Strengths and Weaknesses of Current Methods for Evaluating the Aerobic Power of Dancers

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Abstract

The methods of measuring aerobic power in dance is reviewed. The underlying metabolic pathways used during dance class and performance are examined and, in conclusion, dance has been classified as an intermittent form of exercise. The relevancy of measuring maximal oxygen uptake (VO_2max) in relation to intermittent exercise is discussed with regard to other sports. Previous dance VO_2max data is examined in relationship to other exercise forms and it is shown to be comparable to results in other non-endurance sports. The limitations of graded exercise tests with regards to extrapolating oxygen data from heart rates during dance has been highlighted as a flaw in a number of previous research studies and a limitation to be aware of in future research. Due to the infancy of dance science, the availability of valid and reliable laboratory and field tests are limited and, therefore, until further research is done, there needs to be a reliance on tests developed in the health and sport environments. Such tests should be graded, either in speed or gradient, with stages of at least 3 minutes and be weight-bearing. Even though no research to date has shown that dancers with improved VO_2max perform better, the review suggests that both the aerobic and anaerobic systems need to be stressed to a greater extent than seen presently within dance class.

An understanding of the energy requirements of dance and of the physiological status of dancers can help in the development of more effective and appropriate tests and training programs. However, because of the transitory and intermittent work output of dance, it has been difficult to accurately measure these parameters within a dance-specific setting.[1,2] Moreover, the physiological classification of dance has proven to be an area of contention mainly due to the fact that dancers see themselves as artists and not athletes and that physiological training is only a symptom of a primary requirement, the search for the aesthetic.[3] The importance of aerobic power as an aspect of dance training and the positive adaptations to dance performance could be made more explicit to the dance teacher. This might then in turn, enhance attitudes toward dance science research and the importance of testing dancers and dance movements so that more effective and appropriate training programs can be prescribed.

The following article will review the methods and results of previous research studies that have measured the aerobic power of dancers and the physiological characteristics of dance, discuss the challenge of testing dancers and dance itself, and offer suggestions of where future research efforts might be aimed. The importance and relevance of measuring the aerobic power of dancers will also be addressed.

As the demands of the choreography increase, many believe that there is a need to train dancers to be more able to cope with the new demands. Rist[4] noted that in ballet there seemed to be a marked difference between the demands of class (which have remained the same for decades) and performance, both physiologically and in the diversity of the skills required. Adaptability is a prerequisite for the modern dancer to cope with the different physical and technical demands of different choreographers. However, often rehearsal periods are short and do not allow enough time for the physiological adaptation to take place that would enable the dancer to cope with the increased demands of performance. It might be argued, therefore, that the class may need to be adapted to cope with the increased demands or that additional or supplementary training be included in the dancer's routine.

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Table 1 Summary of VO_2 and Heart Rate Data from Previous Studies

Study	Sex	Style	ml·kg^{-1}·min^{-1}	b·min^{-1}
Cohen et al.[33]	M	Ballet (barre)	18.48	134
	F	Ballet (barre)	16.49	117
	M	Ballet (center)	26.32	153
	F	Ballet (center)	20.0	137
Cohen et al.[6]		Ballet (performance)		184 (peak)
		Ballet (performance)		169 (mean)
Schantz and Astrand[1]	M	Ballet (barre)	20.1*	
		Ballet (center)	26.7*	
	F	Ballet (barre)	18.4*	
		Ballet (center)	23.5*	
	M	Ballet (performance)	48.5*	
	F	Ballet (performance)	43.4*	

*Calculated from percent of VO_2max data.

It is only through careful examination of the physiological demands of performance that the ideal physiological characteristics that dancers require can be determined. Direct measurement of the physiological cost of dance has until now proven difficult due to the limitations of apparatus available to researchers. Schantz and Astrand[1] used Douglas bags as the main method of gas analysis, but noted problems with potential movement restriction caused by the device as well as the fact that the data provided were only a mean value of the workload. Other studies[5-7] used heart rate monitors via telemetry, which overcame the problem of movement restriction but did not take into account potential variations in the heart rate-oxygen relationship between dance and steady-state exercise.

