Endurance Exercise Performance in Masters Runners: Physiological Determinants and Training Recommendations

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ABSTRACT

Masters athletes are typically characterised as middle-aged and older men and women who continue physical training and sport activities at different levels throughout life. However, regardless of training, a decline in peak athletic performance usually occurs with ageing. In endurance exercise the reduction of performance and its physiological determinants appear to be mediated in large part by a reduction in the exercise training 'stimulus'. This reduction is mainly a result of increased work and family commitments, the inability to follow structured training programmes, increased prevalence of exercise training-associated injuries contributing to reduced training intensity and volume. These concerns highlight the importance for choosing and administering an adequate training stimulus in order to achieve maximum results in the shortest available time for training. Therefore, the first part of this article analyses the factors responsible for the decrease in performance with increased age. It is followed by a presentation different training methodologies that Masters runners in the middle- to long-distance events can use in order to prevent this decrease and, more importantly, increase their performance.

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Introduction

According to the rules of the International Association of Athletic Federations (IAAF) and World Masters Athletics (WMA), Masters athletes are men and women older than 35 years who continue to physically train, compete recreationally or at organised competitive events.

Since the inaugural World Masters Games in Toronto (Canada) in 1985, where 8,305 participants competed in 22 sports, the number of Masters athletes has been steadily increasing. In 2013, approximately 25,000 athletes competed in the Games in Torino, Italy. Focusing on the marathon, in 1980 the number of U.S. marathon finishers over 40 years old was 37,180 (26% of estimated total of U.S. marathon finishers) and by 2013 this number had grown to 254,270 (47% of estimated total of U.S. marathon finishers)[2]. This huge increase in participation has prompted an interest in issues related to the enhancement of the performance of Masters athletes[1].

Several studies show a decline in peak athletic performance with age across all disciplines[3-5]. For example, the age-related decrease in the performance of elite level Masters endurance athletes appears curvilinear from age 35 until approximately 60–70 years, increasing exponential thereafter[4, 6]. This decrease occurs even if the athletes train for 10 or more hours per week, which they typically do over many decades[3]. Therefore, the first part of this review will analyse the factors causing the decrease in performance related to ageing while the second part will present the main training methodologies used by Masters runners to enhance performance in the middle- and long-distance events.

Physiological Determinants of Endurance Performance and Ageing

Performance in endurance events is dependent upon three main physiological factors: maximal oxygen consumption, the exercise intensity at which a high fraction of the maximal oxygen consumption can be sustained, and exercise economy[7, 8].

Maximal oxygen consumption

In Masters athletes the progressive reduction in VO_2max appears to be a key physiological mechanism associated with the decline in endurance performance[4]. Although it is quite clear that it is higher in endurance-trained than in sedentary men of similar age[9], VO_2max is estimated to decline approximately 10% per decade after the age of 25 in both healthy and sedentary individuals of both sexes[10-16]. However, attenuated[17], similar[18], or slightly greater[19] rates of decline have been reported in Masters endurance athletes. Without discussing the reasons of these discrepant results among the studies, reductions in habitual exercise with ageing seems to be the major factor affecting rates of decline in VO_2max in endurance-trained athletes[10, 14-16].

Both central (maximal heart rate and maximal stroke volume) and peripheral (maximal arteriovenous oxygen difference) factors may play a role in age-related declines in VO_2max. An age-related decrease in maximum heart rate (HRmax) is commonly observed in endurance athletes[4,11,20]. This decline of HRmax occurs regardless of exercise or gender, at a rate of approximately 3–5% per decade[11, 21]. A significant age-related decline in maximal stroke volume in endurance-trained athletes has also been observed[22]. However, compared to age matched sedentary controls, the available research suggests that maximal stroke volume of Masters endurance athletes is elevated[23]. This suggests that with this population, long-term physical training maintains a high level of cardiac function and stroke volume. Consequently, the decreased maximal cardiac output and VO_2max observed in Masters athletes appears to be an age-related decrease in HRmax rather than a significant change in stroke volume or cardiac morphology.

Peripheral adaptations include an arteriovenous oxygen difference - influenced by a variety of factors such as: muscle mass, the capacity of blood to transport and relinquish oxygen (blood volume, hemoglobin) - and the capacity of the working tissues to take up and utilise oxygen (capillarisation, muscle fibre type, aerobic enzyme activity). Reductions in peripheral oxygen extraction during maximal exercise appear to contribute to the decline in VO_2max with age in endurance exercise-trained adults. In fact, maximal arterio-venous O_2 difference declines modestly (5–10%) in this group over a span of ~30 years[24-26]. It remains to be determined if this reduction in maximal arterio-venous O_2 difference with age reflects reductions in maximal oxygen delivery to or extraction by the active muscles. However, older endurance-trained athletes can oxygenate blood in the lungs to a similar extent as young athletes. Also, their contracting muscles are capable of extracting oxygen as much as their younger counterparts[25]. Furthermore, a similarity is observed in young and old endurance athletes regarding muscle oxidative enzyme activities and capillarisation (expressed per area or per fibre)[27]. Thus, it is likely that maximal oxygen delivery, rather than oxygen extraction, is a major contributor to the age-related reduction in maximal arterio-venous O_2 difference in endurance-trained adults. As skeletal muscle mass is closely related to maximal aerobic capacity among healthy humans across the adult age range[28], a recent longitudinal investigation demonstrated that maintenance of lean body mass was associated with maintenance of VO_2max in male Masters runners[19].

