test;
- There should be reliability in end BLa between each trial of the fitness test; and
- There should be no differences in HR, VO_2 , or BLa between the results of the fitness test

and a maximal oxygen uptake treadmill test undertaken concurrently by a subset of the participants.

Methods

Dance Test Protocol

A one minute movement phrase was developed over several rehearsals by professional dancers and teachers based at a leading UK dance vocational training institution. They were asked to use movement material that was representative of contemporary dance (sometimes known as modern dance). It was important for the intensity to be similar to the intensity levels previously noted in dance performance.^{1,8} This meant that the test tempo/speed, size, and type of movement were taken into consideration. The work to rest ratio was set at 1:2. It was also important to keep the movement phrase as simple as possible to reduce the learning effect across time. The emphasis of the test is therefore physiologically based rather than skill oriented, reducing the effect of movement economy through practice.

The completed test protocol (Table 1) consists of jumps in first and second position, rolls to the floor, weight transference from feet to hands and back to feet, circular springs with an arm pattern, and a parallel jump forward in space using an arm swing. The phrase is completed three times within one minute at a tempo of 106 bpm, and repeated again after two minutes of rest. This sequence occurs four times.

Participants

Following ethical approval from Laban’s Ethics Committee, 16 participants volunteered to take part in this study. There were 12 females and 4 males, all professional contemporary dancers with at least three years of full-time training and currently injury free. Participant characteristics can be found in Table 2.

The tests and procedures were fully explained to all participants, who then gave informed consent and completed a medical questionnaire. They were advised that they could withdraw

Table 1 The Dance Fitness Test Protocol

1 minute dancing
2 minute rest
1 minute dancing
2 minute rest
1 minute dancing
2 minute rest
1 minute dancing
Tempo throughout each 1 minute dancing: 106 bpm

from testing at any time should they wish to do so without giving reason or notice.

Procedures

Each dancer performed a prescribed 6.5 minute warm-up, followed by an opportunity to stretch as they wished. The warm-up consisted of walking, skipping, and jogging in a circle, changing direction while incorporating an upper-body mobility pattern. The participants were tested once each day on two, three, or four separate days (2 to 4 trials each) within a two-week period. It was necessary to limit the overall duration of testing to ensure that any changes between trials would be a result of some inconsistency in the test rather than an actual physiological improvement in physical fitness, which could occur from a longer lapse between trials. The test was conducted at the same time each day (early morning), in the same studio, and with the same musical accompaniment and metronome. In nearly all cases the participants performed the test in twos.

Prior to the test all participants were introduced to the tempo and movement phrase by listening to the metronome and "marking" the movements.

Participants were fitted with a

heart rate monitor and watch (Polar Accurex, USA). Heart rate (HR) was calculated across the trials and for the end of each of the four one-minute stages of dancing. Heart rate was also calculated as a percentage of the participant's age-predicted maximum.

Other physiological parameters measured during the test were blood lactate (BLa) and oxygen uptake (VO_2). Blood lactate samples were taken from the earlobe using a Lactate-Pro (Arkay KDK, Kyoto, Japan) within 3 minutes after the last dancing minute of the test. The procedure for blood taking was compliant with the British Association of Sport and Exercise Sciences (BASES) laboratory guidelines.¹³ VO_2 was recorded throughout one full testing session for five of the participants using a portable telemetric gas analyser (Metamax 3b, Germany).

During the two-week testing period, five of the participants undertook a maximal oxygen uptake ($\text{VO}_{2\text{max}}$) treadmill test to determine whether maximal values established in a standardized lab test were similar to those measured in the dance test (unfortunately not all participants were able to take this test due to other work commitments). The procedures for the $\text{VO}_{2\text{max}}$ treadmill test, as well as the criteria for determining whether the participants had reached their maximum capacity during the treadmill test, were taken from the British Association of Sport and Exercise Sciences (BASES) laboratory guidelines.¹³ During both the treadmill test and the dance test all participants were given verbal encouragement.

Eight of the participants were performing contemporary dance repertoire during the testing period as part of their work with a con-

temporary dance company. Their HR and BLa were measured while performing four dance pieces from the company's current five piece repertoire in order to compare this data with that gathered during the high intensity dance test.

Statistical Analysis

Hopkins¹⁴ and Hopkins and colleagues¹⁵ suggested that the main measures of reliability are within-subject random variation, systematic change in the mean, and retest correlation. They further suggested that an adaptable form of within-subject variation is the typical (standard) error of measurement, or the standard deviation of an individual's repeated measurements. This can be expressed as a coefficient of variation (percentage of the mean). In the present study the reliability of HR, BLa and %HR max between bouts and participants were assessed using repeated measures ANOVA and the Bland-Altman test [coefficient of variation (CV) and the percentage change in the mean between trials (% Δ mean)].

A repeated measures ANOVA between subjects design with within-subject repeated contrasts was used to detect and analyze a main effect for the relationship between trials. Reliability of the high intensity dance test was calculated by determining the CV and the % Δ mean.

Results

The variables measured were mean HR ($\text{b}\cdot\text{min}^{-1}$) for each bout of all trials, and mean HR and end BLa for each trial (Table 3 and Fig. 1).

The mean BLa at the end of the high intensity dance test for all 16 participants was $5.7 \text{ mmol}\cdot\text{L}^{-1}$, indicating that the intensity of the test was high

Table 2 Participant Characteristics

Number of Participants (N = 16)	Level of Experience	Age (yr) (SD)	Body Mass Index (SD)
Male (N = 4)	Professional	24.6 $\pm$ 0.5	21.9 $\pm$ 0.9
Female (N = 12)	Professional	27.8 $\pm$ 7.8	20 $\pm$ 1.9

Table 3 Mean Heart Rate and Blood Lactate Data for Each Trial (Day) of the 4-Bout Dance Test (see also Fig. 1)

	Trial 1	Trial 2	Trial 3	Trial 4
HR ($\text{b}\cdot\text{min}^{-1}$)	167 $\pm$ 7.98	175 $\pm$ 7.6	176 $\pm$ 8.2	177 $\pm$ 8.2
BLa	5.1 $\pm$ 2.01	5.2 $\pm$ 2.8	5.9 $\pm$ 2.5	6.2 $\pm$ 1.4

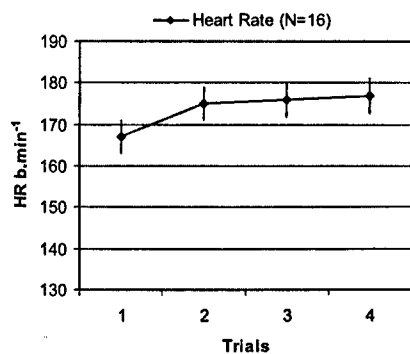


Figure 1 Mean heart rate for all participants (N = 16) across four bouts of each trial.

enough to stress the anaerobic energy pathways (Table 4).

Hopkins¹⁵ and Hopkins and associates¹⁶ suggest that the coefficient of variation be expressed as a percentage of change between trials. Further, percentage changes below 5% between trials are to be considered as reliable. As can be seen in Table 5, the percent-

age changes in coefficient of variation for HR are within this designated limit (below 5%). The larger variation in BLA as expressed as a percentage of change is due to the slight biological variation seen within the raw data (mean 6.1 ± 2.1) when expressed as a percentage change, exaggerating the variation in scores.

Results show HR consistency across each one minute bout of the test and across each of the four days (trials) of testing for all participants, indicating that the test is reliable. There was good reliability between bouts of each trial (typical error as % of CV = 1.5), intraclass "r" = 0.8, and good reliability between the four trials (typical error as % of CV = 2.1), intraclass "r" = 0.82 (Tables 5 and 6).

Dance Performance

The duration of each of the four dance pieces varied for each individual. The

mean BLA values taken at the end of each dance piece were below 4 mmol·L⁻¹ (Table 7), indicating that for these participants the dance pieces were not particularly stressing on the anaerobic pathways.

The mean HR across all four dance pieces for the eight participants was 101 b·min⁻¹, and the mean peak HR was 187 b·min⁻¹. Not all dancers were dancing for the whole duration of each piece.

Maximal Oxygen Uptake Treadmill Test

All five participants who undertook the VO₂ max treadmill test met at least three of the four criteria as outlined by BASES¹⁴ for determining VO₂ maximum: Respiratory Exchange Ratio (RER) value greater than 1.1, which indicates a rise in VCO₂ relative to VO₂; a greater shift toward metabolism of the substrate CHO; attainment of age-

Table 4 Mean Heart Rate and Percentage of Age-Predicted Heart Rate Maximum at the End of Each Bout of the Test Across All Trials and Mean Blood Lactate at End of the 4-Bout Dance Test (N = 16)

Bouts/stages of Dance Test	Mean HR (b·min ⁻¹)	% of HR age-predicted maximum	End Test Blood Lactate (BLA mmol ⁻¹)
1	167.9 ± 7.3	87	
2	174.4 ± 7.5	90	
3	175.9 ± 8.1	91	
4	175.9 ± 8.1	91	5.7 ± 0.4)
Mean	173.4 ± 3.7	90	

Table 5 Reliability Data for Heart Rate and Blood Lactate

	HR	BLA
Changes in mean	2.54	0.92
Typical error	5.01	1.12
Changes in mean as a %	1.6	17.8
Typical error as a CV%	3.1	21.7

Table 6 Repeated Measures

Repeated measures BLA	
Within subject effect	F(3,12) = 1.262; p > .05
Within subject contrasts	F(1,4) = 0.259; p > .05
Repeated measures HR	
Within subject effect	F(3,54) = 0.5; p > .05
Within subject contrasts	F(1,18) = 0.015; p > .05

Table 7 Mean (and SD) Blood Lactate at the End of Each of the Four Dance Pieces (N = 8)

	Dance Piece 1	Dance Piece 2	Dance Piece 3	Dance Piece 4
Duration of dance (min)	35-51	101-112	125-144	157-210
Mean BLA (mmol·L ⁻¹) (SD)	1.6 (0.4)	3.9 (1.6)	2.3 (1.0)	2.0 (0.4)

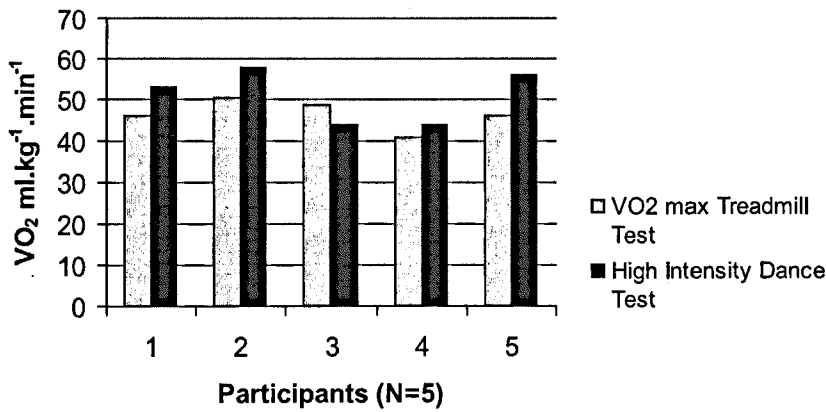


Figure 2 Maximal oxygen uptake during the treadmill test and dance test for five participants.

predicted maximum HR; plateau of no more than 4 ml.kg⁻¹.min⁻¹ of VO₂; or the participant chose to stop. A comparison between maximal oxygen uptake values established during the treadmill test and those observed in the dance test can be seen in Figure 2.

The dancers' mean maximum VO₂ values during the treadmill and VO₂ peak values during the dance test were 46.4 (± 3.6) ml.kg⁻¹.min⁻¹ and 51 (± 6.6) ml.kg⁻¹.min⁻¹, respectively. These differences were statistically non-significant ($p > .05$), indicating that the dance test was at a maximum intensity for these particular participants. The HR values recorded during the maximal treadmill test and the high intensity dance test were calculated as percentage of the five participants' HR_{max}. Mean % of HR_{max} for participants during the treadmill and dance test was 101% and 97.5%, respectively. These differences were statistically significant ($p < .05$). Mean peak BLA recorded during the treadmill and dance test was 6.3 (± 1.7) mmol.L⁻¹ and 6.1 (1.9) mmol.L⁻¹, respectively (Table 8),

and these differences were statistically non-significant ($p > .05$).

Discussion

Cohen and coworkers¹ noted peak HR values of 184 b.min⁻¹ and a mean HR of 169 b.min⁻¹ during dance performance. The mean HR for all participants during the dance test in the present study was 173 b.min⁻¹. However, absolute HR values should be used with caution, as they do not take into account age-related variances. Cohen and coworkers¹ also found that dancers perform at 90% of their maximum HR, and in this study the mean % of HR_{max} for all participants was also 90%, indicating that the intensity of the dance test is similar to the intensity previously measured in dance performance. Interestingly, the performance HR data gathered in the current study were from contemporary dance, and previous results show that mean HR values are lower in contemporary dance performance than in ballet (101 b.min⁻¹ versus 169 b.min⁻¹), although peak HR values are similar (187.9 b.min⁻¹ and 184 b.min⁻¹, re-

spectively).¹ It should be noted that almost all published research in this area has been undertaken with classical ballet performance, and caution must be applied when comparing physiological characteristics within different dance genres. Thus, Cohen's study and this one cannot be matched for intensity, as the dance genres are so different. This further supports the argument for more performance data across dance genres.

Previous research has found that dancers sometimes perform at 80% of their VO₂max,⁸ which is at least the case in this study when comparing the dance test with VO₂max treadmill test scores (Fig. 2). During the dance test, those participants who undertook the VO₂max treadmill test were working at 115%, 115%, 90%, 108%, and 121% of the maximum VO₂max scores on their treadmill tests (Fig. 2). In all but one case, the dancers seemed to push themselves harder when dancing than when running, probably because of their familiarity with the movement. This further substantiates the argument for dance-specific methods of measurement.