The data presented in Table 1 must be examined carefully as it does not represent the mean oxygen consumption (VO_2) for the whole of class or performance but rather sections of them. Recent research on modern dance[2] noted lower mean values for both class and performance but also noted that peak requirements for both male and female dancers reached quite high values (60 to 65 ml·kg^{-1}·min^{-1}). As dance is intermittent in nature and often coupled with intense periods of exertion for short periods of time, it might be that the dancer does not need to develop aerobic power to match the energy levels required during performance and can rely on anaerobic energy production to meet the excess demands. In fact, aerobic energy production might be too slow to meet the muscles' demands for energy during these intense periods.[8]

Aerobic Power

Aerobic power, sometimes referred to as cardiorespiratory endurance, relates to the extent to which energy can be derived from the oxidative (aerobic) energy system in the execution of movement. Generally speaking, a person with a good aerobic power can execute movement aerobically at a higher intensity. Aerobic power (VO_2max) is the product of maximal cardiac output and arterial-venous oxygen difference. Within normal populations the difference in VO_2max is primarily due to the differences in cardiac output[9]; in elite endurance trained populations the limitations are mainly seen peripherally within the muscle cell.[10,11]

High-intensity, intermittent exercise uses all three energy systems (ATP-CP, glycolysis, and aerobic) to varying degrees depending on the intensity and duration of the dance period. The energy system is a continuum from high-energy phosphates supplying the energy at one end (very short duration) to energy being provided aerobically (prolonged duration) at the other. The rate of demand for energy by muscle cells will determine the energy system that dominates. Except for high intensity exercise lasting less than 30 seconds, most exercise periods employ both energy systems to varying degrees. Hill[12] examined the contributions of the different energy systems during a 30-second maximal exercise period and noted that over the entire period the aerobic contribution was 16%, the glycolytic was 56%, and the ATP-CP was 28%. As the exercise period increases, the percentage of energy derived from anaerobic metabolism decreases while the use of the aerobic system increases. At two minutes of maximal exercise, the ratio between aerobic and anaerobic energy production is 50:50[13] and even after 70 seconds of intensive exercise the aerobic system contributes 47% of the energy.[14] During steady-state maximal exercise lasting more than 4 minutes, the aerobic system dominates in the provision of energy. During high intensity maximal exercise the aerobic system cannot generate energy fast enough and the anaerobic system makes up the energy deficit. In this case the energy demand is greater than the maximal oxygen uptake (referred to as "supramaximal").

Recovery of each system is dependent upon the speed at which it can reach homeostasis after being depleted. Pascoe[15] noted that 70% of phosphagen restoration occurred in 30 seconds and full restoration took 3 to 5 minutes. Factors that can influence creatine phosphate (CP) restoration are the concentrations of adenine triphosphate (ATP), adenine diphosphate (ADP), and creatine (Cr) within the cell.

Full restoration of glycogen can be a long process and is dependent on the type of work that was undertaken. The rate of glycogen resynthesis after prolonged work is much slower than that observed after high intensity, short duration exercise.[16] The reason that the glycogen resynthesis rate is faster after short-term, high-intensity work is unclear. After high-intensity short-duration work, the blood glucose concentration is higher than after prolonged exercise, and this may be an important substrate for the differences in resynthe-

Table 2 Summary Previous Research on the Maximal Aerobic Uptake of Dancers and Sportspeople

