Aging has greater impact on anaerobic versus aerobic power in trained masters athletes

DEBRA NICOLE GENT & KEVIN NORTON

School of Health Sciences, University of South Australia, Adelaide, 5000 Australia

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Abstract

This study measured the relative rates of change of the three human energy systems across a 30-year age range. A cross-section of highly trained masters cyclists (n = 156 males and 17 females; 35–64 years) were tested for maximal cycling performance. There were 50 (29%) track sprint cyclists and the remaining (71%) were predominantly road cycling specialists. A 10 s peak power test measured anaerobic power, a 30 s test measured anaerobic capacity, and a progressive test to volitional fatigue was used to determine peak aerobic power. Participants’ exercise patterns were recorded using a physical activity recall questionnaire. Linear regression showed significant changes in anaerobic performance with aging. Peak anaerobic power (W/kg) declined at a rate (mean ± SEE) of 8.1 ± 4.1% per decade (P < 0.0001) and anaerobic capacity (kJ/kg) declined at 8.0 ± 3.3% per decade (P < 0.0001). Peak aerobic power [W/kg] did not change significantly with age [−1.8 ± 1.5% per decade (P = 0.218)]. This cross-sectional study showed performance of the two anaerobic energy systems declined significantly across the age spectrum with no change in aerobic capacity.

Keywords: anaerobic power, anaerobic capacity, aerobic power, energy systems, masters athletes, aging

Introduction

Physical activity (PA) helps to reduce the incidence of chronic disease and improve the quality of life at all stages of aging (Haskell et al., 2007). This is because participation in physical activity and sport at both the recreational and competitive levels contributes to health-enhancing physiological adaptations, even among octogenarians (Bickel, Cross, & Bamman, 2011; Stessman, Hammerman-Rosenberg, Cohen, Ein-Mor, & Jacobs, 2009). From a public health perspective it is important to have more people physically active and independent because while life expectancies in most countries are increasing, disability-free years are not keeping pace (Australian Bureau of Statistics, 2002; Baker, Gupta, & Kelly, 2000).

Encouragingly, the number of masters athletes is increasing and this has led to growing interest in understanding the health benefits of active aging (Donato et al., 2003) as well as helping these athletes achieve peak performance (Reaburn & Dascombe, 2009). Competitive masters athletes provide a unique opportunity to determine the effects of biological aging per se because the effects of disuse and a sedentary lifestyle, as well as any co-morbidities, are significantly reduced due to extensive training (Rittweger, di Prampero, Maffulli, & Narici, 2009).

The three human energy systems (anaerobic alactic, anaerobic lactic, and aerobic) form a closely integrated network that provides the energy for working muscles (Gastin, 2001). It is clear the capacities of these systems, when viewed across populations, decline with aging (Fitzgerald, Tanaka, Tran, & Seals, 1997; Reaburn & Dascombe, 2009; Wilson & Tanaka, 2000). This can be problematic in daily tasks where poor musculoskeletal health is associated with increased injury, disability and mortality, and decreased independent living in the elderly (Kell, Bell, & Quinney, 2001). Muscle power, in particular, has been shown to be a more important predictor of functional capacity in the elderly compared with muscle strength (Reid & Fielding, 2012). Aerobic fitness has also been shown to be a significant predictor of all-cause mortality (Kodama et al., 2009). From a performance perspective the energy systems are critical and training can help improve their maximal rates and capacities even among the oldest members of society (Malbut,
Dinan, & Young, 2002). Aging, however, is inevitable and previous work suggests relatively consistent declines of the aerobic energy system in both trained and untrained individuals of approximately 5% to 12% per decade (DASET, 1992; Fleg et al., 2005; Wilson & Tanaka, 2000; Wiswell et al., 2001). Similarly, other studies have found declines of anaerobic power and capacity of about 6% to 8% per decade (Reaburn & Dascombe, 2009). However, there are no published papers comparing the age-related rates of decline of all three energy systems in the same individuals, particularly those who continue to be highly active. Although a longitudinal study would be ideal, the use of the same participants for all three tests helps to standardise the comparison of the three energy systems across age.

The interaction of training and aging is a valuable model to understand the processes of biological deterioration and how PA can improve healthy life expectancy. It is also important that the growing population of masters athletes have an evidence base to help them optimise training and performance. This study measured the capacities of the three energy systems in well-conditioned masters level athletes to determine the age-related rates of change in a cross-sectional sample.