A rise in BLA beyond 4 mmol.L⁻¹ is an indicator that the demand for ATP cannot be met solely by the aerobic glycolysis, and that the proportion of energy derived from anaerobic pathways has increased.¹⁶ Previous research has noted BLA values of 10 mmol.L⁻¹ during a ballet solo⁸; however, again, this was ballet rather than contemporary dance. The mean BLA values recorded for the participants in this study after the dance test were above 4 mmol.L⁻¹, which indicates that the dance test calls upon the anaerobic energy pathways. Mean peak BLA scores recorded after the treadmill and dance test were 6.3 (± 1.7) mmol.L⁻¹ and 6.1 (± 1.9) mmol.L⁻¹, respectively (Table 8). These differences were statistically non-significant ($p > .05$), which further supports the view that the dancers were working at a high intensity during the dance test. In addition, there was no significant difference in the physiological parameters recorded for VO₂ between the treadmill and dance tests, indicating

Table 8 Differences in HR, VO₂ and BLA Between the Treadmill and Dance Tests for Five Participants

Physiological Parameter	Maximal Treadmill	Dance Test	Statistical
	Test Mean (SD)		
% HR _{max} b.min ⁻¹	101	97.5	$p = .02$
VO ₂ ml.kg.min ⁻¹	46.4 (3.6)	51 (6.6)	$p = .10$
BLA mmol.L ⁻¹	6.3 (1.7)	6.1 (1.9)	$p = .86$

that the dance-specific performance test for this group of dancers was set at an adequate intensity to be considered as a high intensity test. The significant difference in HR between the treadmill and dance tests may relate to the dancers being less anxious when dancing (lower HR) than when treadmill running (higher heart rate), even though intensities between the two were similar (as shown in the VO_2 and BLa).

The development of the dancer's physical fitness seems to be more a byproduct of skill acquisition than focused fitness training. Enhancement of the aerobic system, at least, is required, probably pre-rehearsal, to allow dancers the physiological capability to cope with the stresses placed upon them during performance. Also, as previous research has shown, dancers are required to perform at high intensities, calling upon the anaerobic energy pathways.

It should be noted that while the dance test may be maximal for most, dancers who are particularly fit and whose anaerobic threshold is at a higher percentage of their $\text{VO}_{2\text{max}}$ may not be working maximally during the dance test, and may not produce BLa values above the 4 $\text{mmol}\cdot\text{L}^{-1}$ point. Interestingly, the dance performance mean BLa values calculated in the current study did not exceed the 4 $\text{mmol}\cdot\text{L}^{-1}$ threshold. The challenge with assessing contemporary dance is that it is so diverse, that while one study may show contemporary dance performance to be high in intensity another may show the opposite to be true. It would be fair to suggest, therefore, that contemporary dancers need to be both aerobically and anaerobically fit in order to be prepared for the many different demands of the genre. However, so long as the dance test is set at an appropriate intensity level to meet the physiological demands of performance, the test should be suitable. It was not the aim of this study to devise a maximal test, such as the Wingate Anaerobic Bike Test. Rather, the aim was to devise a test that was of an intensity that is rep-

resentative of previously reported dance performance in order to help evaluate whether a dancer is physiologically fit enough to perform. As mentioned earlier, previous research has shown a discrepancy between class, rehearsal, and performance in terms of cardiovascular demands.⁶ A dance test such as this can be used for both testing and training purposes as part of a dancer's training regimen to ensure that those higher intensity demands are addressed. Observations can be made across time not only through quantitative means such as HR, but also through qualitative means, such as the observation of movement proficiency.

One of the main reported causes of injury in dance is fatigue, and a high level of physical fitness will delay the onset of fatigue.^{17,18} A test of this kind may help provide information about a dancer's physiological capabilities through relevant and applicable means. As a result of this information more effective dance training programs may be devised to help reduce the risk of injury.

Limitations and Future Research

The main limitation of this study is the low number of participants for some of the tests. Unfortunately, not all participants were able to undertake the maximal oxygen uptake treadmill test. Other limitations relate to the administration of the dance test; presently only its designers have taught the test to participants, and possible differences will have to be monitored when the test is administered by others. The effects of learning the dance test from film and the use of subjective movement observation criteria could be investigated in the future.

Professional dancers were used for this study, and it would be interesting to compare professional dancers to novice dancers so as to ensure that changes in the performance of the dance test across time are due to physiological improvements rather than the learned skill effect.

There is an argument for dance genre-specific fitness tests. Given that

the research in sports science recommends activity-specific testing techniques in sport, perhaps the diversity shown between dance genre styles may also warrant genre-specific ways of assessing physical fitness in dance. The extent to which this present contemporary dance test is applicable to dancers in classical ballet or jazz, for example, is therefore questionable.

Finally, supplementary fitness training is now being recommended in dance training to prepare the dancer for the demands of rehearsal and performance.^{19,20} What is unknown is whether fitter dancers are better dancers. Future research could focus on finding ways to correlate fitness levels with technical and performance outcomes, thereby combining the functional with the aesthetic.

Conclusion

The new high intensity dance performance fitness dance test looks feasible, and promises to yield accurate results in measuring physiological capabilities at high intensities through contemporary dance. The test allows dancers to be assessed within an environment they are used to (the studio), with a mode of exercise that is relevant (dance), and at an adequate intensity to be representative of some contemporary dance performance.

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When Art Meets Science

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When Art Meets Science

An Action Research Approach to Improving Professional Dance Teaching and Learning Using Scientific Methods

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Abstract: Learning and teaching methods in dance have typically evolved from tradition and experience. In recent decades, science has become a major contributor to advances in sport training and performance. However progress in the field of dance has not been equivocal and for dancers to realise their full potential, it is important that training methods advance. Therefore, it is imperative that dance researchers evaluate scientific principles related to superior dance performance and use this knowledge to progress and develop methods of practice in dance education. This paper will report an ongoing action research project at a specific dance training establishment, Laban (UK). This research involves a cyclical process within which dance students are required to undertake an extensive multidisciplinary screening programme, designed to measure the parameters associated with quality performance and well-being. This screening process provides biomechanical, physiological and psychological information which is analysed and interpreted by a multidisciplinary team of dance science researchers. This paper will reflect upon the process of applying these findings to improve learning and teaching practices in dance. This will include discussion of how findings are applied to enhance understanding of performance demands, to develop measures of performance and to improve the holistic learning experience for dancers. The importance of disseminating findings and recommendations to dance teachers and students will be also be considered. Prior to this research dancers did not receive such specific, detailed information about their performance strengths and weaknesses. The evolution of dance science methods has enabled dance students to be empowered by this information about their bodies in a way never before possible. This paper will reflect on the role of science in advancing learning and teaching in the performing arts using the example of an applied action research project in dance.

Keywords: Dance, Evaluation, Action Research, Science, Empowerment, Performance

Introduction

IN THE LAST thirty years there has been a dramatic growth in the application of scientific methods to evaluate performance and improve practice in athletic settings. The progression in technology of measurement tools has allowed for those working in physical education and the sport and exercise sciences to use a wide range of techniques to assess physical, psychological and affective qualities to evaluate and instigate change to improve practice (Lacy & Hastad, 2003). More recently, these approaches have been transferred to other performance settings, such as dance. Dance science has emerged as a relatively new but fast growing area of research and study. The discipline developed out of a need to give the same rigour to the analysis of dance training as had been previously applied to sport. Dance science identifies dance as being unique in terms of the demands placed on the dancer who is required to take his/her body to extremes in terms of joint range of motion. Thus, the dancer is required to be both artist and athlete. Typically dance teaching has been based upon tradition, however the evolution of dance science at Laban (the world's largest Con-

servatoire for dance artist training) in London (UK), allowed for a new kind of progression in practice using scientific and evidence based information in a way never before applied in dance. This paper will introduce and discuss an ongoing research project at Laban in which dance science is being applied using an action research framework to evaluate and improve dance teaching, learning and dancer well-being.

The Setting

Laban is the largest conservatoire for contemporary artist training in the world and its mission is to develop high calibre, versatile, resourceful performers and choreographers as specialists in an increasingly collaborative and interdisciplinary world of artistic practice. Laban aims to promote a culture of innovation and creativity which encourages and enables its students and staff to take leadership roles in advancing its art form. Training of international excellence is contingent on pervasive contact throughout the organisation with the foremost practising artists and scientists in dance.



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Laban seeks to promote lifelong learning opportunities for students at all stages of their artistic development (from early years to professional), allowing individuals to fulfil their maximum potential and serve the wider future of the art form at local, national and international levels. In order to meet these aims, it is important for Laban to be at the cutting edge in learning and teaching. Laban faculty are therefore encouraged to review their own teaching practice, seek ways to enhance dance training and the learning experience of the student and be a world leader at producing autonomous, collaborative and creative dance artists.

The health facilities in the new Laban building include a large Pilates studio and treatment rooms for osteopathy, physiotherapy and remedial massage. The new dance science laboratory is situated within Laban's health facilities ensuring an accessible resource for students as well as collaboration between the health and dance science provision and research.

Dance Science

The aim of dance science is to enhance dance training and optimise dance performance potential through disciplines such as physiology, psychology and biomechanics. In 2001, the world's first Masters degree in dance science (MSc Dance Science) was pioneered by Laban. Laban has recently been involved in many innovative dance science research projects with organisations such as Dance UK, the International Association of Dance Medicine and Science (IADMS), the British Olympic Association (BOA) and UK universities (e.g. Whyte et al, 2003). As a developing arts venue, Laban is exploring arts projects that are informed by science as well as science projects that are informed by the arts, through collaborative, cross-discipline experimental projects. Therefore alongside scientific research and promoting health and well-being through dance, Laban aims to offer new insights into the relationship between art and science.

Although dance science is still in its infancy, research has shown that dancers are injured more than many other athletes (Brinson & Dick, 1996; Laws, 2005) and possible causes for dance injuries have been at the forefront of debate in recent years. Huge demands are placed on the dancer and while choreographers seek ways to express their ideas through inventive movement vocabulary, dancers are sometimes subjected to an increased risk of injury simply because they are unprepared for the unknown. Dance training has until recently been based on tradition and past personal experiences rather than scientific movement principles and the emergence of dance science during the last two decades has encouraged dance teachers to review their training methods

(Clarkson & Skrinar, 1998). Fatigue is also cited as a common cause of injury (Brinson & Dick, 1996) and some have suggested that dance training regimes should be addressed in light of concepts from sports science such as periodisation and tapering (Bompa, 1999). In order to suggest modifications to current training regimes, it is important for dance scientists to establish baseline data of the current status of dancers at both student and elite professional level. This can enable alternative, progressive training methods to be tried and tested.

A common method of assessing the physical status of dancers is known as screening. Most screening research has concentrated on injury epidemiology and biomechanical injury risk factors (Siev-Ner et al, 1997; Solomon, 1997; Molnar & Esterson, 1997), and only a few studies have assessed physical fitness (Liederbach, 1997). To date, no screening programme has included psychological assessment.

Therefore there seemed to be a need to develop a multi-disciplinary screening programme in order to gather baseline information about dancers, establish injury risk factors and monitor the effect of current training regimes in dance on the 'whole dancer'. The emergence of dance science as a discipline, and its presence in Laban prompted the initiation of a long-term action research project to serve this purpose. Prior to this research, no quantifiable measurements of skill and movement ability were recorded and this limited the opportunity to assess the impact of teaching and student progression. One of the main aims of dance is to convey meaning as an art form, so therefore methods of assessment need to be primarily qualitative as this is how an audience judges dance. However, a challenge faced within this subjective discipline is the fact that there are few benchmarks and thus it is difficult to measure improvement. Yet there are factors that are considered to be attributable to good dance performance such as jump height and these can be measured both qualitatively and quantitatively. The gathering of this kind of information can help dancers gain awareness and understanding of their capabilities, inform staff of the effects of training and create benchmarks associated with quality performance for future progression. As previously noted, injury is common amongst dancers and a screening programme would help identify those students at risk as well as establish common variables amongst those who get injured.

A Multidisciplinary Approach

It has long been established that in order to evaluate and enhance human movement, a multidisciplinary approach is required. As Abernethy, Mackinnon, Neal & Hanrahan, (1997) observed, there are key

sub-disciplines from which information should be integrated in order for successful application in performance contexts. Hence, this current project incorporates an appreciation of physiological, psychological and biomechanical principles.

Physiology

Previous research has examined the physical fitness status of professional and student dancers (Cohen, Segal, & McArdle, 1982; Dahlstrom et al, 1996), but there is still debate about *how* fit dancers should be. What is clear is that dancers' cardiovascular capabilities are similar to those of non-endurance athletes (Whyte et al, 2003) even though the demands of dance performance in terms of exercise intensity are high (Rimmer, Jay & Plowman, 1994). An understanding of the energy requirements of dance can help in the development of more effective and appropriate training programmes for dancers. In addition, there appears to be a discrepancy between the intensity at which training (class) is conducted compared with performance. In performance, the cardiorespiratory demands are higher and therefore there is a lack of preparation for these demands in current training regimes (Wyon, 2002). Given that the biggest perceived cause of injury in dance is fatigue (Brinson & Dick, 1996; Laws, 2005), it is important to improve the aerobic capacities of dancers in order to help delay the onset of fatigue (McArdle, Katch & Katch, 2001). Therefore it was imperative that the screening programme assessed aerobic and anaerobic fitness, and applied this information to monitor the extent to which fitness improves as a result of current training regimes.

Biomechanics

Research indicates that bi-lateral (right to left) differences with regards to joint range of motion or muscle strength may contribute towards injury (Grossman, 2000). Differences in turn out (lateral rotation of hip) for example, of more than 10 degrees (Grossman, 2000) could be considered an injury risk factor. The physiotherapist would want to address such discrepancies and work with those dance students in a preventative manner. This type of quantifiable information from screening will help inform the teacher and the dancer about the effectiveness of their work.

Psychology

Substantial research advocates that psychological skills can lead to performance enhancement (Highlen & Bennet, 1979; Mahoney & Avenier, 1977; Ravizza, 1977). For example, Williams and Krane (1993) identified that self-regulation of arousal, high confidence, concentration, perceived control and positive

imagery and thoughts were characteristics associated with elite performers. Psychological skills are also commonly found to be characteristic of the elite in a variety of excellence settings (e.g. Talbot-Honeck & Orlick, 1998; Tribble & Newburg, 1998). In sporting situations, athletes employ psychological skills to control psychological factors, and use them to improve performance. For example, emotions effect thinking, feeling and behaving (Jones, 2003; Lazurus, 2000) so emotional control is vital for performers. The premise of using psychological skills is that by replicating the peak performance state, superior performance can be emulated. Hays (2000) advocated the application of such skills in the performing arts. It therefore seemed appropriate and necessary to incorporate an assessment of use of psychological skills in dance into the screening programme.

Research Aim

The over-riding aim of this project is to improve teaching and learning practices at Laban. Therefore this research intended to address this through the development and application of a multidisciplinary screening programme. Specifically, the focus of this phase of the research was to examine:

- The physical and psychological status of the student dancer
- The effects of the three year contemporary dance training programme on physiological, psychological and biomechanical parameters
- Factors associated with injury

It was the intention of this research to directly apply theories of dance science and the research findings to practice in teaching environments. It was also a key objective of the project to empower staff and students within the setting and to encourage reflection and progression of methods.