Study	Sex	Style	$ml \cdot kg^{-1} \cdot min^{-1}$
Novak et al.[34]	Female	Ballet	41.0 ± 6.7
Cohen et al.[33]	Male	Ballet	48.2
	Female	Ballet	43.73
Mostardi et al.[35]	Females	Ballet	48.6
	Males	Ballet	59.3
Schantz and Astrand[1]	Male	Ballet	57.0
	Female	Ballet	51.0
Chemlar et al.[36]	Female	Ballet	42.2
	Female	Modern	49.1
Chatfield et al.[37]	Female	Modern	43.6
Rimmer et al.[5]	Male	Ballet	50.5
	Female	Ballet	44.5
Brinson and Dick[31]	Male	Modern	55.7
	Female	Modern	43.5
	Male	Ballet	53.2
	Female	Ballet	39.1
Koutedakis and Sharp[38]	Males	Untrained	42.0
	Females	Untrained	38.0
Neumann[39]	Males	Figure Skating	50.0 - 55.0
	Females	Figure Skating	45.0 - 50.0
	Males	Gymnastics	45.0 - 50.0
	Females	Gymnastics	40.0 - 45.0
Alexander[40]	Females	Gymnasts	50.3
Chin et al.[41]	Males	Squash	61.7
Jensson and Larsson[42]	Females	Football	57.6
Kouidi et al.[43]	Males	Football	55.7
	Males	Handball	51.1
Heller et al.[44]	Males	Football	60.1
Ueno et al.[45]	Males	Rugby	54.8

sis.[15] Generally during high-intensity work the fast twitch (Type II) fibers are recruited. These have a faster glycolytic ability than Type I fibers, and for this reason it has been suggested that there is a greater breakdown of glycogen in these fibers during high-intensity work.[17] Due to these fibers having greater glycogen synthase activity ability, two studies have reported greater glycogen resynthesis in Type II fibers than Type I.[17]

Much of dance physiology research has looked at the physiological status of dancers (their fitness levels), but few studies have attempted to measure the physiological characteristics of dance itself and the energy systems required during dance. There seems to be a difference between the intensity at which dance training (class) and dance performance are conducted. Understanding the differences is valuable in prescribing appropriate training to dancers.

Dancers' cardiorespiratory parameters (VO_2max and heart rate) reach near maximal levels during performance and center work during class. The work-to-rest ratio of these sections indicates short periods of high intensity followed by longer rest periods, however the work periods are seen to be longer during performance than in the dance class. Class offers little stimulant cardiovascular stress (within the ACSM's guidelines of between 70% to 95% of maximum heart rate[9]) with the longer periods of continuous dance; the barre work, for example is at too low an intensity to stimulate cardiovascular adaptation. In theory, the greater the dancer's aerobic power, the larger the contribution of the aerobic system in the provision of energy at any given workload. This obviously reduces the percentage contribution of the anaerobic system at high intensity work and allows the dancer to work for a longer period at this intensity before fatigue sets in. If the aerobic system is over developed within a muscle, then the muscle's ability to produce energy fast enough for supramaximal periods of exercise is diminished because the development of the anaerobic pathways have been neglected. This has been noted through the reduced levels of the enzymes creatine kinase and myokinase (these enzymes are involved with the breakdown of CP to regenerate ATP from ADP), and a decreased ability to work at low pH. Aerobic work also promotes the use and development of slow twitch (ST) muscle fibers and the increased ability of fast twitch (FT) fibers to generate energy aerobically (FTb fibers adapting to Fta). This decreased stress utilization of FTb fibers will limit power production resulting in, for example, potentially lower jumps. Whether increased aerobic power is beneficial to dance performance, and therefore dancers, has not been researched and it is not for this review to draw conclusions, but a suggestion would be an aerobic power similar to other non-endurance sports (Table 2).

There are many positive adaptations to regular aerobic endurance training.[18] The benefits that are of particular interest to the dancer might include decreased recovery time between movement sequences, increased anaerobic threshold and delayed onset of blood lactate as well as the ability to carry out the same dance sequence at a lower heart rate so as to allow concentration on the more artistic aspects of the performance.