Methods

The study was approved by the University of South Australia Human Research Ethics Committee. A total of 173 healthy masters cyclists and triathletes (17 female, 156 male) aged between 35 and 64 years provided informed written consent and were recruited as participants. The participants were required to be training and/or competing for a minimum of two years and achieving a minimum 150 min of weighted PA per week (vigorous minutes are weighted × 2) as determined using the Active Australia Survey (AAS; AIHW, 2003). Testing of all athletes was completed over a period of eight weeks. They also underwent pre-exercise screening to ensure they had no established cardiovascular, metabolic or respiratory disease or signs and symptoms of these conditions (Sports Medicine Australia, 2009).

Participants were asked to avoid heavy meals in the four hours prior to testing. Stretch stature was measured using a wall-mounted stadiometer accurate to the nearest millimetre and body mass in minimal clothing was recorded using calibrated scales accurate to 50 g.

Maximal performance of the three energy systems was performed on a calibrated cycle ergometer. The ergometer consisted of a wind-resistance indoor training unit (Bike Technologies Australia, Melbourne, Victoria) that replaced the back wheel of each rider’s bike. Riders were set up in precisely the same way as they would be on the road. Calibration was performed using a dynamic calibration rig (Woods, Day, Withers, Ilsley, & Maxwell, 1994). A calibration curve was generated and used in the computer program that converted flywheel revolutions into a power output. The standard error of prediction was less than 1% throughout the physiological range. The training unit was interfaced with a computer to measure and store test results. Performance variables measured were peak power (W kg\(^{-1}\)) in the 10 s test, total work done (kJ kg\(^{-1}\)) in the 30 s test, and peak power (W kg\(^{-1}\)) for the aerobic test. These test protocols allowed us to determine proxy measures of anaerobic power, anaerobic capacity and aerobic power, respectively (Gastin, 2001; Storer, Davis, & Caiozz, 1990). The measurement units were chosen to standardise comparisons across the energy systems. Power and work were calculated up to 25 times per second and averages were recorded each second for all tests. During the aerobic power test protocol a graphic on a computer screen placed in front of the participants indicated the power target at each stage and this was reinforced by the testers throughout the test. Owing to obvious small fluctuations around this power level an average power per minute was automatically calculated by the software. Peak aerobic power was the highest minute average achieved during the test. Adjustments were made for changes in air density according to the daily environmental conditions (Woods et al., 1994).

A standardised warm-up period of ten minutes at a moderate, self-selected intensity on the cycle ergometer ensured participants were ready to perform to maximal levels of exertion (Bishop, 2003). The order of the testing was the same for all athletes. Following the warm up, anaerobic power and then anaerobic capacity were measured. These tests were performed from a stationary, competitive position start. Participants remained off the seat throughout the 10 s test but had the option to sit back down after the start in the 30 s test. Participants were able to choose their own gear ratio; however, they were not able to change gears throughout the sprint tests. Allowing participants to choose their own gear ratio catered for individual preferences in cadence and resistance as they would have in competition. Strong verbal encouragement was provided throughout each test in order to extract a maximal effort. The 10 s test was followed by a minimum active, self-paced rest period of five minutes, and the 30 s test by a minimum active rest period of ten minutes.

The aerobic energy system was measured using an incremental protocol to determine the peak aerobic power achieved at volitional fatigue (Storer, Davis, & Caiozz, 1990). The test began at 100 W and
increased by 15 W each minute until exhaustion. The test was performed seated with the participants permitted to change gears throughout the test. The average power output (W) was recorded for each stage. The highest average power output (W) in a completed one-minute stage was used in further analyses. Volitional fatigue was determined based upon a subject’s obvious inability to maintain the power output required at a given stage or self-determined inability to continue. All measures are shown as mass-specific values for comparative purposes across energy systems.

Prior to commencement of data collection, reliability of testing methods was determined using ten repeat measures for one well-trained masters subject on each of the three maximal performance tests. Testing was performed over 10 days with one test set each day. The testing was structured in the same way the study was undertaken for the athlete volunteers. The reliability results showed coefficients of variation of 2.96%, 3.08% and 1.58% for the anaerobic power, anaerobic capacity and peak aerobic power tests, respectively.

Linear regression was used to determine the rate of change in the performance variables with aging. Mann-Whitney was used to test for differences between genders for PA patterns. A probability level of 0.05 was used to indicate significance.

**Results**

The characteristics of the participants who completed testing in this study are shown in Table I. The results of the AAS showed a weighted median PA level of 900 min·week⁻¹ (Interquartile range (IQR) = 690 and mean = 1043 min·week⁻¹) across all participants. When regressed against age there was no change in weekly PA patterns (r = 0.08, P > 0.05). Participants reported a mixture of road and track cycling histories with a median duration of 7 years of training (IQR = 9.5 and mean 7.9 years) and 2.5 years of competition (IQR = 7.0 and mean 4.5 years). The proportion of total minutes of activity spent undertaking vigorous intensity exercise was 78 ± 19% (mean ± SD = 458 ± 278 min·week⁻¹). Regression analysis showed no change in minutes of vigorous PA across the age range in the study (r = 0.119, P = 0.121).