Research Design

This research is longitudinal in design and situation-specific to Laban. Therefore between each stage of testing, methods of dance training and methods of measurement evolve, often as a result of evaluating data and also to ensure that the project continues to focus on pertinent issues. Consequently, this research does not fall into the category of typical experimental research. Many of the features of the approach adopt some of the characteristics of 'action research' (AR). AR is a method commonly used in education, health and more recently sport (Gilbourne, 1999) to evaluate and improve practice. The AR framework takes into account knowledge and methods already in place at the setting, termed craft knowledge (McFee, 1993).

The AR cycle involves creating or redefining the way in which practice operates to overcome problems and improve practice (Carr & Kemmis, 1986). It is a cyclical process involving collaboration of researchers aiming to improve practice using action and evaluation, operating separately yet simultaneously (Banister et al, 1994). The process of this research adapts that of a "typical" AR cycle (see figure 1). The research cycle involves identifying a problem

(e.g. rate of injuries), implementing action (changes to dancer training and modification of screening methods), observation (through extensive scientific evaluation of all dancers, i.e. screening) and reflection on action (evaluating the effects of change and further modification required), at which point the cycle begins again with the next screening data collection (see figure 2).

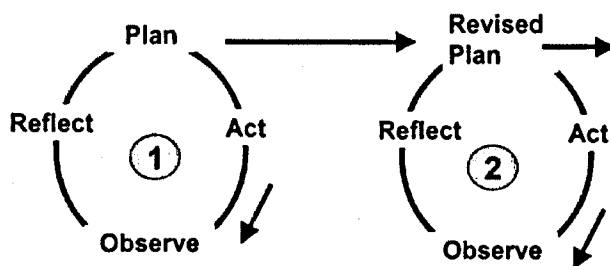


Figure 1: The Traditional Action Research Cycle (Zuber-Skeritt, 1990)

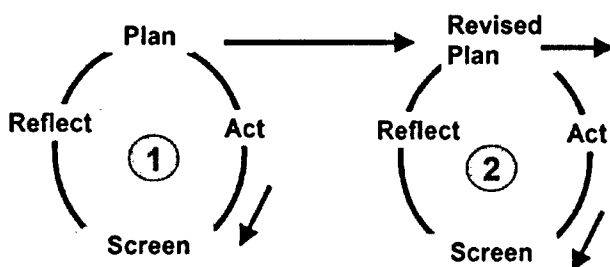


Figure 2: The Research Cycle Applied In This Research (Adapted from Zuber-Skeritt, 1990)

While the benefits of applying these characteristics in this research are clear, it is acknowledged this may not be seen as "traditional" AR as the approach is quite diverse. This is not greatly concerning as the intention was not to argue an epistemological standpoint, but to improve dancer teaching, learning and welfare within this establishment.

Participants

With informed consent, approximately one hundred and seventy dance students undertaking a three year,

full time vocational training as part of the BA (Hons) Dance Theatre at Laban, participate in the study each academic year.

Data collection

All students are screened at the beginning and end of their first year of training and then again at the end of their third final year. The screening takes approximately one hour per student and involves a multi-disciplinary team which includes a physiother-

apist, dance teachers, and dance scientists. The methods of screening are annually reviewed and modified to try and produce the most useful and relevant information from each dancer. Since the commencement of this screening programme, assessments have increased from 12 to 26. Examples of the screening assessments undertaken twice yearly are:

- **Physiological** – e.g. aerobic and anaerobic fitness, body composition.

Physiological assessments consist of both standardised techniques commonly used in sport science such as the anaerobic Wingate 30 seconds bike test (WAnT) and Vertical Jump Height (VJH) as well as dance specific tests such as the Dance Aerobic Fitness Test (Wyon, 2003).

- **Biomechanical** – e.g. joint range of motion, balance.

Biomechanical assessments are derived from recognised and widely used tests such as the modified Thomas Test (Harvey, 1998) that measures hip extension as well as more functional and dance specific tests such as the Dynamic Turn-Out Test which measures movement paramount to good performance in dance (lateral rotation of the hip).

- **Psychological** – e.g. markers of well being, use of psychological skills.

Students complete assessments to gauge well-being and optimal functioning, as well as to determine their use of psychological performance strategies. Assessments include the Test of Performance Strategies questionnaire (TOPS;

Thomas, Murphy and Hardy, 1999), which was modified for a dance population. The TOPS measures use of psychological skills and asks dancers to respond to statements such as "I practice a way to relax" on a scale of often to never. The questionnaire contains 64 items that measure use of 8 psychological skills (such as goal setting, relaxation, self-talk) in practice (i.e. training and classes) and performance contexts.

- **Health-related** – e.g. smoking behaviours, sleep disturbance, menstrual health (females).

The project employs and develops expertise from nearly every area of the institution. Students themselves are involved in the process of data collection, reflection, change and re-assessment and so collaboration is at the heart of the project.

Examples of Research Findings

Physiological

Data from the VJH test was analysed in order to assess the effect of the current training regime. Figure 3 shows that VJH did not significantly improve for year 1 students (cohort 2004-05) during the training year ($P > 0.05$). Changes in the other physiological assessments (e.g. body composition, Dance Aerobic Fitness Test, WAnT) were also non significant. As a result of these findings, a weekly dance specific fitness class was implemented into the timetable for the following year's first year cohort. Figure 3 shows that the students who received a weekly fitness class (cohort 2005-06) improved their VJH ($P < 0.05$). The other physiological assessments (body composition, Dance Aerobic Fitness Test, WAnT) displayed similar trends in results.

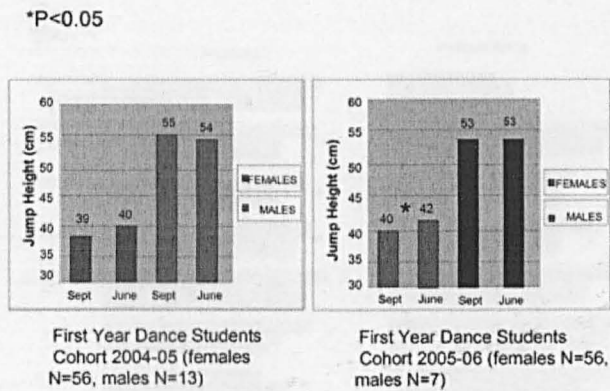


Figure 3: Mean Results for Female and Male Vertical Jump Height (VJH) for First Year Student Cohort 2004-05 (No Fitness class) and First Year Student Cohort 2005-06 (with Fitness class)

So, in summary, following the initial fitness assessment results (Evidence), discussions between dance scientists and teachers occurred (Reflection) and fitness classes were implemented (Action). Screening was used to monitor the effects of the classes on parameters of fitness (Evaluation) and data analysis revealed positive improvements since the implementation of the class (Evidence).

Psychological

TOPS data was analysed in order to describe students' use of psychological skills and also to compare skill usage by 1st years and 3rd years. This would help to indicate whether students develop these skills during their time at Laban. Overall the modified version of the questionnaire demonstrated good scale reliability with Cronbach alpha scores ranging between 0.7-0.84 for all but four of the sixteen sub-scales.

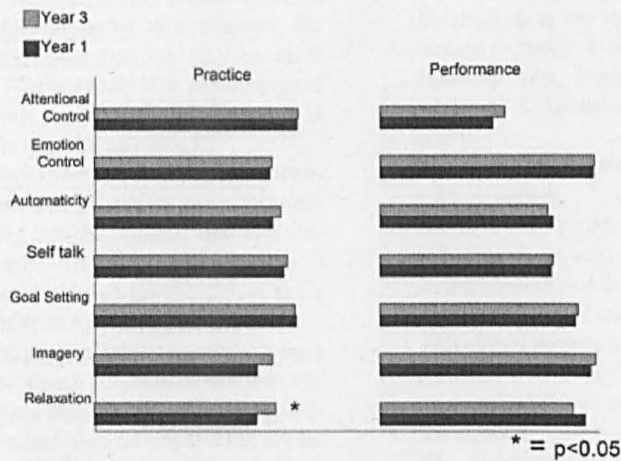


Figure 4: Use of Psychological Skills in Dance: Comparing Dance Students in Years 1 and 3

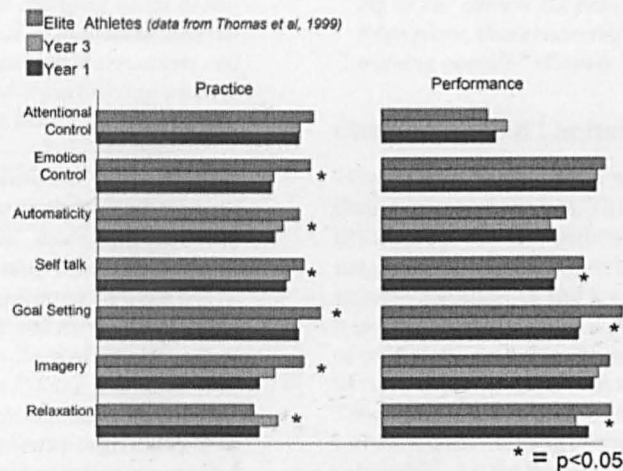


Figure 5: Use of Psychological Skills in Dance: Comparing Dance Students in Year 1, Dance Students in Year 3 and Elite Sports Athletes

Figure 4 illustrates that the only statistically significant difference in psychological skills use between third years and first years was use of relaxation in a practice context and this skill was used more by third years. There were no significant differences in use of any skill in a performance context. Considering the breadth of evidence relating psychological skills to optimal performance, these results indicate that dancers are not being developed to their full potential without psychological skills training.

Figure 5 shows a comparison between the dance students with data taken from international female elite athletes (Thomas et al, 1999). Nearly all skills are used significantly more by elite athletes, for whom psychological skills training may be more readily available. This suggests that psychological skills will not develop naturally and their use in dance environments must be advanced.

This is an area the screening research has identified for development and the integration of psychological skills training into the training regime is currently being discussed. The aim would then be to review the implementation of psychological skills training longitudinally to establish its effects.

To summarise, the psychological assessments have so far identified that dance students do not innately develop psychological skills (Evidence); these findings are being discussed (Reflection) and the implementation of psychological skills training (Action) will be monitored through screening (Evaluation).

Discussion

Reflection and Feedback

Reflection and feedback take many forms. *Individually* - every student receives their results individually and any individual student who has been identified

as 'at risk' of injury will be given coaching and training advice. *In groups* - presentations are given to all students and staff where the purposes of assessments are explained and group mean data is interpreted. The staff meet in small groups and in large seminars to look at the findings the data has produced and to discuss possible methods of addressing problems identified in the current training.

The empowerment of students and staff is an important part of this research and as evidenced in their feedback, this is something being achieved.

"The screening process provides a foundation for students at the very beginning of their advanced training. At this point, it reassures and supports them, helping to motivate them for what will be demanding and challenging few years.

The screening experience provides the student with knowledge about their personal strengths and potential weaknesses. Students become familiar early on with relevant physiological information that they can relate to and that affects them directly and specifically.

This allows them to take some responsibility for their own well-being during their training, while reassuring them that they are supported throughout.

The awareness they gain operates on several levels: For example, preparation - the need for warm-up, balanced nutrition etc, maintenance - physical fitness management to allow maximum training effects, injury management, and development - application of knowledge to their maturing technical skills in many different areas.

The nature of the screening as research is ongoing, reflective and evolving. The structure and

purpose respond to the changing needs of student dancers, individual by individual, and cohort by cohort. The resulting observations and data feed back are used in partnership with the training curriculum to benefit the whole community.

Tutors feel part of a team that works together for the well-being of the students. Both staff and students feel "protected" and supported by the foundation that screening provides. There is also enhanced communication between teachers, pastoral care staff and therapists. For example, students can be directed into immediate remedial work, such as Pilates, if necessary, or guided through "rehabilitation through practice" classes or counselled through injury, with the knowledge that there is a network to monitor and reinforce these channels". (Dance Technique Teacher)

"The students have a very positive reaction to the screening process. They love being told more about their bodies and relish the thought that they could improve their performance and reduce the risk of injury if they follow the advice they receive. The process provides each student with a personal introduction to the Health Research Team - this has proved invaluable in the formation of trusting and caring relationships between the students and the professionals who offer health support". (Physiotherapist)

"As a fitness teacher on the BA programme, I sincerely feel that the interest and enthusiasm our students have in learning about their bodies as athletes and in treating their bodies as athletes is incredible. I believe that the screening programme has huge benefits for both staff and students.

Students become much more aware of their bodies when given individual results from the screening process and as they mature through their training, are able to make clear connections with feedback that they receive in their dance technique classes. They also become empowered with the knowledge of how to continue training appropriately for themselves once they enter the profession.

Staff greatly benefit from the screening as it enables us to fully understand at what level our students enter the BA programme, at what level they leave the programme, and thus what effect our institution's overall training programme has on these up and coming dance professionals. The screening programme allows us to measure this effect and thus prepare our dance students for the profession as best as possible. Based on the results from screening, restructur-

ing of our current BA programme has already taken place, thus enhancing the dance students' training overall." (Fitness Teacher)

Challenges and Limitations

This research has not been without its own set of challenges and dilemmas. There has been some resistance from teachers particularly during the early stages of the project however the majority have been extremely supportive and are keen to get involved. It is important to maintain a multi-disciplinary team of enthusiastic individuals who share a common interest in developing learning and teaching in dance. The project is costly in terms of time and money and currently, those working on the project do so entirely voluntarily. As the project continues to grow, the demand for more resources will also increase. There is also inevitably the challenge of gaining acceptance of the action research approach to this study within the typically scientific world of dance research.

Future Directions

There are several future directions that can be pursued in terms of specific learning and teaching issues. It is also important to identify how and where methods could improve within the research.

A major development of methods has been the purchase of injury tracking software. This will significantly contribute to the level of information that will be available for identifying causes and effects of injury. This form of data management will also enhance the possibilities of longitudinal and multidisciplinary analysis.

There are a number of health related issues that warrant consideration such as eating disorders, particularly given the prevalence of eating disorders in dance as compared to the normal population (Buckroyd, 2000). It is important however that expertise and resources are available to act on the information gathered so as to properly support the students if necessary.

Conclusion

Despite the developments of screening methods and applications to dance training that have already occurred as a result of this research, the project should still be considered to be in its infancy. However, this research has already helped to identify and resolve teaching and learning issues using a collaborative, reflective and yet evidence based approach. It is encouraging those involved to rethink and review their daily practice with an outcome focus. This is beneficial not only for achieving the aims of Laban but also for developing personal empowerment of staff and students.

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The effect of a one year dance specific fitness training programme on undergraduate modern dance students; An experimental study.