Assessing Aerobic Power

In sport and exercise science, aerobic power is tested using submaximal or maximal graded exercise tests (GXT). Submaximal tests have the ability to *estimate* maximal aerobic power without having to exercise maximally and are often used within the health industry. The degree of error within the estimation varies between tests, even in steady state exercise where the heart rate and oxygen consumption (HR - VO_2) relationship is strong the stan-

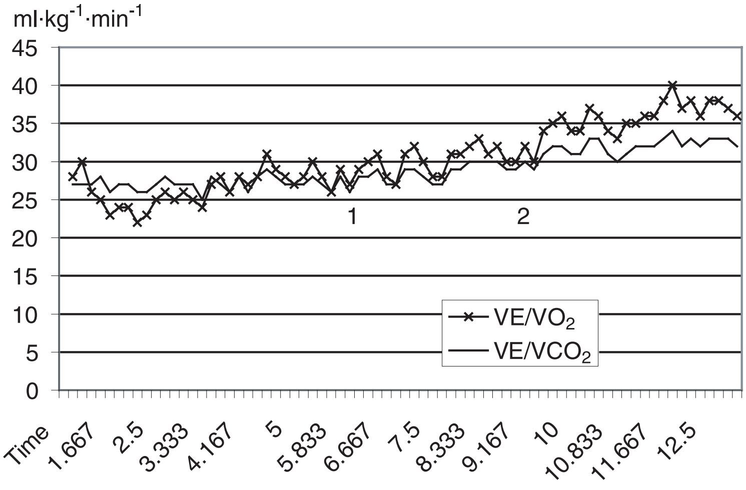

Figure 1 Estimation of the upper and lower aerobic training zones; 1 = Lower aerobic zone 2 = Upper aerobic zone.[20]

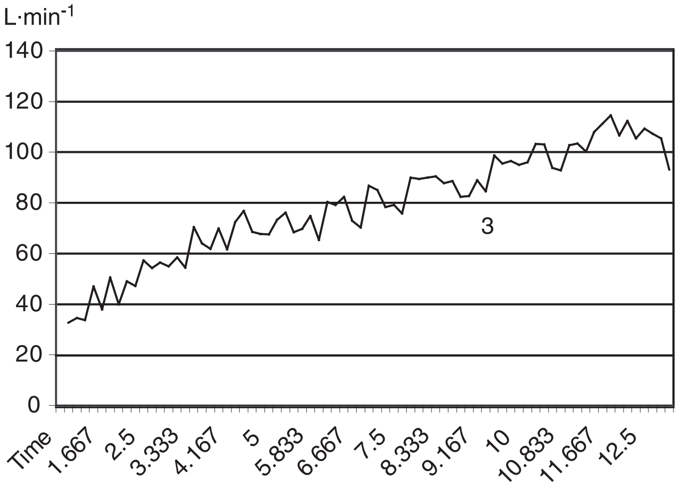

Figure 2 Ventilatory threshold; 3 = Ventilatory threshold.[20]

dard error of estimation can be up to 10%.[19] Either test includes a multistage protocol, which can be either continuous or discontinuous and requires each stage to last for at least 3 minutes so that steady state is reached.[20] Oxygen uptake (VO_2) is measured as an indicator of aerobic power and VO_2 peak, either submaximally or maximally, is recorded. Other parameters, calculated from the gas data, are upper and lower aerobic training zones and ventilatory threshold (Figs. 1 and 2). The upper and lower aerobic zones are calculated by plotting the ventilation equivalents for oxygen (VE/VO_2) and carbon dioxide (VE/VCO_2) against time. When VE/VO_2 rises and VE/VCO_2 remains constant this is considered to be the lower end of the aerobic training zone (Fig. 1, position 1). When both these variables start to rise the upper end of the aerobic training zone is considered to have been reached (Fig. 1, position 2) and corresponds to the ventilatory threshold (Fig. 2, position 3) These are important in the provision of training information for the athlete.[20] Ergometer treadmills and ergometer stationary cycles are commonly used in these tests. Measurements can be taken directly via on line equipment such as Douglas bags and metabolic carts or other tests that have been devised whereby VO_2 max values are estimated using formulas to convert a given work output during a GXT to VO_2. Field tests have also been created that use prediction equations to estimate VO_2 from "performance" predictor, heart rate, and physiological or demographic variables. Conversion formulas and prediction equations are not direct measurements of VO_2 and, therefore, have greater potential for containing prediction errors,[40] however such tests can be more activity specific and perhaps in a sense, therefore, more valid.