Analysis of the mass-specific performance associated with each predominant energy system versus age showed a similar response between genders and the regressions did not change significantly when the females were included or excluded from the dataset. There were also no differences between genders in total PA min·week⁻¹ of training (P = 0.35) and the total number of female athletes (n = 17) was too small for meaningful separate analyses. Therefore, since all performance measures were adjusted for body mass, the regression analyses were performed using all participants. Not every participant completed all three tests, with final numbers shown in Table I. This was due to factors such as feeling ill or technical problems.

The relationship between the performance of each energy system and age is shown in Figure 1. Peak anaerobic power, relative to body mass (W·kg⁻¹) declined significantly with age at a rate (mean ± SEE) of 8.1 ± 4.1% per decade between 35–64 years (P < 0.0001). Similarly, the mass-specific anaerobic capacity (kJ·kg⁻¹) decreased across the age range tested at a rate of 8.0 ± 3.3% per decade (P < 0.0001). The peak aerobic power (W·kg⁻¹) was unchanged across the age range tested −1.8 ± 1.5% per decade (P = 0.218).

The ratio of peak anaerobic to peak aerobic power was regressed against age as shown in Figure 2. This showed a significant ratio decrease that was equivalent to a decline of 6.0 ± 4.6% per decade.

The correlation between the two anaerobic performances was highly significant (r = 0.84) whereas the relationships with peak aerobic power were relatively weak although statistically significant (r = −0.27 and r = −0.24, for anaerobic power and anaerobic capacity, respectively). The ratio of anaerobic power to anaerobic capacity versus age showed it did not change with age (r = −0.01, P = 0.88).

There was no association between either of the anaerobic performance tests versus PA patterns (r = −0.03 and r = −0.03 for the anaerobic power and capacity systems, respectively; P > 0.05) and a weak significant relationship between peak

<table>
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<th>Table I. Participant characteristics reported as mean ± SD. * = total minutes per week where vigorous minutes are weighted × 2 (AIHW 2003).</th>
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<tr>
<td>Age (yr) Height (cm) Mass (kg) Peak power (W/kg) Anaerobic capacity (kJ/kg) Peak aerobic power (W/kg) Physical activity (min/wk)*</td>
</tr>
<tr>
<td>Male (n = 156)</td>
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<tr>
<td>Female (n = 17)</td>
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<td>All (n = 173)</td>
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The relationships between the performances of the three human energy systems, and how these change within individuals as a result of the aging process is not well understood. In this study, the three energy systems were measured in masters athletes undertaking high levels of training and competition. Significant declines in the anaerobic systems relative to body mass were found but there was no change across the 30 year age range for mass-specific peak aerobic power.

The participants in the present study were well conditioned and comprised a mixture of fitness-orientated and competitive triathletes, and road and track cyclists. There were 50 participants (29%) recruited from the state velodrome and were predominantly track competitors involved in sprint-oriented events. An interesting finding in the present study was the consistently high level of weekly PA patterns among the participants, independent of age. This is not a typical pattern within the general population, where it is well established that PA habits decline with age. For example, South Australian population PA levels decrease by approximately 20% across the same age range (Gill, Fullerton, & Taylor, 2008).

The current study showed that anaerobic power and anaerobic capacity declined at similar rates among the masters cyclists at about 8% per decade while at the same time there was no significant decline in peak aerobic power. The close alignment of the anaerobic energy systems is not surprising given the considerable overlap in their contributions during the 10 and 30 s test protocols (Gastin, 2001). The correlation between these two anaerobic performances was highly significant \((r = 0.84)\). This can be contrasted to the relationships with peak aerobic power, which were relatively weak although statistically significant \((r = 0.27 \text{ and } r = 0.24, \text{ for the alactic and lactic systems, respectively})\). Furthermore, analysis of the ratio of anaerobic power to anaerobic capacity versus age showed it did not change with age \((r = 0.01, P = 0.88)\) suggesting the aging process was affecting both anaerobic systems at about the same rate.