Lactate threshold velocity

A reduction in the ability to sustain a high fraction of maximal oxygen consumption during submaximal exercise, typically evaluated using the blood lactate threshold, also contributes to the reduction in endurance performance with ageing. In older runners, endurance running performance is correlated with both VO_2max and velocity at lactate threshold[18, 29-31]. WISWELL et al.[31] determined that 60% of the variability in performance for runners aged 23–47 year was explained by the running velocity at which lactate threshold occurred, whereas VO_2max accounted for 74% of the variability for the runners aged 37–56 years. Absolute work rate or running speed at lactate threshold declines with advancing age in endurance athletes[29, 31-33]. However, lactate threshold has been observed not change or even increase with increased age when expressed relative to the percentage of VO_2max[29, 31, 33, 34].

Running economy

Running economy is measured as the steady-state oxygen consumption while exercising at a specific submaximal intensity below the anaerobic threshold[35]. This has been shown to be a stronger predictor of endurance performance than VO_2max in a homogenous group of endurance athletes[36, 37]. The few studies focused on Masters endurance athletes[31, 37] conclude that running economy does not change with age, suggesting that this factor does not contribute significantly to age related decreases in endurance performance.

Ageing

Ageing has been associated with a progressive increase in free radical production, i.e., synthesis of reactive oxygen species, (ROS), which can damage DNA and lipids, and oxidize proteins[38-40], with a concomitant decrease in the enzymatic defense mechanisms (antioxidant). Free radicals promote the development of oxidative stress increasing oxidative damage[41-44]. Optimal higher levels of ROS can improve physical fitness and subsequently delay the ageing process reducing the morbidity or mortality of all-cause diseases. However, an excessive rise in ROS levels may constitute a stress signal damaging antioxidant defenses, ultimately accelerating the ageing process and age-related diseases. On the other hand, lowering ROS levels below the allostatic set point may interrupt the physiological role of ROS in maintaining redox status and cellular adaption to exercise[45].

Physical exercise is perhaps one of the most characteristic examples demonstrating that ROS are not necessarily harmful, when considering the well-known benefits of regular exercise on the human organism accompanied by repeated episodes of oxidative stress[46,47]. During exercise, the high energy demanded by muscle contraction causes an increase of oxygen delivery/uptake, leading to an increase of O_2 consumption. The high O_2 flux along the mitochondrial electron transport chain, in association with an electron leakage, is correlated with an increased production of ROS. However, the chronic repetition of exercise may have the capability to develop a compensation to oxidative stress in skeletal muscle fibres[48] by means of an adaptation of the antioxidant and repair systems. This may result in a decreased resting level of oxidative damage and an increased resistance to oxidative stress[49].

Training Recommendations for Masters Runners

Apart from physiological factors, age-related declines in endurance performance have been related to decreased training volumes and intensities resulting from increased work and family commitments and reduced motivation to train (few Masters athletes have coaches and they spend less time training than younger athletes)[20]. In addition, an increased prevalence of exercise or training-associated injuries among Masters athletes probably contributes to their reduced training intensity and volume[50]. All these factors lead to a reduction in the exercise training 'stimulus' (i.e. exercise-training intensity, session duration and weekly frequency), which combined with aging and the aforementioned physiological considerations may have a role in the decline of peak performance[10, 15, 51, 52].

This highlights the importance of the choice of adequate stimulus to be administered in order to achieve maximum results in the shortest time available for training. Therefore, the second part of this review will focus on the different running training methodologies available that can be used to preserve physiological parameters mentioned above but more importantly increase performance.

Endurance training methods

In general, the main types of endurance training used are: i) continuous training (CON) at moderate intensity or running velocity, characterised by high volumes of training (> 30 min) with intensities between 60% and 80% of VO_2peak or below the "anaerobic threshold" (AT) with a nearly constant O_2 consumption and without a "slow component" in O_2 kinetics of oxygen[53-57]; and ii) discontinuous high intensity training (DHIT) characterised by repeated exercises performed at running velocities corresponding to VO_2peak (or slightly lower) or above AT or "all-out". High intensity efforts generally last from a few seconds to several minutes, being interspersed with periods of passive or low intensity recovery, resulting in partial but not complete recovery[58, 59].