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LABAN

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Rationale

Research over the last two decades has examined the physical fitness status of professional and student dancers^{1,2,3,4,5}, but there is still debate about how fit dancers *should* be. One study⁶ assessed the effect of an integrated endurance training programme for ballet dancers (n=16) across a ballet season and found positive results. Some studies have suggested a discrepancy in the intensity level between training, rehearsal and performance^{7,8,9} and the idea of supplementary fitness training has been debated albeit untested longitudinally with large groups of dancers.

The applicability of lab tests and training regimes from sports is questionable^{10,11} and it is becoming increasingly necessary to gather relevant data and qualitative observations, physiological and psychological, in order to develop specific methods of promoting and assessing dance fitness.

The purpose of this study, longitudinal and experimental in design, was to examine the effect of a one-year dance specific fitness programme on undergraduate modern dance students undertaking full time training.

Methods

Existing screening information for each of 86 first year students (N=86) provided initial data on a series of physiological tests (including the Dance Aerobic Fitness Test (DAFT)¹², the Wingate Anaerobic bike Test (WAnT), and vertical jump height, which were repeated at the end of the one-year intervention. Students also completed

an intrinsic motivation inventory¹³ regarding their personal appreciation of the programme, and were asked to keep a log of personal extra fitness activities.

A weekly 90 minute fitness class was developed across the year according to principles of periodisation and specificity¹⁴. The primary aim was for the structure and content to be responsive to curriculum needs and to engage in a dialogue with technique teachers and therapists. The introduction of a software package to record injuries treated by the team of therapists enabled a tracking and monitoring system to be developed. The intention was that feedback from this system would also affect the content in terms of possible counteractive measures.

Intensity and duration of exercises were considered. The class was initially 60 min in duration and increased across the year to 90 min. The dancers' heart rates were regularly monitored to ensure that the intensity level was appropriate to elicit a training response. Functional fitness training preceded more dance-based movement that increasingly replicated vocabulary from technique classes. For example, plyometric training was introduced, initially using basic parallel foot positions, and later modified to include turned out positions, which more closely mimicked the type of jumps seen in dance. Upper body strength exercises gradually progressed to incorporate partner lifting of varying speeds and complexities. During the final phase, a circuit type structure also reflected the variety of activity and speed of succession that would be encountered in a dance class.

Preliminary results

Results from the DAFT test (figure 1) have shown that, following the intervention, there was a significant decrease in mean heart rates across all 5 stages of the test, indicating improvement in the dancers' aerobic capabilities. In addition, it appears that this particular group of students displayed lower heart rates at every stage, compared to the group of first year students from the previous year who did not engage in regular fitness training (table 1).

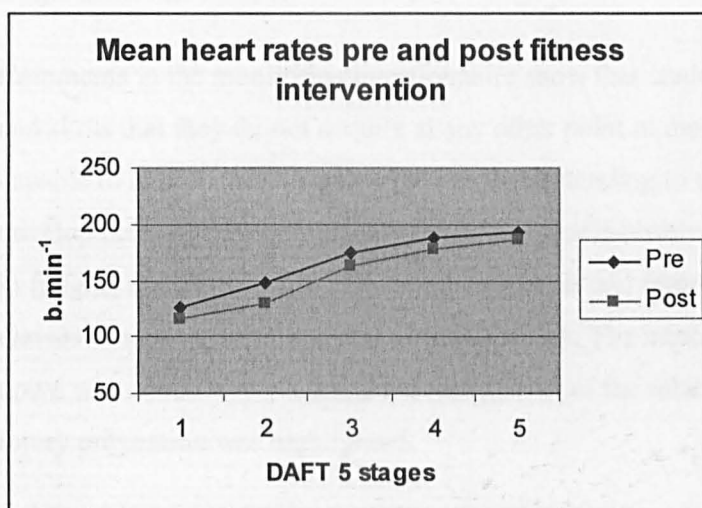


Figure 1. Mean heart rates of dancers undertaking dance specific fitness training before and after the one year intervention.

There was a significant difference between the 2 groups at every stage ($P<0.05$)	Stage 1 (b.min ⁻¹)	Stage 2 (b.min ⁻¹)	Stage 3 (b.min ⁻¹)	Stage 4 (b.min ⁻¹)
First year students with no fitness at end of year 1 (N=38)	122+/-13	153+/-15	179+/-14	190+/-13
First year students post fitness end of year 1 (N=50)	115+/-12	129+/-23	162+/-13	177+/-11

Table 1. Mean heart rates across each stage of the DAFT for 3 different groups of dance students.

The Intrinsic Motivation Inventory has not yet been analysed. However comments in a monitoring questionnaire suggest that the students *are* motivated to participate in their fitness classes. Responses focused on students' increased knowledge with respect to physical preparation for their dance skills training, the importance of application of the theoretical aspects of their fitness course and the new perspective they have of dancers as athletes as well as creative artists.

Discussion

Although not all results have been processed, preliminary results from the DAFT test show that aerobic fitness has improved over the one-year period, supporting the findings of previous studies¹⁵. When comparing the DAFT heart rate data to that of the dancers who did not participate (from the previous Year 1 cohort), there appears to be an overall reduction at each stage, indicating that it is the fitness training intervention that has contributed to this effect. Further tests on anaerobic capacities at the end of the intervention will add more comparative data.

Comments in the monitoring questionnaire show that students have gained knowledge and skills that they do not acquire at any other point in their dance training and are capable of applying this knowledge and understanding to their wider physical development. The most frequent physiological self-observed effects were reductions in fatigue, improvement to general energy levels and improved capacity in dance classes to sustain technique and jumping ability. The importance of warm-up and cool down was commonly cited and the recognition of the relationship between fitness and injury prevention was highlighted.

In psychological terms, preliminary analysis of the comments reveals that students have found fitness valuable as a relaxation tool. They explain that they feel more positive and confident in general, and find a reduction in stress, tension and frustration. Reasons include the holistic approach, the absence of competition in the fitness class and the increased knowledge, awareness and value of relaxation techniques as an element of fitness. Motivation appears to be increased, although it is still debatable whether this is specific to Fitness classes or can be transferred to other areas of training. Results of the Intrinsic Motivation questionnaire will provide further information in relation to this.

At present, the integration of the injury software is providing ongoing data collection on injury patterns and has allowed for additional communication between the student, the therapists, the technique teachers, and the personal tutors. This data can be used to inform the training at various levels. Course leaders will be able to respond to curriculum stress points, technique teachers can adapt their demands on the student at such times, and the students' own awareness of potential personal risk can be enhanced. The dance-specific fitness team aimed to counteract some possible injury risk factors, such as lack of strength and jumping ability, through the introduction of dance-specific strength work using partnering and plyometric jump training. Also specific short term demands have been addressed. For example, groups of students have followed a prescribed training plan to prepare for a three week historical project, dealing with specific pieces from Limon, Graham and Cunningham repertory.

The extent to which the dancers will take on the new information of the benefits of fitness training on their own in future years will be monitored through additional screening at the end of the third year. Feedback of results via presentations and workshops will help encourage this. It is hoped that this study will have a more far-reaching effect than functional sports fitness and provide a stimulus for students that can enhance the complete training experience. This study is the first of its kind in that it addresses the need for specificity in dance training whilst attending to theories and concepts from sports science. It is hoped that other dance training institutions might consider adopting a similar model so that findings can be shared and more effective training programmes for dancers devised.

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4.0 Appraisal and Application of the Research

This chapter critically appraises the six studies submitted in this thesis. It will discuss how each study relates to the next and how all six studies address an overarching question about today's contemporary dance training. It highlights the specific limitations of each study and of the studies collectively and offers recommendations for where future research efforts might lie. The application of the research from the educator and researcher's perspective is offered and the significance of the work is considered.

The aims of the progressive research are highlighted below:

4.1 Research aims

- To investigate the physiological demands of dance training and performance
- To assess the role of supplementary fitness training in dance
- To examine new dance specific methods of testing and training dancers

The studies explicated in this thesis that are submitted for a PhD degree by prior publication are:

Study 1: Validity of using heart rate as a predictor of oxygen consumption in dance. Journal of Dance Medicine and Science, 8(3), 2004.

Study 2: Development, reliability and validity of a multistage dance specific aerobic fitness test. Journal of Dance Medicine and Science, 7(3), 2003.

Study 3: Physiological monitoring of cardiorespiratory adaptations during rehearsal and performance of contemporary dance. Journal of Strength and Conditioning Research, 19(3), 2005.

Study 4: Development of a High Intensity Dance Performance Fitness Test. Journal of Dance Medicine and Science, 13(1), 2009.

Study 5: When art meets science: An action research approach to improving professional dance teaching and learning using scientific methods. International Journal of Learning, 13, 2006.

Study 6: The effect of a one year dance specific fitness training programme on undergraduate modern dance students; An experimental study. International Association of Dance Medicine and Science, 16th Annual Meeting, USA (published in conference proceedings and Abstract published in Journal of Dance Medicine and Science, 11(1), 2007.

These studies address the primary concerns articulated in chapters one and two and address the aforementioned aims.

4.2 Relationship between the studies and to previous research

Study one, *Validity of using heart rate as a predictor of oxygen consumption in dance* provided the impetus for study two, *Development, reliability and validity of a multistage dance specific aerobic fitness test* and study four, *Reliability and validity of a new high intensity dance performance fitness test* in that study one highlighted a clear rationale for dance specific methods of evaluating the energy requirements of dance and for the physiological status of dancers.

Findings from study one, *Validity of using heart rate as a predictor of oxygen consumption in dance* showed that it is no longer acceptable to use steady state treadmill running to generate a HR-VO₂ relationship for the prediction of oxygen consumption during dance as originally advised by Astrand and Ryming (1954) and that the use of group data may not be reliable. Such findings from study one support those of Bernard et al (1996) and refute previous dance literature such as Dahlstrom et

al (1996) that utilised this method for predicting VO_2 albeit with cycling tests. Study one therefore prefigured studies two and four which were the developments of dance specific tests of physical fitness.

Previous studies show that dance utilises both the aerobic and anaerobic energy systems (Novak et al 1978; Cohen et al 1982a,b; Chatfield et al 1990, Rimmer et al 1994, Wyon et al 2004) highlighting the value of devising dance specific tests of both aerobic (study 2) and anaerobic (study 4) fitness. Study three, *Physiological monitoring of cardiorespiratory adaptations during rehearsal and performance of contemporary dance* then utilised the dance specific aerobic fitness test from study two to assess the physiological differences in energy expenditure between dance training and dance performance. Previous research conducted within classical ballet has indicated a discrepancy between dance training and performance (Cohen et al 1982a,b; Schantz & Astrand 1984). The extent to which such a discrepancy exists in contemporary dance is less known. Wyon and colleagues measured oxygen uptake to determine the intensity of modern dance class, rehearsal and performance (Wyon et al 2004). Findings showed a discrepancy between the class and rehearsal phases and performance intensity. Wyon et al's study measured dress rehearsals rather than actual performances: this was due to the gas analyser inhibiting performance of the choreographic movements and because the machine produced a noise which the choreographer considered would compromise the performance. Study three expanded and furthered this research by measuring changes in dancers' cardiorespiratory fitness levels across the rehearsal and performance seasons. Findings of study three, *Physiological monitoring of cardiorespiratory adaptations during rehearsal and performance of contemporary dance* demonstrated a clear discrepancy in the intensity

between training and performance in contemporary dance as indicated by changes in cardiorespiratory fitness as a result of performing.

Koutedakis and Sharp (1999) argue for supplementary fitness training to be incorporated as part of dance training in order to better prepare the dancer for the requirements of performance. Findings from study three, *Physiological monitoring of cardiorespiratory adaptations during rehearsal and performance of contemporary dance* validated this perspective. It seemed a logical progression then, to measure the role of fitness training within a full time vocational dance training institution as a response to a call for supplementary training of this kind. Study five, *When art meets science: An action research approach to improving professional dance teaching and learning using scientific methods* comprised an interdisciplinary screening and profiling programme to assess an action research approach to enhancing the learning and teaching experience of the dancer in vocational training. The initial findings from the physical fitness testing that formed part of this screening and profiling programme in study five justified the need for supplementary fitness training, preparing the ground for study six, *The effect of a one year dance specific fitness training programme on undergraduate modern dance students; An experimental study*.

The six studies relate to each other in their investigations of the physiological demands of contemporary dance and of effective methods of testing and training dancers. These studies explicate new knowledge within the discipline by calling into question methodologies used in previous research and by offering alternative methods of evaluating the physiological capacities of dancers. These studies also highlight the

need for a more systematic approach to teaching and learning in dance through screening and profiling and for a more science informed dance pedagogy.

4.3 Application of the work

From the perspective of researchers, the work submitted in this thesis responds to questions about the relationship of cardiorespiratory fitness and contemporary dance; the physiological differences between training and performance; effective methods for evaluating physical fitness in dance and the importance of screening and profiling in dance. Such information has the potential for application for dance practice in that it can inform the content and intensity of training thereby making it more relevant to today's dancers. It can also encourage the systematic monitoring of physiological adaptations to training thereby providing an assessment of its effectiveness.

Researchers are now using this information to work within a dance company or school setting when advising on curriculum design or when undertaking a needs analysis of a particular performance work. Dance companies are beginning to recognise the value of employing Dance Scientists⁷ and Exercise Physiologists to advise in this regard.

The dance specific fitness tests developed by this research (study 2, Wyon et al 2003; study four, Redding et al 2009) can be used by researchers within a dance company or school setting as part of a coaching programme to monitor changes to dancers' physiological capacities at various stages within the training and rehearsal periods. Such information can confirm that the dancers have adequate physiological capabilities to undertake training; are ready to return to training post injury or from

⁷ Ballet Lorent currently employs a Dance Scientist to advise on issues relating to dancer health and training as well as provide psychological skills training for the dancers. Birmingham Royal Ballet employs an Exercise Physiologist to undertake regular fitness testing and advise on training regimens.

holiday or be at their physiological best for performance. Dance schools and companies are now utilising the fitness tests developed by the research submitted in this thesis (Laws, 2005).

The screening and profiling activity that forms part of the research in this thesis (study five) has been adopted by Laban and is now embedded within its undergraduate dance training programme. It has also been published as an ideal model for use by others (Redding et al 2006). In 2005, the screening research (study five) was presented at the International Association of Dance Medicine and Science 15th Annual Meeting in Stockholm, Sweden (Redding et al 2005). Laws (2005) advocates the use of this particular screening model (presented in this thesis) and a greater number of dance schools and companies are now screening their dancers for injury preventative purposes (Laws, 2005). In the publication, *Fit to Dance 2*, Laws states that, “In 2004, Laban introduced a broad physical assessment screening programme for its students, which includes a range of fitness and biomechanical assessments alongside orthopaedic, anthropometric assessments and medical questionnaires. The Health Research Team plans to monitor the dance students’ injuries over time” (Laws, 2005: p77).