Most physiological measurements taken from sports are done within standardized conditions in laboratory settings and not in the field. This is to ensure that they remain valid, reliable, and objective. However, the specificity of such tests is often questioned and the debate between laboratory and field-testing is on going. While laboratory tests are more likely to yield accurate results, they may be less relevant to actual performance conditions. And while field tests are more relevant and specific, the measurements obtained are potentially less accurate. The use of cycle ergometry as a means of testing could be inappropriate for dancers given that it is not weight-bearing and that the muscles used and the percentage of muscles working are different than those seen within dance. This suggests that aerobic power does not always have the ability to indicate performance capabilities and that sport-specific tests are developed to increase validity. For instance, a runner carrying out a VO_2max test on a cycle ergometer and treadmill could have a variance in their maximal scores of between 5% to 10%. Though there is little research that has questioned whether dance performance and aerobic power are significantly correlated, research on other intermittent sports has noted strong correlations.[22] The relationship will depend on work:rest ratios and work intensity however. Bangsbo's[22] study for example, is based on soccer that has work intensities and work to rest ratios greater than that seen in dance.[1,2]

The relationship between heart rate and oxygen consumption is lin-

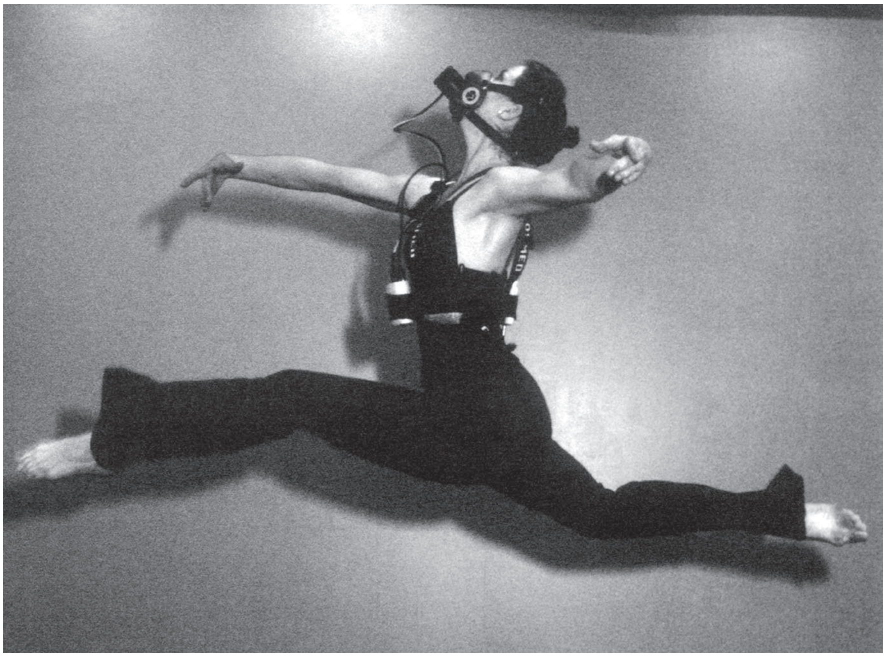

Figure 3 Dancer wearing portable gas analyzer.

ear in steady state exercise[18] and a number of studies have assumed that the HR/VO_2 relationship established during a treadmill or cycle ergometer test was the same as in dance. Dance sequences can consist of fast, jerky movements, off-balance turns, twists, and falls to the floor as well as use props and other dancers. Movement patterns within dance can be very 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. 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. Sports characterized by cyclic and constant work rates are more likely to show a greater correlation.[21]