There appears to be remarkably similar patterns of age-related declines in anaerobic power and capacity, which cluster around the 6–8% range across numerous heterogeneous studies and range in duration from 10–100 s (Perusse et al., 2002). However, many of the previous studies have used healthy active, but not well-trained aging participants (Bonnetoy, Kostka,Arsac, Berthouze, & Lacour, 1998; Kostka, 2005), or have specifically excluded well-trained athletes (Makrides, Heigenhauser, McCartney, & Jones, 1985). For example, Makrides and colleagues (1985) found a 6% per decade decline in anaerobic capacity measured as total work done in 30 s across a sample age range of 15–71 years, which
consisted of healthy males and females but excluded competitive athletes. Marsh, Paterson, Govindasamy, and Cunningham (1999) found that average power during a 30 s Wingate test declined by 6.3% per decade between two groups of healthy active men with mean ages of 30.6 and 68.5 years. The fact that participants in the present study had well-established and high-levels of physical training, and this PA level was consistent across a 30-year age span, helps isolate the biological effects of aging among the three energy systems. It is unusual, especially in relatively large cross-sectional studies, to find PA patterns held constant over a 30-year age range. However, it was not possible to determine the specific training intensities the participants undertook, except to quantify training in terms of minutes of ‘moderate’ and ‘vigorous’ activity. Notwithstanding, there was no relationship between age and minutes of vigorous intensity training reported and 115 participants (66%) stated they currently competed in cycling or triathlon-related events.

Although it is almost impossible to conduct studies to disassociate the human energy systems under maximal performance, the results suggest the anaerobic power and anaerobic capacity may be influenced less by environmental factors such as training type and volume and relatively more by genetic components with aging (Bouchard & Rankinen, 2001; Calvo et al., 2002). There are several lines of evidence to support this. First, the literature demonstrates relatively consistent declines in anaerobic power with age across many different types of studies and training habits. The small variation in the rate of decline in anaerobic power with age has been shown across studies using competitive athletes (Anton, Spirduso, & Tanaka, 2004; Chamari, Ahmaidi, Fabre, Masse-Biron, & Prefaut, 1995; Donato et al., 2003; Michaelis et al., 2008; Reaburn & Dascombe, 2009), former competitive athletes in their post-competition years (Hagerman et al., 1996; Ladyga, Faff, Borkowski, & Burkhard-Jagodzinska, 2009), healthy active people (Bonnefoy et al., 1998; Kostka, 2005; Marsh et al., 1999), and healthy but sedentary individuals (Kostka, 2005; Makrides et al., 1985). These studies have also used a variety of testing methods including vertical jump, 6–10 s peak power tests on cycle ergometers, and performance records analysis using powerlifting (Anton et al., 2004) and track and field world records (Rittweger et al., 2009). Secondly, there was a lack of association between PA levels and anaerobic performance measures for participants in the present study although there was a significant, albeit weak, relationship between PA levels and aerobic performance. Thirdly, muscle physiology studies have generally found aging involves a selective atrophy of type II skeletal muscle fibres in comparison to type I skeletal muscle fibres (Brunner et al., 2007; Deschenes, 2004; Korhonen et al., 2006), although not everyone has observed this (Frontera et al., 2005; Tarpenning, Hamilton-Wessler, Wiswell, & Hawkins, 2004). Anaerobic performances in humans rely heavily on the energy transfer in type II muscle fibres and both anaerobic test protocols in the current study demand maximal recruitment and power output from these fibres. Other studies have shown very few changes in type I skeletal muscle fibre number and cross-sectional area, possibly up until the eighth decade of life (Tarpenning et al., 2004). Fourthly, there are numerous alterations in systems specifically related to oxygen flux, other than muscles, that also affect aerobic power production, such as heart size and efficiency, blood viscosity and buffering capacity, and in the regulation of the distribution of blood flow during exercise. These are all responsive to physical training (Fitzgerald et al., 1997; Fleg et al., 2005; Wilson & Tanaka, 2000; Wiswell et al., 2001). This may explain the significant association between peak aerobic power and PA levels in the current study that were absent for the anaerobic systems. Fifthly, when the performances among the male sprint-trained cyclists (n = 40) in the present study were analysed separately, the same patterns of decline were found across age for the anaerobic tests with no change in the aerobic performance test. Finally, twin studies show that anaerobic power has a heritability index as high as 0.74 and anaerobic capacity as high as 0.84 (Calvo et al., 2002) compared with lower levels of around 0.30–0.50 for the aerobic system (Bouchard & Rankinen, 2001; Perusse et al., 2003).

Conclusions

The results of the current study support the notion that the anaerobic energy systems decline faster than the aerobic energy system with age. The magnitude of these differences in the present sample of masters athletes was substantial; however, the physiological basis for these differences is still not clear. The high PA levels among the participants helped to maintain mass-specific peak aerobic power but it did not have the same effect on anaerobic power, despite large volumes of vigorous training and competition.

References


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