While the research submitted in this thesis has specifically addressed contemporary dance and not other dance genres such as jazz and tap dance, it is argued here, certain findings can be applied to other genres. For example, the findings of study one, *Validity of using heart rate as a predictor of oxygen consumption in dance*, are potentially applicable to any activity that is non steady state transitory in intensity and this includes most other dance genres. Indeed, most of the previous research that

showed dance to be an intermittent activity was conducted on classical ballet dancers yet study one was undertaken with contemporary dancers. Researchers may wish to consider the findings of study one when devising methods of evaluating energy requirements of other dance genres particularly if these are similar in intensity to contemporary dance and are transitory rather than steady-state.

From the perspective of the *teacher*, this work should provoke a thorough review of what has been accepted for too long as ‘the right way’ to train dancers. As previously mentioned, learning and teaching methods in dance have typically evolved from tradition and personal experiences rather than scientific principles, and the present research submitted in this thesis demonstrates the effective role of applying scientific principles to training methods. Dance training previously consisted primarily of technique skill based classes. Study three, *Physiological monitoring of cardiorespiratory adaptations during rehearsal and performance of contemporary dance*, study five, *When art meets science: An action research approach to improving professional dance teaching and learning using scientific methods* and study six, *The effect of a one year dance specific fitness training programme on undergraduate modern dance students; An experimental study* show the need to implement functional preparatory classes for cardiorespiratory fitness into dance training regimens. Findings (from studies 3,5,6) and publications such as the Fit and Healthy Dancer (Koutedakis & Sharp, 1999) and Fit to Dance 2 (Laws, 2005) have shifted thinking about what should constitute an effective training programme for today’s dancer (Laws, 2005: p84).

Anecdotally, it appears that as a result of the present research, some dance training schools, for example, Rambert School, Central School of Ballet, Bird College, as well as companies such as Birmingham Royal Ballet, English National Ballet, Swedish Royal Ballet, now include regular fitness training and testing within in their training programmes. The dance aerobic and high intensity fitness tests (studies 2 and 4) can be, and are usefully utilised by the dance educator/teacher within the dance studio setting. The tests are easy to administer and involve a form of activity that is familiar to the dance educator/teacher (dance). As previously mentioned, the tests can be used to indicate whether a dancer is physiologically fit enough to undertake training or perform (through effective completion of stage 5 of the aerobic test and/or completion of the high intensity fitness test) or start back in training post injury or holiday (which constitutes stages 1-3 of the aerobic fitness test).

4.4 Limitations of present research and future research

All research, particularly research that involves human participants, comes with its own set of limitations and challenges. Each of the six studies had specific limitations as well as strengths and valid contributions to make. In addition, there were some challenges that apply to all six studies collectively. Many of the study specific limitations have been articulated at the end of each published paper (chapter 3). In summary, they are as follows:

Study one: *Validity of using heart rate as a predictor of oxygen consumption in dance.*

The laboratory treadmill protocol that was used to evaluate the reliability of the HR-VO₂ relationship was a steady state protocol, while the dance protocol (class) was non steady state intermittent. This was not strictly a limitation however. Lothian &

Farrally (1995) suggested that individual estimation of oxygen consumption was possible from heart rate data when a similar form of exercise was used initially to calculate the HR-VO₂ relationship. Previous studies have established a HR-VO₂ relationship for use in dance, hence the incorporation of a steady state protocol for comparison.

Studies two and four: *Development, reliability and validity of a multistage dance specific aerobic fitness test* and *Development of a High Intensity Dance Performance Fitness Test*.

The main limitation of the dance specific aerobic test (Wyon et al 2004) and the high intensity dance fitness test (Redding et al 2009) is that the tests were administered by its designers. It would have been useful to monitor possible physiological differences with someone other than the designer teaching the movement material to the dancers. The effects of learning the tests from video and the use of subjective test termination criteria were not examined and this could have been a useful additional aspect to the research.

Lastly, the genre of dance in the tests is contemporary dance. Given that research in sports science argues for activity specific tests (McArdle et al 2001), it might be interesting for future researchers to create a fitness test for each dance genre. The extent to which dance specific tests can remain valid over time is debatable since dance itself is so diverse and is continually developing in terms of the style, physiological requirements and demands of choreography and dance techniques. The tests need to adapt to such changes.

Study three: Physiological monitoring of cardiorespiratory adaptations during rehearsal and performance of contemporary dance.

Dancers from one of the two dance companies observed in this study were encouraged to undertake their own aerobic training outside of the scheduled rehearsals, and ergometry equipment was provided for this. A limitation of this study is that the use of this fitness equipment was not rigorously monitored. Findings showed that dancers from this company were fitter than dancers from the other company. This supports the view that rehearsals and training alone cannot be relied upon and that additional ergometry equipment is needed. It would have been useful to know the extent to which the equipment was used by those who had access to it.

This study did not monitor other fitness components such as muscular power, strength or muscular endurance. While the findings show that aerobic fitness adaptations can occur during a performance period, indicating that performing itself can have a positive impact upon cardiorespiratory fitness, it would have been pertinent to ascertain whether the same holds true for other aspects of fitness. Physical fitness comprises other factors, such as muscular strength and muscular flexibility, important components for dance (Koutedakis & Sharp, 1999). Previous studies have measured the benefits of strength training primarily among the ballet dance population (Koutedakis et al 1996) indicating the value of observing other components of physical fitness. While it is always useful to enhance and extend existing literature, the focus of this particular study was to observe changes in aerobic fitness across the rehearsal and performance period since this had not been investigated.

Study four: Development of a High Intensity Dance Performance Fitness Test.

Semi-professional and professional dancers were used for this study. This study did not compare professional dancers with novice dancers. This would have further ensured that any changes in the performance of the dance test across time are due to physiological improvements rather than the learned skill affect. It would have been useful to assess novice as well as professional dancers as was done for the dance aerobic fitness test (study two), and future researchers should consider this. Findings of study four indicate that the high intensity dance fitness test is feasible and promises to yield accurate results in measuring physiological capabilities at high intensities, however additional research should be conducted to strengthen the external validity of its findings.

Study 5: When art meets science: An action research approach to improving professional dance teaching and learning using scientific methods

Gaining acceptance of an action research type methodological approach within the traditional scientific world of research is an inevitable challenge. While features of action research do not fall into the category of typical experimental research, the action research methodological framework takes into account knowledge and methods already in place at the research site. In other words, this approach was the most appropriate for the environment in which the research was located. The study's design was longitudinal and situation-specific to Laban. Therefore between each stage of testing, methods of dance training and methods of measurement evolved, often as a result of evaluating data and also to ensure that the project continued to focus on pertinent issues. While this means that research variables are manipulated during the study (which is appropriate in action research), data is collected at specific intervals so as to assess change in a quasi-experimental design before evaluating and

manipulating accordingly. As advised in chapter one, the action research framework takes into account craft knowledge (McFee, 1993 as cited in Gilbourne, 2001) and methods already in place at the setting. The action research cycle involves creating or redefining the way in which practice operates to overcome problems and improve practice (Carr & Kemmis, 1986).

Study 6: The effect of a one year dance specific fitness training programme on undergraduate modern dance students; An experimental study

While this study utilised the dance aerobic fitness test (study two) (Wyon et al 2004), the high intensity dance fitness test (study four) (Redding et al 2009) had not yet been fully developed at this time. Consequently, the Wingate Anaerobic bike Test (WAnT) was used to measure the dancers' ability to perform at maximal intensities before and after the one-year fitness intervention. The high intensity dance fitness test (study four) is not a maximal test and as such, is not comparable to the WAnT. The high intensity dance fitness test uses a mode of exercise more familiar and relevant to the dancer than cycling, while the high intensity fitness test (study four) is also more representative of the performance intensities seen in dance. Quin et al (2008) found the WAnT to be a valid albeit less relevant test for dancers. The use of the WAnT in study six is not necessarily a limitation as such, however further research is needed to extend Quin et al's work to further justify the need for dance specific methods for measuring dancers' capabilities.

4.5 Additional issues with the research

As is often the case with research that involves human participants, a small participant pool is often cited as a limitation of the research. This was the case for studies two

and four. Larger participant numbers may have increased the power of the statistics and the external validity of the findings to the dance population.

With regard to future research, there is scope and potential for dance science to develop further knowledge in support of dance training and optimum dancer performance. Contemporary dance companies in the UK, America and Europe include dancers from a range of cultural and training backgrounds and embrace a combination of eclectic movement vocabularies and influences from different cultures (Foster, 1997). Hence, the potential for the application of this research to other dance genres across a geographical spectrum is proposed.

The research submitted in this thesis observed contemporary dance. Previous research has found differences in physical effort between different dance styles (Chmelar et al 1988; Dahlstrom et al 1996). In contemporary dance, distinct differences can be found within the repertoire: contemporary dance choreographers are in search of innovative and unique ways of communicating ideas, and this must be taken into account by researchers evaluating training and testing in this genre. The research in this thesis raises new issues in the debate about health and fitness for dancers in general; it foregrounds methods of measuring physiological parameters in dance, and argues for the importance of monitoring physiological adaptations across time. While physical effort may be different for different genres (Chmelar et al 1988; Dahlstrom, et al 1996), issues of dancer health and fitness, as well as the value of regular screening and monitoring, are proposed as crucial in supporting optimum performance in all dance genres.

Much of dance physiology research is dependent upon the analysis of performance as something that can be scored. A quantitative score will allow statistical tests to be performed in order to determine the group average score: quantitative improvements over time or effect of a particular intervention on aspects of performance, for example. For many dance artists, the quantitative measurement of performance is considered problematic since potentially each observer could score the performance differently. While the measuring of any physical activity that includes an aesthetic component is more challenging, some would argue that it is not impossible. Research in empirical aesthetics, for example, (International Association of Empirical Aesthetics; Kennard, 2008) suggests that there is some value in pursuing this path for dance to establish a quantitative measure of dance performance. Dance educators quantify technical components of dance, their criteria including the measurement of artistic aspects of technique such as musicality and the dynamic qualities of movement. If a consistent method of scoring performance can be achieved, the effect of modified training interventions can be observed and the physiological determinants of performance can be derived as they have been in sport. Until determinants can be articulated, it is not possible to discern whether the physiological characteristics observed during performance are optimal or whether a particular experimental intervention has had a positive impact upon the characteristics. Preliminary work has begun in this area for dance (Twitchett et al 2007).

4.6 Summary

This chapter has discussed how each of the six studies presented in this thesis relate and how they address an overarching question about today's contemporary dance training. The application of the research from the researcher and the educator's perspective was offered and the significance of the work considered. A summary of

the limitations of each study submitted in this thesis was offered while a more detailed list of limitations can be found at the end of each published paper in chapter three. It is hoped that these limitations will be taken into account by future researchers who wish to enhance and extend this work.

The following chapter describes how the research presented in this thesis generates new knowledge and advances understanding of dance physiology. A synopsis of the research will be offered as well as a discussion about how the work is placed within the broader dance world context. Reflections upon the research process will be shared and a summary of its contribution to the dance world outlined.

5.0 Significance of the research and synopsis

5.1 Introduction

This chapter explicates how the research presented in this thesis generates new knowledge and advances understanding of dance physiology. A synopsis of the research is offered with its most salient points, as well as a discussion about how the work is placed within the broader dance world context. Finally, a conclusion articulating the specific contributions is provided.

5.2 Significance of the work and its contribution to new knowledge

An understanding of the energy requirements of dance and of the physiological status of dancers facilitates the development of more effective and appropriate training programmes for dancers. While some previous research has examined the physiological demands of dance (Rimmer et al 1994; Cohen et al 1982a; Dahlstrom et al 1996; Schantz & Astrand, 1984; Chmelar et al 1988), study one, *Validity of using heart rate as a predictor of oxygen consumption in dance* shows that the methods utilised in the previous research are questionable. The reliable, valid and objective measurement of dancer capacities is vital to developing a greater understanding of the effect of dance training (Welsh, 2003). Hence, the findings of study one contributes to new knowledge: future researchers can evaluate more accurately the energy expenditure of dance and thereafter inform training. Study three, *Physiological monitoring of cardiorespiratory adaptations during rehearsal and performance of contemporary dance* measured the energy yield of contemporary dance training and performance and while previous research has attempted to measure the energy yield of dance, there are differences either in the methods used or the dance genre studied.

Schantz & Astrand (1984) and Cohen et al (1982a) used Douglas bag equipment to measure the oxygen uptake in classical ballet, however the equipment was cumbersome and noted by the dancers as restrictive (Cohen et al 1982 a). Dahlstrom et al (1996) measured the physical effort of various dance genres including contemporary dance, however data was analysed using either the HR-VO₂ relationship, which has since been shown in the current research to be unreliable or, by calculating HR alone. The problem with monitoring HR during non steady state activity is that this does not take into account the potential elevated HR to compensate for the decrease in stroke volume during rest periods. Study one, *Validity of using heart rate as a predictor of oxygen consumption in dance* therefore contributes to new knowledge in that it calls into question methods used in previous research and recommends the use of more portable light weight gas analysers and the development of dance specific methods.

Studies two and four provide dance specific methods for measuring physical fitness in contemporary dance. Such tests did not exist prior to this research. Previously, researchers tended to rely upon tests taken from sports using equipment such as cycle ergometers which were unfamiliar to dancers. The dance specific tests developed in studies two, *Development, reliability and validity of a multistage dance specific aerobic fitness test* and four, *Development of a High Intensity Dance Performance Fitness Test* address the concept of specificity and while sports specific equipment such as swimming flumes and rowing ergometers have now been devised for athletes, until studies two, *Development, reliability and validity of a multistage dance specific aerobic fitness test* and four, *Development of a High Intensity Dance Performance Fitness Test*, no specific fitness tests existed for dance.

The dance aerobic fitness test (DAFT) developed in study 2, *Development, reliability and validity of a multistage dance specific aerobic fitness test*, is now used internationally by dance schools such as Bird College, UK; Central School of Ballet, UK; Cornish College of the Arts Seattle, USA; the Australian Ballet School in Melbourne Australia; and dance companies such as the Birmingham Royal Ballet, UK; Transitions Dance Company, UK. In Laws' (2005) publication, 'Fit to Dance 2' it is indicated that "Dance Scientists are developing protocols for testing dancers' fitness, working with dance schools and companies to make the tests as dance specific and relevant as possible" (Laws 2005, p84). Laws cited the publication from study two, *Development, reliability and validity of a multistage dance specific aerobic fitness test* to support her statement in her book (2005).