Redding and colleagues[23] assessed the validity of estimating VO_2 in dance from the HR/VO_2 relationship established from an incremental treadmill test. Nineteen elite modern dancers were measured during their daily dance class (90 min) and during an incremental treadmill test using a telemetric breath-by-breath gas analyser. The use of a paired t-test showed that there was no significant difference between the dance and treadmill scores, however, it also showed a large variability (highlighted by the standard deviation). Although mean difference is important, consideration must be given to the variation between individual scores. The use of limits of agreement[24] takes into consideration both the mean differences and the variability. Results indicate that there could be a variation of up to 31 $b \cdot min^{-1}$ at 10 $ml \cdot kg^{-1} \cdot min^{-1}$ and 49 $b \cdot min^{-1}$ at 60 $ml \cdot kg^{-1} \cdot min^{-1}$ between the dance class and treadmill scores. Results also suggest that an individual with a heart rate of 200 $b \cdot min^{-1}$ could have values between 151 and 249 $b \cdot min^{-1}$ the next time around ($p = 0.95$) and that the difference would be purely due to measurement error. Measurement error is the differences that can occur due to the amount of error in the estimate. In the case of HR/VO_2 relationships, the stronger the correlation between the two variables the smaller the amount of error within the estimate there is. During steady state exercise there is a strong relationship between HR/VO_2 ($r = 0.94$ to 0.98)[25] and even then the measurement error of estimation of oxygen consumption from heart rate values is in the region of 15%. In dance exercise, and other types of intermittent exercise, the relationship between heart rate and oxygen consumption is weaker ($r = 0.68$ to 0.88)[23] and, therefore, the measurement error of estimation is increased, thus making it more difficult to estimate oxygen demands from heart rate values with accuracy. The difference between the HR/VO_2 relationship during dance and an incremental treadmill test is significant. Researchers have suggested that the use of individual HR/VO_2 relationships is required to reduce the measurement error rather than group-wise data.

The development of more specific and precise methods of evaluating highly specific sport activities has been of interest to many sport scientists. This has lead to the development of specific ergometers like kayak ergometers and swimming flumes as well as the invention of highly sophisticated data collection equipment for field environments, like the miniaturized low weight telemetric gas analyzers such as the K4b2 (Cosmed, Italy) and 3b Ultra (Cortex-Medical, Germany) that record not only heart rate, ventilation, and oxygen intake, but also carbon dioxide production (Fig. 3). Given that dance is by nature not a steady-state form of exercise[2,5,26] 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. Any newly devised activity-specific test should consider the following parameters: the type of sport, spatial position of the athletes body, the frequency of movements used, the duration of testing in order to simulate the energy sources used by the athlete in performance, and the kinds of stress and environmental conditions the athlete will experience during performance. While the established standardized tests may be reliable and objective, their relevance to dance is questionable. Most of the tests that have previously been and are currently being devised require steady-state movements like running or cycling,[27] whereas dance is not a steady-state activity and dancers are untrained in both running and cycling.

Summary

Dance research that has attempted to measure work output in class, rehearsal, and performance often appears not to have considered two factors; first, that dance is not a steady-state activity and cannot be compared with the HR/O_2 relationship established from an ergometer standardized GXT protocol and second, that mean calculation of work output probably does not provide particularly useful information.

The selection of the correct method of testing is dependent on the variables the physiologist requires. For research, the problems highlighted in this discussion indicate that the use of a GXT is not ideal in extrapolating dance VO_2 data from heart rates. The exercise mode needs to be weight-bearing, making the test more dance specific, which prohibits the use of rowing or cycle ergometers. A dance specific weight-bearing GXT protocol would be the most relevant in providing information about dancers' aerobic capabilities. Parameters will provide the data required to set upper and lower aerobic training zones and the monitoring of changes in the VO_2 peak.[20] The aerobic and ventilatory thresholds and lactate profiles could also be measured if required. Such a field test should be tested for validity and reliability as previously discussed. In theory, any piece of dance lasting more than 4 minutes can be used, as this is a long enough period to tax the dancer's aerobic system. The monitoring of heart rate during the test will allow comparisons over time and, as aerobic power improves, decreases in heart rate would be expected. It is important to keep the dance movement of the test simple given that the aim is to examine changes in the dancer's physiology rather than their skill, which will help reduce the effect of "test familiarization" (heart rates are lower only because the dancer has done the test before). Most submaximal tests stipulate that heart rates need to rise above 110 to 120 $b \cdot min^{-1}$ for 3 to 4 minutes to be valid.[29]