The natural progression from studies one, *Validity of using heart rate as a predictor of oxygen consumption in dance*, two, *Development, reliability and validity of a multistage dance specific aerobic fitness test*, three, *Physiological monitoring of cardiorespiratory adaptations during rehearsal and performance of contemporary dance* and four, *Development of a High Intensity Dance Performance Fitness Test* were designed to assess the effect of fitness training within a real dance training setting. Study five, *When art meets science: An action research approach to improving professional dance teaching and learning using scientific methods* provided a new approach to screening and profiling dancers. It advocates a multi-disciplinary team of individuals to understand the 'whole' dancer within his/her own environment: to consider physiological, biomechanical and psychological aspects. It also recommends a methodological framework that is conducive to the environment

in which the research is placed, thereby acknowledging the methods and knowledge already in place at the setting and building on learning and teaching practices. This screening and profiling programme model (study five, Redding et al 2006) was developed as a response to a call by organisations such as Dance UK and the International Association for Dance Medicine and Science for effective injury tracking and performance monitoring. The model has been presented at several national and international conferences and has been of interest to other dance training schools, some of whom have now effectively implemented the same or modified model⁸. Study five was published in *The International Learning Journal* in 2006 and won an International Award for Excellence in the area of Literacy and Education. Most recently, the screening and profiling model developed in study five, has formed the basis for two successful research funding applications to The Leverhulme Trust and the Department for Children, Families and Schools to undertake the following investigations: *The identification and development of contemporary dance talent in young people: An interdisciplinary longitudinal research project* (awarded £363,000) and *Music & Dance Science: Optimizing Performance Potential* (awarded £54,000). It is anticipated that these two substantial projects will advance the field of dance science and specifically the area of interdisciplinary screening and profiling (see appendix 8.4 and 8.5).

Study six, *The effect of a one year dance specific fitness training programme on undergraduate modern dance students; An experimental study* was the evaluation of a fitness training intervention within a longitudinal research design. Until this study, no other research had measured the effect of supplementary fitness training beyond one

⁸ The Centre performing arts college, London, Central School Ballet, Balettakademien Stockholm, Sweden and Bird College, Kent have implemented aspects of Laban's screening programme within their courses.

single ballet season (Wanke, 2001). Study six was conducted across one year and involved the evaluation of several physiological as well as psychological parameters. No other study of its kind had been previously published.

Collectively, the overarching aim of the research presented in this thesis has been to address concerns from dancers, dance teachers and choreographers about their anecdotal belief that dancers should be fitter and that dance training does not prepare the body for performance. While the current research does not purport to solve all the questions posed by dance practitioners it does address many of their enquiries by advancing knowledge and understanding of the physiological demands of contemporary dance, the value of physiological assessment and the importance of screening and profiling. The research offers new reliable methods of evaluating the physical fitness of dancers and shows that supplementary fitness training is effective.

5.3 Synopsis and broader dance world context

Adaptability is a prerequisite for today's contemporary dancer to cope with the different physical and technical demands of different choreographers. Until relatively recently, a significant proportion of contemporary dance choreographers developed movement vocabularies and movement styles which prepared dancers for their performance works and for the work of others whose choreography was in the same genre and style. Today's 'independent choreographers' expect dancers to train in a variety of techniques, demanding a more versatile dancer (Foster, 1997). Technical training and the demands of performance are not congruent: account must be taken of physiological demands; and the research explicated in this thesis verifies this view. There may be the possibility for dancers to become 'match-fit' for performance once

the choreographic piece is devised: this could be done by running and re-running the piece over time in order for the dancers physiologically to adapt to the demands of the work. This is in some ways, the ideal situation. Funding restrictions are such however, that rehearsal periods are often too short to allow adequate time for physiological adaptation to take place. It is argued, therefore, that technique training alone cannot provide all the necessary skills and physical fitness required for performance, and the rehearsal period may be too short, especially in contemporary dance, to allow positive physiological adaptations to occur prior to performance. Supplementary activity specific fitness training is a necessary component within dance training in schools and companies, and there is a need to highlight the importance of such fitness training for the independent dancer.

There is evidence of a shift in thinking in recent years. Many dance training schools and dance companies are in the process of assessing their training methodologies. Attempts are being made to address the discrepancy between class, rehearsal and performance. For example, some schools and companies have Pilates and fitness training equipment available on the premises while others have introduced supplementary fitness training in order to improve dancers' physical fitness (Laws, 2005)⁹.

The monitoring of dancers physical fitness throughout the year, whether dancers are in training or are professional, should be the norm. The physical demands placed on dancers by current choreography indicate that the physiological development of the dancer is as important as skill development. Furthermore, the monitoring of aerobic

⁹ Laws cites Laban as an example of good practice with regards to its screening models in her publication, *Fit to Dance 2* (2005 p.77)

power would help to reduce the occurrence of fatigue orientated injuries (Koutedakis & Sharp, 1996). As the demands of choreography evolve, training regimens must be reviewed so that dancers are equipped to meet new physiological demands.

As noted previously, while the research submitted in this thesis focuses on cardiorespiratory fitness, it is important that any supplementary fitness training incorporates an appropriate balance of all components of physical fitness. Dancers do not only require good cardiorespiratory stamina and muscular power to cope with the demands of performance, they also require a wide joint range of motion for limb extensions, good balance for turning and good strength for lifting and weight bearing of others. Unless and until research indicates the specific effect of enhancing one component of physical fitness over another, it is important to ensure that the focus is not on one or two components only. For example, it should be appreciated that over-developing one energy system may be to the detriment of the other energy providing systems (Newsholme, 1983). The development of aerobic capacity must be a part of a comprehensive supplemental training programme that addresses all aspects of physical fitness including strength, power, flexibility and agility.

The concept of specificity developed in sports science acknowledges not only a need for activity specific testing but also activity specific training. In sport, exercise training programmes to enhance performance should be designed within an environment in which athletes are comfortable. Similarly, fitness training tailored to dance is required so that dancers can improve their cardiovascular capabilities for an optimal dance outcome.

5.4 Summary

In conclusion, the research explicated in this thesis has extended present knowledge and generated new knowledge associated with the value of dance specific fitness training and the effective monitoring of dancer fitness. It is postulated that fitter dancers are probably less likely to suffer from fatigue related injuries and will be able to sustain high intensity dance sequences for longer (Koutedakis & Sharp, 1999) and the research submitted in this thesis proposes ways of enhancing dancers' fitness.

The research in this thesis contributes to new knowledge in that it offers insight into the physiological demands of dance training and performance; it has assessed the role of supplementary fitness training in dance and examined new dance specific methods of testing and training dancers. What is not yet known is whether fitter dancers are better dancers. Without such data, it cannot be said with certainty that dancers who have higher cardiorespiratory fitness capabilities will be the dancers that an audience prefers to watch. Dance science is an emerging discipline, and until the determinants of good dance performance are scientifically established, dance educators are not able to determine with confidence what constitutes an ideal training methodology. It can be argued, however, that dancers who are fitter, healthier and less injured, will adhere to training more consistently, will have more stamina to endure and be able to focus on the qualitative and artistic aspects of their dancing, resulting in optimum performance.

Researchers investigating areas of dance science have been perplexed about the perceived lack of interest to incorporate new knowledge and understanding about the physiological demands of dance and subsequent new ideas about training (Krasnow,

2005). It is hoped that over time, a new generation of fitter and healthier dancers will demonstrate that artistry is not lost but rather enhanced through new or modified science informed training. Gill Clarke's keynote address summarises these points effectively:

"Perhaps with increased fitness, dancers could have been freed to enter the 'flow' or the 'zone' of the present moment, where the 'self' is so integrated that they would be almost unaware of their physical body or the concerted action of its parts. In this state the imagination can fly unfettered" (Appendix 8.1).

In 1990, Sharp said that "...dancers do not yet use the knowledge which sports and medical science generally could contribute to their art - this is something both sides should discuss" (Sharp, 1990: p18). The changes that have taken place within the last eighteen years witness a growing understanding amongst those responsible for training dance artists: the development of screening programmes; the growth of supplementary fitness training, and improved understanding of dancer health.

Immediately subsequent to the publication of the research explicated in this thesis, Dance UK produced its Dance Manifesto, developed in consultation with the UK dance sector. One of the four achievable ambitions identified in the Dance Manifesto is for dance to be a "sustainable and healthy profession" (Dance Manifesto 2007: p7). The Dance Manifesto also endorsed the view that dance schools and companies should be urged to "provide individual strength and fitness training programmes for all" and cites the dance science and health work operating at Laban as a model to follow (Dance UK Manifesto 2007: p10). There has been a clear and irreversible shift in thinking about the importance of issues of health and fitness in dance training, in part due to the research submitted in this thesis for the award of PhD.

6.0 Conclusion

This thesis introduced the potential for the application of dance science to dance training. It provided a brief account of key factors in the development of the contemporary dance genre to offer context for the discussion of current training methods and their ‘fitness for purpose;’ and justification for the research submitted in this thesis. The original impetus for the research and the research aims were presented, with subsequent introduction to each research study.

The physiological theory underpinning energy transfer and the various pathways in which energy is re-synthesised for biological work was introduced. Previous research that has measured the cardiorespiratory capabilities of dancers and the physiological characteristics of dance was reviewed. The need for dance specific methods of testing and training physical fitness in contemporary dance was proposed.

The six published papers constituting chapter three, have been critically appraised in chapter four. The relationship between each study and how the six studies address an overarching question about the appropriateness of today’s contemporary dance training has been considered and some recommendations proffered. Specific limitations of each study and of the studies collectively have been articulated with recommendations for where future research efforts might be focused. Application of the research from the educator and researcher’s perspective is suggested, and the significance of the work proposed, highlighting the contribution of this work in securing substantial private and public funding for postdoctoral research.

Finally, this thesis has explicated how the research generates new knowledge and advances understanding of dance physiology. A synopsis of the research identified salient points within a discussion of how such work is placed within the broader dance context. The conclusion refocuses the reader's attention to the issues confronting contemporary dance training methods and traces the trajectory of the author's ideas and the results that have informed the presentation of this thesis.

The ideas that have provided and will continue to give impetus to the development of the contemporary dance genre are concerned essentially with the dancer's relation with and expression of the self. This relation has changed over time as choreographers have articulated their own particular version of what dance and dancing is about in dancers' expression of their work. The notion of the dance artist – performer, collaborator, researcher - in the creation, realisation and performance of dance work, currently takes precedence.

Hence Foster's concept of 'The Hired Body' (1997) assumes a new and welcome significance in the continuing development of, and debates about the art form. It places even greater responsibility on dancers and those of us who train them to respect the preparation of 'this body for hire'.

Dance training must reflect this new dancer/choreographer relationship by providing a range of techniques and experiences and an environment that fosters the interrogation and development of the physiological body. Dance science, and more particularly the physiological perspectives articulated in this thesis have the potential to contribute to and enhance just this artistic endeavour.

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Clipped wings or soaring flight?

Keynote at Dance UK's Healthier Dancer Programme Conference
27 November 2006 at Laban, England

Optimising potential, maximising performance: Evaluating performance and health to ensure effective dance training. 27/11/06

The issues on today's agenda concern, on a very practical level, how we can best train and prepare our students to enter the profession – and remain healthy within it -, and how and when we best enrol the aid of scientific tools and tests both to enhance capacity and in the making of difficult artistic judgements.

I have been drawn over the last few years to how scientists and artists have written about their respective disciplines, about the interesting conjunctions as well as differences in world view between them.And why I have been drawn.....is because of a deepening sense of my moving self as a research laboratory where questions arise, where theoretical information is tested,.... at the same time as my reading around cognitive science and quantum physics makes me realise how scientists' ways of thinking are moving closer to those of dance artists.....

However

When I look at the timetable for the day I think I have probably been invited in some way to fly the flag for 'art' at the beginning of a day devoted to scientific contributions to dance practice....

I also feel a certain weight of responsibility as a keynote speaker to try and provoke, at least a little !!

So then perhaps my role is to be a devil's advocate: to don witches garb and pointing finger and warn that we must not allow science to infiltrate out precious art.

Keats wrote of scientists that they :

'veile their secrets with metric speech

+..

'will clip an angel's wings

conquer all mysteries by rule and line' !!!

Thankfully I feel we have moved beyond that mistrust and duality. (C P Snow famously spoke of the rift between the 'two cultures', of science and art but that was in 1959)

Or perhaps, now, the dangers are almost at the opposite extreme.....

... although as a public we do not have a great deal of knowledge of the detailed workings of science, yet we nevertheless bow to it (or more especially to the numbers and labels it produces). We look to it, rather unquestioningly, as arbiter, problem-solver, almost as the new religion.

I confess to being a Radio 4 news junky each morning. Hardly a day goes by without at least one survey result, one set of statistics to reassure us with its banner headline,

its false impression of certainty, its easy generalisations. As our world, (at least as portrayed by the media,) looks ever less certain and ever-more complex we seek simplification, solutions, guiding lights.

Since Descartes we have continued to consider what is rational and measurable as authoritative, and been rather dismissive of the qualitative and intuitive as ways of knowing.

So perhaps my question in relation to dance and today's agenda is:

How can we **harness** the powerful tools becoming available through dance science to **enhance** our **art** and to help our artists **sustain** healthy careers, and yet not be seduced, almost without even being conscious of it, into imagining that scientific data equates with an ultimate 'truth', that scientific intervention can take responsibility for the difficult human judgements we have to make as educators, or be relied upon to keep our body machine in good working order so that our mind and attention can be elsewhere.

If we were to over-simplify and identify some of the different and defining characteristics of Science and of Art we would probably identify some of the following opposites:

Science could be seen as -	objective
	Detached
	A third person view of experience

Art by contrast would be	subjective
	Engaged and immersed
	Offering a first person perspective

Science would be seen as concerned with	
	Fact
	The concrete
	With tying down and measuring

Whereas Art would be seen as dealing in	
	Fictions
	Abstractions and the intangible
	With opening up ideas
	and looking qualitatively at the world

Science would seek	simplification, answers and certainty
And aim to produce	explanations, predictions and generally applicable laws

Whereas Art	embraces complexity, uncertainty, ambiguity
	And elicits individual responses and experiences

(Graham Greene wrote : when we are not sure we are most alive)

Science is seen as rational and logical
 Accumulating data step by step

Whereas Art is intuitive
 And works through imagery whose impact might be
 immediate and total

But here I feel already on shaky ground. Of course the distinctions are not so clear cut. If we think of them perhaps as two modes of thought, then there are aspects of each that enter into scientific and artistic practices and methodologies. Scientists for example make intuitive leaps and artists engage in analytical scrutiny of their work.