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 programs for dancers. This initially requires the development of suitable testing methodologies, which require validity, reliability, and sensitivity. It is clear that dance science research is beginning to acknowledge the need for dance-specific tests while appreciating the reliability of standardized laboratory protocols. The extent to which dance-specific tests can become standardized is debatable since dance itself is so diverse in terms of the style and physiological requirements of each piece of choreography.

Recommendations

The monitoring of dancers aerobic power throughout the year, whether they are in-training or professional, should be considered the norm. The physical demands that are placed on them from current choreography indicate that the development of the dancer physiologically is just as important as skill development. Research has shown that dancers' (both classical ballet and modern) improve their aerobic capacity during performance periods, which suggests that class and rehearsal[29] place a different metabolic stress on the dancer than seen during performance. The monitoring of aerobic power would help to reduce possible fatigue-orientated injuries.[30,31] The tests can be as simple or complex as required or budget allows. The ideal test would be a "threshold" test using full gas analysis. This would provide the individual heart rate zones for supplemental training (*see* Fig. 1), as well as allow the monitoring of changes in maximal aerobic power. At the other end of the spectrum would be a simple treadmill test just using a heart rate monitor. The recording of heart rate at the end of each 3-minute stage until either a set heart rate had been achieved or the dancer wants to stop would allow monitoring of the dancer's aerobic fitness. Repeated test data would be compared with the initial data and either a lower heart rate at a specific workload (speed) or a higher workload at the same heart rate would indicate improved aerobic capacity.

A note of caution must be made here, until research has indicated the extent that improved aerobic power can actually enhance dance performance, there is a need to make sure that dancer's do not over develop their aerobic systems to the detriment of the other energy providing systems. The development of aerobic capacity must be a part of a comprehensive supplemental training program that addresses all aspects of dance performance demands, such as strength, power, and agility.

References

1. Schantz PG, Astrand PO: Physiological characteristics of classical ballet. Med Sci Sport Exerc 16(5):472-476, 1984.
2. Wyon MA, Redding E, Head A, Sharpe C: The physiological cost of modern dance class and performance. Presented at the Tenth Annual Meeting of the International Association for Dance Medicine and Science Miami, Florida, 2000.
3. Krasnow DH, Chatfield SJ: Dance science and the dance technique class. Impulse 4:162-172, 1996.
4. Rist R: Children and exercise: Training young dancers: A dance medicine perspective. Sportcare J 1(6):5-

7, 1994.

5. Rimmer JH, Jay D, Plowman SA: Physiological characteristics of trained dancers and intensity level of ballet class and rehearsal. Impulse 2:97-105, 1994.
6. Cohen JL, Segal KR, McArdle WD: Heart rate response to ballet stage performance. Physician Sportsmed 10(11):120-133, 1982.
7. Dahlstrom M, Inasio J, Jansson E, Kaijer L: Physical fitness and physical effort in dancers: A comparison of four major dance styles. Impulse 4:193-209, 1996.
8. Newsholme E: Basic aspects of metabolic regulation and their application to provision of energy in exercise. *In:* Poortmans J (ed): *Principles of Exercise Biochemistry*. Basel: Karger, 1993, pp. 51-88.
9. Franklin BA, Whaley MH, Howley ET: *ACSM's guidelines for exercise testing and prescription* (6th ed). Philadelphia: Lippincott Williams & Wilkins, 2000.
10. Saltin B, Strange S: Maximal oxygen uptake: "Old" and "new" arguments for a cardiovascular limitation. Med Sci Sports Exerc 24(1):30-37, 1992.
11. Sutton JR: Limitations to maximal oxygen uptake. Sports Medicine 13(2):127-133, 1992.
12. Hill DW, Smith JC: Calculation of aerobic contribution during high intensity exercise. Res Quarterly Exerc Sport 63(1):85-88, 1991.
13. McArdle WD, Katch VL, Katch FI: *Exercise Physiology: Energy, Nutrition and Human Performance*. Baltimore: Williams and Wilkins, 1996.
14. Keul J: Limiting factors of physical performance. Presented at the International Symposium on the Limiting Factors of Physical Performance. Gravenbruch, Germany, 1971.
15. Pascoe DD, Gladden LB: Muscle glycogen resynthesis after short term, high intensity exercise and resistance exercise. Sports Medicine 21(2):98-118, 1996.
16. Bangsbo J, Saltin B: Recovery of muscle from exercise: Its importance for subsequent performance. *In:* Macleod M (ed): *Intermittent High Intensity Exercise: Preparation, Stresses and Damage Limitations.* London: E and FN Spon, 1993, pp. 49-69.
17. Piehl K: Time course for refilling of glycogen stores in human muscle fibres following exercise-induced glycogen depletion. Acta Physiol Scand 90:297-302, 1974.
18. Wilmore JH, Costill DL: *Physiology of Sport and Exercise* (2nd ed). Champaign, IL: Human Kinetics Publishers, Inc., 1994,
19. Astrand P, Rodahl K: *Textbook of Work Physiology: Physiological Bases of Exercise* (3rd ed). New York: McGraw-Hill International Editions, 1986.
20. Wasserman K, Hansen J, Sue D, Whipp B, Casaburi R: *Principles of Exercise Testing and Interpretation* (2nd ed). Philadelphia: Lea & Febiger, 1994.
21. Alexander MJ: Physiological characteristics of top ranked rhythmic gymnasts over three years. J Human Movement Studies 21:99-127, 1991.
22. Bangsbo J: Physiological factors associated with efficiency in high intensity exercise. Sports Medicine 22(5):299-305, 1996.
23. Redding E, Wyon MA, Sellens MH, Shearman JP: Heart rate and oxygen kinetics in contemporary dance: Development of a submaximal aerobic test of dance performance. Presented at the Tenth Annual Meeting of the International Association for Dance Medicine and Science, Miami, Florida, 2000.
24. Atkinson G, Nevill A: Selected issues in the design and analysis of sport performance research. J Sport Sci 19:811-827, 2001.
25. Rodahl K, Vokac Z, Fugelli P, Vaage O, Maehlum S: Circulatory strain, estimated energy output and catecholamine excretion in Norweigian coastal fisherman. Ergonomics 17:585-602, 1974.
26. Cohen A: Dance: Aerobic and anaerobic. J Phys Ed Rec Dance 55(3):51-53, 1984.
27. Shepherd VH: *Advanced Fitness Assessment and Exercise Prescription* (3rd ed). Champaign, IL: Human Kinetics Publishers, Inc., 1998.
28. Ward A, Ebbeling C, Ahlquist L: Indirect methods for estimation of aerobic power. *In:* Maud P, Foster C (eds): *Physiological Assessment of Human Fitness*. Champaign, IL: Human Kinetics Publishers, Inc., 1995.
29. Wyon M: Cardiorespiratory demands of contemporary dance, in School of Life and Sport Sciences. London. Thesis, University of Roehampton, 2002.
30. Brinson P, Dick F: *Fit to Dance?* London: Calouste Gulbenkian Foundation, 1996.
31. Koutedakis Y, Myszkewycz L, Soulas D, Papapostolou V, et al: The effects of rest and subsequent training on selected physiological parameters in professional female classical dancers. Intl J Sports Medicine 20(6):379-383, 1999.