Einstein wrote that the elements of his thought manifested themselves not in logical, rational ways, but in the 'combinatory play' of 'certain signs and more or less clear images....(which) are in my case of visual and some of muscular type....'

....that could well be a dance artist speaking !

And while we are with Einstein I should note that my list of oppositions drew on a very traditional, positivist view of science. As soon as one thinks rather of quantum physics and how that invites us to see the world – as in flux, complex, uncertain, relative - then science and movement art come much closer together in exciting ways.

But even at a more fundamental level there are many potential overlaps in the concerns of Science and Art - Both could be seen as attempts to make sense of the world, to explore the unknown, to ask questions, to experiment and find ways to communicate or translate their findings,yet whilst art is ultimately un-describable, untie-down-able, unexplainable in any medium other than itself, traditional science aims to find answers which translate into applications, predictions and explanations

P W Medawar wrote in *The Art of the Soluble* –

'Good Scientists study the most important problems that they think they can solve. It is, after all, in their professional business to solve problems, not merely to grapple with them.'

By contrast, there must be very many an artist who feels that they never get close to solving the problem, but are driven through each new work to keep grappling.

Perhaps then one way in which science and art differ is in how they go about their business, and the underlying beliefs about the world upon which they build their methodologies...

The scientific method developed during the Enlightenment to counter the prevailing religious orthodoxies and the power of superstition. It was an assertion by man (– yes we can assume it was men !) of his agency in the world - his ability to observe and fashion, control and improve his environment.....There was a belief in a progress engineered by man, rather than a future pre-ordained by God.

Such a scientific view saw the world as an objective reality, and developed an experimental method that could observe phenomena within it by setting up a controlled environment with limited variables. The aim was to produce replicable results, to offer explanations and make predictions about the future.....

When the scientific method was appropriated to study social contexts and lived human experience inevitably tensions arose: society is not predictable any more than human behaviour within it, and the variables and influences that come into play are many and complex. When controlled experimental conditions were abstracted from the real world to enable the isolation of certain variables, how could one be sure that these results would be replicable in, or applicable to, lived experience? And how value-free could the observations of a scientist be, who was him/herself situated : - a member of that same society she/he was studying?

Philosopher Mary Midgley writes

There is no way in which we can collect facts about any significant aspect of human life without looking at them from some particular angle. We have to guide our selection by means of some value judgements about what matters in it and what does not.'

Midgley (2004 p470)

We come to our observing with tacit assumptions drawn from our culture, our personal history, and from the paradigms of our own discipline. Facts cannot exist independent of our interpretation of them. We select the facts that we look for and choose to pay attention to.

Perception is not a passive receiving and processing of sensory information. It is a selective, proactive and embodied process – to a degree we see what we already know, we take our own history and memory to the act of looking....

We think of science as dealing in facts. Yet the root of the word fact means 'to make' – ie something that is constructed in some way. In other words it is not 'a thing' existing out there ready to be apprehended, nor something objective that we would all 'read' in exactly the same way.

Philosopher Mary Warnock suggests we should rather speak of the 'findings' of science with its implication of the active role of the researcher in the 'finding' process, and

Sociologist Steven Fuller writes of scientific findings as 'way stations on the path of inquiry' to be superseded if false or subsumed, if true, by the next traveller along the way.

(Is this so far away from how a choreographer might look at their latest work? – it feels like one's best solution for now, but throws up new questions which drive one forward to new propositions.)

So - A scientific perspective then is a particular view of the world, one way of looking at things, one way of telling a story. It can enable us, as dance educators, to abstract

an aspect of a problem, zoom in on it, collect data, attempt to explain it in certain terms. Then it is our job to add this new knowledge back to our consideration and understanding of the bigger, more complex picture.

Poet William Carlos Williams writes:

'It's hard to get the news from poems, but men die miserably every day for lack of what is found there'

so there are occasions on which we should look for scientific answers, times when we should read the news, and times we should turn to poetry !

Or poet Seamus Heaney wrote:

'The paradox of the arts is that they are all made up and yet they allow us to get at truths about who and what we are or might be.'

I apologise if that has all seemed a little abstract.

Let me turn to the business of today –

How might some of this apply to our teaching of dancers and preparation of future professionals ?

How might we embrace the scientific tools and knowledge available without losing sight of our artistic and human concerns and values?

I think I would begin from another question.

How can we, within our educational or professional practice, draw together or build bridges between the detached, third person view of science and the subjective, first person experience of the performer? The former can aid our ability to execute movement. However it is the latter, the intangible, that ultimately communicates to an audience, in contrast to the impression made on us by the measurable achievements of, say, an athlete.

To be very concrete for a moment:

I remember vividly teaching a student who was young and injury –free. She was told that she had a scoliosis and I proceeded then to watch her begin to embody, or enact her image of what this meant and the limitations it might impose on her movements. In other words the label became a self-fulfilling prophecy. At that point in time, and in relation to where she was in terms of her understanding of her own 'self' in movement, the only way she knew to assimilate that information was through artificially limiting her range of movement and the freedom she might allow herself.

I imagine a very different student.

Perhaps she is more mature and has suffered an injury.

Through sensation and the referred pain she is experiencing her body/mind begins to pose its own questions, for example about her overall use and functioning. She senses very directly the interrelationship of various parts of her body. In such a state she might be quite open to the information, for example that she has a scoliosis which is

causing an overall imbalance, even though her primary pain is in the knee. As well as treating the immediate symptoms she might be able to harness this information (and her own proprioceptive experience) and begin an extended re-education of her overall movement patterning.

One key difference between these examples is that the second student's learning is prompted by her own sensation and experience, whereas the first student was told, was given a piece of 'factual' information.

Einstein wrote:

learning is experience. Everything else is just information...

Many of us may have experienced an acute injury and the process of recuperation and know how hugely learningful it can be. An injury is not an abstraction. Through pain and discomfort the body speaks to us clearly, subjectively, draws attention to itself in ways that it does not do during 'normal' functioning.

No - I am not advocating injury as a desirable learning strategy ! – just for an awareness of the power of 'experience'.

Sociologist Richard Sennett wrote of architecture students using computer aided design tools:

when you draw a site, when you put in the counter lines and the trees, it becomes ingrained in your mind. You come to know the site in a way that is not possible with the computer....you get to know a terrain by tracing and re-tracing it, not by letting the computer 're-generate' it for you.

(Corrosion of character p73)

In relation to the first person experience of our students we have become more sophisticated in our pedagogical psychology. We, ourselves, might have been taught dance very didactically, even been frightened of our teacher and their negative criticism, seeing them as the ultimate, objective judge of our progress.

Now we know so much more about, for example, the power of positive reinforcement, and self-confidence. We can begin to see our role as the facilitators of learning rather than, or over and above, the holders of knowledge and power. We have a sense of education as the drawing out of the potential of each individual, each student's encounter with the material, rather than focusing only, or primarily, on the acquisition and memorisation of content and vocabulary as ends in themselves. Such shifts are guided by, or run alongside shifts within the profession.

What is required of dancers has changed. Dancers of all kinds need to be open and adaptable, the diversity of influences on new work is growing continuously. There is no single movement vocabulary, or narrow set of skills, that we can teach them that will serve all their needs. They are unlikely to join a company for life or dance the work of only one choreographer, and they will almost certainly be called upon to be creative collaborators, devising and manipulating movement material.

So perhaps our role as teachers is less 'to teach' (with a sense of transmitting existing information and solutions) and rather to set up the experiences through which students

can learn, through which they can engage their whole 'selves' physical, mental, emotional in their dancing.

I envy the Germans who have two different words to describe the body: one word 'Körper' for the physical body, and another, 'Leib' – with a sense of lived/ experiencing body. I shall refer to this mindful, emotional, physical whole as the 'self'.

The importance of the engagement of 'self' in dance training is worth reiterating because it reflects the nature of our artform. Dancers are the medium through which our art speaks – even in reconstructions or existing repertoire they are the active agents of translation of the work into the here and now. They are the expressive tools, the meaning makers, as if the musical instrument as well as the player. They are not machines, nor athletes – although extraordinary virtuosity might be one of their means of expression. They are imaginative artists. What we see in performance is not their physical bodies, but their 'selves' – their imaginations and intentions and wills and desires in disciplined motion. If my attention as audience member, is drawn through the dancer's own focus, to their physical exertion per se, to its execution, the physical effort, then, unless this is the very content and idea of the work, I have been distracted, my experience is lessened....What I am drawn to is influenced by what the dancer is paying attention to, the decisions they are making moment by moment, the 'how' and not only the 'what' of their dancing. If they are focused on the physical execution, standing outside of their dancing to judge it – then this is what I will see – (and it does not interest me !!!)

How vital it is therefore that dancers' whole 'selves' are engaged throughout their training, and that any conceptual information is channelled through an imaginative, experiential process of assimilation so as to become embodied. In this way it becomes an embodied understanding that can be drawn on unconsciously as well as consciously to enhance control, choice and freedom in movement and to adapt and contribute to new and changing creative situations.

In relation to this contrast between experiencing and being told, I feel I have learnt a lot in terms of my own involvement in somatic approaches to dance. When this information was relatively new to me I was more precious about retaining the integrity of its particular discipline and information. I have gradually learnt more about how to deliver the information that I feel is important for particular students, in such a way that it is less dogmatic, more questioning able to be engaged with through mindful, embodied experience – so that they can discover if and how it makes sense to them. Once, and if, they can become their own feedback mechanism rather than relying on me to tell them, then the information is empowering rather than limiting, concrete and subjective, not abstract.....

To use another simple example if our students are given experiences that result in them becoming aware of their lack of stamina in dancing, and then the enhancement of their capacity once we have given them experiences that will increase their fitness then hopefully their whole self will grab hold of and be motivated by such information – it is no longer abstract.

This is not the place to describe in detail the laban undergraduate programme, but I think the way that we begin by engaging students in an experiential approach to their own dancing bodies empowers them as subjective, individual learners and helps them to be ready to assimilate both the future experience of the various techniques that they study and the early dance science interventions of screening and fitness work. (I'm sure there is much more we could do to bring these areas together.)

In the example I gave above of the dancer focused on the physical effort of their movement - perhaps lack of stamina was the distraction. Perhaps with increased fitness they could have been freed to enter the 'flow' or the 'zone' of the present moment, where the 'self' is so integrated that they would be almost unaware of their physical body or the concerted action of its parts. In this state the imagination can fly unfettered.....can seek and risk the unknown, rather than resting comfortably with the safety of the perfected and pre-known, pre-programmed execution of dance material.

What we seek from our dancers, what thrills us in performance is not the clipped wings Keats referred to but freedom and soaring flight.

If science – through its measurement and evaluation - can help us enhance our capacity – then it potentially opens up new opportunities for the art to fly.....

But I would argue that if this is to happen then we have to work together and recognise both science and art as valid ways of knowing – that the measurements of science are there as a tool, not to be relied upon unquestioningly, nor to lean on as a prop that restricts our imagination, but to support us in our artistic aspirations.

Jeanette Winterson wrote

'art has the knack of helping us to see what we would normally miss'

But maybe science also has this potential. A profile of the wonderful, popularising neurologist Oliver Sacks paid tribute to this ability:

'the world in his presence seems to enlarge in unexpected directions.'

That would be a great tribute to the impact of the meeting of dance and science.

Gill Clarke 24/11/06

Appendix 8.2



UNIVERSITY-OF
WOLVERHAMPTON

School of Sport, Performing Arts & Leisure
Dean: Professor Craig Mahoney BEd MA PhD

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11th May 2006

To whom it may concern

I can confirm that Emma Redding has made a considerable contribution to the field of dance science during the last 6 years and has established a body of work, which includes published papers and conference presentations. This contribution is substantive enough to warrant the consideration of the award of PhD by prior publication and that will also include an addition and substantial review paper.

Yours truly,

Yiannis Koutedakis
Professor in Applied Physiology



INVESTOR IN PEOPLE

Vice-Chancellor
Professor John Brooks BSc PhD DSc CEng CPhys FInstP

FACULTY OF HEALTH AND SCIENCES

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15th May 2006

To Whom It May Concern

EMMA REDDING: REGISTRATION FOR A PHD BY PRIOR PUBLICATION

Dear Sir/Madam

I am writing to you in support of Emma Redding's application to study towards a PhD by prior (or part) publication.

I have known Emma since 1998 and she has made an outstanding contribution to the field of dance science during the last 8 years and has established a body of work which includes published papers and conference presentations. I believe that the contribution is substantive enough to consider the award of a PhD by prior publication which might also include an additional substantial review paper. Emma has, despite the burden of setting up and running almost single handedly a very successful masters programme in dance science, been able to produce scientific work that stands up well in comparison to works within her field of interest.

I have had the privilege of working with Emma on several projects and she has proven to be a well organized, thorough researcher and would be the perfect candidate for such a path of study. If you should require any further evidence or support for her application please do not hesitate to contact me.

Yours sincerely

Dr Jeremy Shearman
Head of School
SCHOOL OF APPLIED SCIENCE

Appendix 8.3

17th September 2007

To whom it may concern,

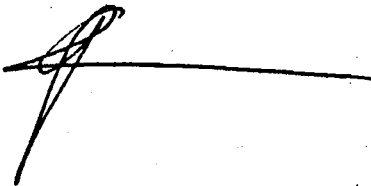
RE: Validity of using heart rate as a predictor of oxygen consumption in dance. Journal of Dance Medicine and Science, 8(3), 2004.

I am writing to confirm that Ms Emma Redding led the research study which culminated in the publication entitled 'Validity of using heart rate as a predictor of oxygen consumption in dance'. This paper was published in the Journal of Dance Medicine and Science.

I was co-author on this paper and can confirm that Ms Redding directed and managed the whole research process which includes developing the initial idea, research design and methodology through to data collecting, analysis and the writing of the manuscript.

If you would like any further clarification, please do not hesitate to contact me.

Yours truly,

A handwritten signature in black ink, consisting of a stylized 'J' and 'S' followed by a horizontal line.

Jeremy Shearman, PhD.

Dr. Matthew Wyon
The Cottage
Meadow Lane
Little Hayward
Stafford
ST18 0TT

20 January 2008

Confirmation of Emma Redding's contribution to collaborative research

To the Examiners

I would like to confirm that Emma Redding and I worked collaboratively on the following research papers:

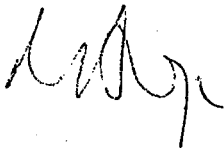
Wyon, M., Redding, E. (2005). Physiological monitoring of cardiorespiratory adaptations during rehearsal and performance of contemporary dance. *Journal of Strength and Conditioning Research*. 19(3).

In this paper, Ms Redding was involved in the recruitment and data collection of the participants and was also involved in review and preparation of the manuscript for publication.

Wyon, M., Redding, E., Abt, G., Head, A. & Sharp, C. (2003). Development, reliability and validity of a multi-stage dance specific fitness test (DAFT). *Journal of Dance Medicine and Science*. 7(3).

In this paper, Ms Redding choreographed and developed the movement material for the test and was involved in recruitment and training of the dancers for the reliability and validity aspects of the study. Ms Redding was also involved in review and preparation of the manuscript for publication.

Sincerely,



Dr. Matthew Wyon

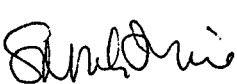
14 January 2009

RE: The development of a high intensity dance performance fitness test.

This is to confirm that Ms Emma Redding led this investigation with a team of research collaborators. She initiated the research and was fully involved from concept to manuscript. The paper is accepted for publication by the Journal of Dance Medicine and Science volume 13, number 1, 2009.

Ms Redding developed the research aims, rationale, and design and managed the data collection process and data analysis. Ms Redding also prepared the manuscript for publication with contributions for co-authors.

Thank you



Sarah Irvine



Edel Quin

11th September 2007

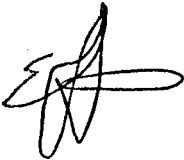
To whom it may concern,

RE: When Art Meets Science: An Action Research Approach to Improving Professional Dance Teaching and Learning Using Scientific Methods.

I am writing to confirm that Ms Emma Redding was a co-author on the paper entitled 'When Art Meets Science: An Action Research Approach to Improving Professional Dance Teaching and Learning Using Scientific Methods'. This work was published in the International Journal of Learning".

Ms Redding contributed substantially to the research process (including the development of the rationale and research aims, research design, data collection and data analysis). She also made a substantial contribution to the writing and preparation of the paper for publication. If you would like any further clarification, please do not hesitate to contact me.

Yours truly,



Eleanor Quested

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ejq665@bham.ac.uk
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24 March 2008

To whom it may concern,

RE: The effect of a one year dance specific fitness training programme on undergraduate modern dance students; An experimental study.

This is to confirm that Ms Emma Redding was co-author on the paper entitled, *The effect of a one year dance specific fitness training programme on undergraduate modern dance students; An experimental study*. This paper was presented at the International Association of Dance Medicine and Science (IADMS) 16th Annual Meeting in West Palm Beach, Florida, USA and also published as an Abstract in Abstract published in *Journal of Dance Medicine and Science* (2007) 11(1).

Ms Redding contributed substantially to the research process. She contributed to the development of the research aims, rationale, and design and she was involved in the data collection and analysis. I can confirm that Ms Redding also made a significant contribution to the writing of the paper and co-presented it at the International Association of Dance Medicine and Science 16th Annual Meeting.

Thank you

Sonia Rafferty

Appendix 8.4

Emma Redding
Laban
Creekside
London
SE8 3DZ

To whom it may concern

In support of Emma Redding's PhD candidacy

Emma Redding has been instrumental in furthering the field of Dance Science in the UK and indeed internationally. She was a driving force behind setting up the first Masters Degree in Dance Science (at Laban) and since its inception in 2001 has supervised a growing pool of extremely capable dance scientists who are now finding work in colleges, universities and working with dance companies throughout the UK and abroad.

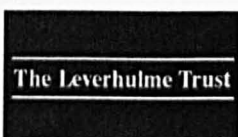
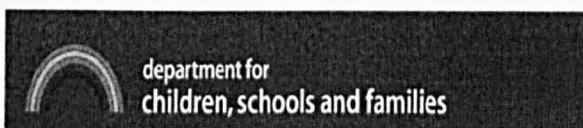
Her own research, some of which is submitted for PhD by publication, has significantly added to our understanding of the physiological aspects of dance performance and of the value of dance specific fitness testing. She has been one of a small but significant number of pioneers dedicated to developing and exploring the use of screening / profiling measures in dance, which are essential if we are to improve our knowledge of factors relating to talent identification and development and the prevention and treatment of dance injuries.

Emma has been a valuable member of Dance UK's advisory groups for the last 8 years, ensuring that the work she is undertaking is always of benefit to and shared with the dance profession at large.

Yours Faithfully



Helen Laws
Healthier Dancer Programme Manager



The Leverhulme Trust Award Grant for Ground-Breaking Dance Science Research at Laban

The Leverhulme Trust has awarded a £183, 917 research project grant to help fund a ground-breaking three year longitudinal dance science project at Laban, the internationally renowned centre for contemporary dance training. The study will use scientific methods to examine the processes of identifying and developing talent in dancers aged 11-18 years.

The innovative project, entitled 'The identification and development of contemporary dance talent in young people: An interdisciplinary longitudinal research project' will study approximately 300 young people training at the six government funded Centres for Advanced Training (CATs) in dance around the country. The CATs are a recent initiative funded and developed by the Department for Children, Schools and Families' Music and Dance Scheme to identify and nurture exceptionally talented young dancers.

The research is interdisciplinary, measuring the physiological, biomechanical and psychological characteristics of talent in dance and exploring the factors that may contribute to its optimal development. Qualitative interview-based research will also explore how these factors relate to creativity.

The research questions were developed in consultation with the six national dance CATs of which Laban is one. Research will be carried out with the full cohort of CAT dance students nationally, providing a unique opportunity to combine the dance science knowledge and expertise of the Laban team with the 'on the ground' dance experience and understanding provided by the CATs. The project's findings will contribute to the development of the CAT programme, ensuring that the dance training scheme is

continually enhanced and informed. The findings will also inform pedagogic practice with young people across the wider sphere of dance education.

This is the first time a study has examined young contemporary dancers in depth from a scientific perspective or in a longitudinal fashion. Never before have dancers of any age or dance genre been studied in an interdisciplinary project that measures the characteristics of dance talent and their interrelationships and potential links to performance and creativity. It is also the first time an organization has been in the position to follow a population of young people already identified as talented across a period of three years, thus enabling the notion of talent to be studied in depth.

The project has been made possible by the very significant support of the Department for Children, Schools and Families (DCSF) both through the initiation and sustaining of the CAT programme and considerable provision towards the core costs of this research.

Principal investigator and Laban's MSc Dance Science Programme Leader Emma Redding: "A research project such as this has never before been undertaken. This grant will allow Laban, in collaboration with the other Centres for Advanced Training, to scientifically investigate contemporary dance talent development in young people. I hope that the findings will inform and enhance dance teaching practices, helping to provide the country's talented young dancers with world-class training opportunities".

Anthony Bowne, Director of Laban: "We are very grateful to both The Leverhulme Trust and the DCSF for enabling this innovative research. The project is in a strong position to advance knowledge within the areas of physiology and psychology for young talented dancers, looking at issues such as physical fitness, growth and injury. We hope the findings will contribute to the physical and psychological well-being of young dancers in the UK, providing them with the chance to flourish."

Tony Hall, Chief Executive of the Royal Opera House: "Dance training tends to be based on tradition and personal experience rather than scientific fact. I highlighted the need for quantitative research into the impact of dance training on children and young people in the recently published *Dance Review*, commissioned by the Department of Culture,

Media and Sport. I am extremely excited about this new research project and its potential impact for developing excellence in dance training for young people."

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For more information, images or to speak to Emma Redding or Anthony Bowne, please contact Miranda Harris. Public Relations and Communications Manager.

Editors Notes

Centres for Advanced Training

Dance CATs in England: Dance City Academy, Newcastle upon Tyne; Dance East Academy, Ipswich, Suffolk (pilot year 2007/08); Laban, SE London; London Contemporary Dance School at The Place, London; Swindon Dance Academy, Swindon, Wiltshire; Yorkshire Young Dancers (in partnership with Northern Ballet Theatre and Northern School of Contemporary Dance in Leeds). Further details on the Music and Dance Scheme and Centres for Advanced Training can be found at www.dcsf.gov.uk/mds

Laban

Laban is an internationally renowned conservatoire for professional contemporary dance training, at the forefront of developing undergraduate, postgraduate and professional level courses. Based in an awe-inspiring landmark building in state-of-the-art facilities include 13 dance studios, a health suite, café and 300-seat purpose built theatre.

Trinity Laban Conservatoire of Music and Dance

In 2005 Laban merged with leading music college Trinity College of Music to become Trinity Laban Conservatoire of Music and Dance.

Dance Science

Dance Science is a relatively new but fast growing area of research and study. By recognising the dancer as an athlete and investigating the dancer from physiological, biomechanical and psychological perspectives, the aim of dance science is to enhance dance training practices and optimise the dancer's potential as an elite performer.

The Leverhulme Trust

The Leverhulme Trust is one of the largest all subjects providers of research funding in the UK, distributing funds of some £40 million every year. For further information about all of the schemes that the Leverhulme Trust fund please visit their website



Trinity Laban Receives Leverhulme Trust Award for the First Music and Dance Collaborative Screening and Profiling Project

Trinity Laban Conservatoire of Music and Dance has received a £54,109 grant from the Leverhulme Trust for a groundbreaking study entitled *Music & Dance Science: Optimizing Performance Potential via an interdisciplinary music and dance screening and profiling programme*.

Research has found that injuries among performing artists are more frequent compared to other professions that use the human body, such as sport. A recent survey of dancers in the UK found that 80% of the dance population incurred an injury inhibiting performance within a 12 month time-span¹. Musicians' playing-related injury rates can be as high as 70% of a population². However, there have been comparatively few longitudinal studies investigating the causes of performance related injuries in dance, and fewer still in music.

The project aims to find ways of optimizing music and dance performance through an advanced screening and profiling programme, assessing biomechanical, physiological, and psychological aspects of approximately 180 vocational music and dance students during their training at Trinity Laban over a two year period. The results will be used to assess the effects of particular training regimes, to develop better education and training techniques, and to thereby contribute to the health of professional dancers and musicians.

Learning and teaching methods in dance and music have typically evolved from tradition

¹ Laws, 2005

² Spahn, Strukely, Lehmann, 2004

and personal experience rather than scientific principles, and within music training, health provision is more treatment-focused than preventative. Laban was one of the first dance training institutions to pilot comprehensive screening within its undergraduate programme and is now perceived as a leader in this field. The recently merged Trinity Laban, which incorporates Laban and Trinity College of Music, is in the ideal position to further develop the dance science model and adapt it for the benefit of musicians also.

Principal Investigator Emma Redding says: "This research is truly ground-breaking. It is the first time vocational music and dance training will be studied in this way from a scientific perspective within a longitudinal study. It's the first interdisciplinary project to investigate the physiological, biomechanical, and psychological aspects of training and performance - their interrelationships and potential links to improvements in vocational training and optimisation of performance of the 'whole' musician and 'whole' dancer. It's also the first time an organization has been in the position to collaborate with music *and* dance with a vocational student population of exceptional calibre, thus enabling interdisciplinary investigation of music and dance talent development at the elite level."

Derek Aviss, Joint Principal of Trinity Laban and Principal of Trinity College of Music comments: "Even less attention has been given to the causes of performance related injuries in music than in dance. This may in part be because musicians' injuries can be very specific, seem small-scale to the non-musician and are sometimes open to mis-diagnosis and vary considerably with instrument. Research also suggests that both professional and student musicians are reluctant to disclose injury³ in case it is perceived as a sign of weakness. Added to this, such is the competitive nature of the music and dance profession that musicians and dancers will often try to conceal injury, or continue playing or dancing in spite of it, thereby exacerbating the situation. Thanks to the generosity of The Leverhulme Trust we are in the position to help address these issues and contribute to the development of health-aware training which will benefit dancers and musicians both physically and psychologically."

Anthony Bowne, Joint Principal of Trinity Laban and Director of Laban says: "The time has come to surmount traditional academic boundaries in music and dance training. Trinity Laban's mission is to promote internationally the highest quality of

³ e.g. Williamon & Thompson, 2006

professionalism through the provision of specialist education reflecting the increasingly collaborative world of artistic practice, dedicated to the career development of students and professional performing artists. This project will contribute to the development of effective music and dance training in the UK and consequently a physically and psychologically healthier work force of professional musicians and dancers."

The Leverhulme Trust has also granted £48,000 over three years to provide student bursaries to young people with exceptional talent and potential in dance to study on Laban's Centre of Advanced Training (CAT) scheme. The innovative scheme, which offers young people the opportunity to access high quality dance training, is part of a national programme funded and developed by the Department for Children, Schools and Families' Music and Dance Scheme.

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Editors Notes

For more information, images or to speak to Emma Redding, Derek Aviss or Anthony Bowne, please contact Miranda Harris, Public Relations and Communications Manager, Trinity Laban Conservatoire of Music and Dance, 020 8469 9549, mharris@trinitylaban.ac.uk

Trinity Laban Conservatoire of Music and Dance

In 2005 Trinity College of Music and Laban, leading centres of music and contemporary dance, came together to form Trinity Laban Conservatoire of Music and Dance. Trinity Laban was ranked first in both music and dance in the Guardian Higher Education/University League Tables 2008. For more information please see www.trinitylaban.ac.uk

Laban

Laban is an internationally renowned conservatoire for professional contemporary dance training, at the forefront of developing undergraduate and postgraduate programmes, as well as a range of continuing professional development opportunities. Laban has a strong programme of work in the community, across London and nationwide in partnership with dance organisations, agencies and professional dance companies. Based in an awe-inspiring landmark building in Deptford Creekside, SE8, state-of-the-art facilities include 13 dance studios, a health suite, café and 300-seat purpose built theatre. For more information please see www.laban.org

Trinity College of Music

Located in the beautiful Wren designed King Charles Court at the Old Royal Naval College in Greenwich, Trinity College of Music is one of the UK's leading centres for the training of professional musicians. It is a creative and cosmopolitan community of

performers, composers, teachers and researchers. The College runs a vibrant programme of performances and festivals as well as groundbreaking education, community and social-inclusion schemes. For more information please see www.tcm.ac.uk

Dance and Music Science

Dance Science is a developing area of research and study and Music Science is a relatively new field with its recent focus primarily being on performance psychology rather than biomechanics and physiology. By recognising dancers and musicians as athletes as well as artists and investigating the physiological, biomechanical and psychological characteristics underlying training and performance, the aim of dance and music science is to enhance pedagogic practices and optimise the potential of every elite performer.

The Leverhulme Trust

The Leverhulme Trust is one of the largest all subjects providers of research funding in the UK, distributing funds of some £40 million every year. For further information about all of the schemes that the Leverhulme Trust fund please visit their website at www.leverhulme.ac.uk