Until a few years ago, it was widely believed that DHIT was a prerogative of elite athletes accustomed to sustain training periods of CON alternating with periods of DHIT, especially during the competitive season[55]. Instead, in sedentary or moderately trained subjects they were prescribed primarily exercises of low-moderate intensity and high-volume, as it was considered safe and more effective to improving aerobic metabolism[60-62]. However, different studies indicate that even in sedentary or moderately trained individuals, DHIT might be an efficient strategy inducing adaptations in skeletal muscle and exercise performance, comparable to conventional endurance training[55, 63-69].

CON enhances VO_2max and reduces lactate concentration at low intensity by causing an increase in mitochondrial density, efficiency and volume[8, 35, 70]. This is coupled with a higher capillarisation, which reduces the blood-mitochondria distance and enhances the aerobic pathway. Further, this improved mitochondrial activity shifts substrate oxidation to lipids, sparing carbohydrates for higher intensity exercise[60].

It is important to remark that the effectiveness of training is strongly related to the training stimulus. For instance, when CON is used to enhance performance over a given distance (let say 10km) the stimulus is mainly determined by the intensity. If athletes continue to train at the same speed, after several sessions the physiological adaptations reach a plateau and the same training will no longer enhance any parameters, including performance.

In studies of DHIT, an improvement in VO_2max was found and, in contrast to CON, running velocity at VO_2max (vVO_2max) possibly mediated by enhanced neuromuscular properties and anaerobic characteristics[71,72] . Higher muscle oxidative capacity with enhanced mitochondrial activity[73], an increased muscular glycogen content at rest and lower glycogen use with lower lactate production during exercise were reported after different DHIT protocols[74]. These improvements may account for improved ventilator and lactate thresholds[71,75] as well as increased time to exhaustion[73]. Interestingly, as pointed out by GIBALA & MCGREE[73], these changes occur in less time and with lower training volume, which are critical parameters for Masters athletes.

As for oxidative damage, high-intensity discontinuous and continuous moderate-intensity training induced similar beneficial effects in Masters runners, by reducing the resting levels of the oxidative stress biomarkers in plasma and urine[76]. In addition, evidence exists that exercise induced alterations in redox homeostasis are attenuated by both training modalities[76].

Application of DHIT

Since DHIT is characterised by high intense efforts, it is quite difficult to prescribe work ranges based on HR. Because of its slow on-kinetic HR, cannot properly describe the metabolic demand in short bouts of exercise. In addition, at intensity levels near or above VO_2max, HR changes are minimal due to the plateau near the HRmax, so differences in running velocity in short periods will not be reflected in variations in HR. Thus, incremental test parameters obtained in the laboratory, a a particular velocity at VO_2max or, for short bouts, maximal running speed, are recognised to be more accurate and effective for achieving desired performance outcomes[58, 77].

However, since laboratory tests may not be feasible, other approaches have been utilised to prescribe DHIT in endurance athletes. For example, coaches traditionally use a percentage of the 100-400m maximal velocity for short intervals (10-60 sec). For longer intervals, the velocity maintained over 800–1500m to 2000–3000m have been incorporated (2–4 to 6–8 min)[58, 77]. In addition, the use of the rate of perceived exertion (RPE) methods is becoming popular because of its simplicity. Using this approach for long intervals, coaches prescribe bouts of duration or distance allowing the athlete to self-regulate intensity, with use of the rate perceived exertion scale. The subjective intensity selected is typically "hard" to "very hard" (i.e. ≥6 on a CR-10 Borg scale and ≥15 on a 6–20 scale)[58, 77].

Unlike CON training, where only two variables (volume and intensity) are manipulated, with DHIT more variables can be incorporated in different sessions. These include, intensity and duration (similar to CON) as well as the type and length of recovery time between sessions[58, 77].

Regardless of the DHIT prescribed (long or short interval), training time dedicated to VO_2max is also of great importance. Current evidence suggests that within the total volume during a session, athletes should dedicate at least 10 minutes at an intensity of ≥90%VO_2max. This can be achieved either as a series of repeated long (≥2 min) or short intervals (≤45 sec).

The nature of the recovery between efforts could be either active or passive, keeping in mind that during these two antithetic modalities, different physiological mechanisms are at work. When recovery is passive there is a higher rate of phosphocreatine (PCr) resynthesis, compared to an active recovery were PCr resynthesis rate is low. However, with an active recovery, a higher rate of muscular lactate removal occurs since there is a large activity of a lactate shuttle[78], maximised when the intensity is between 60–70% VO_2max. Usually passive recovery is shorter than active. Based on these physiological aspects and the use and benefit of DHIT sessions, coaches can employ either recovery modality.

Minimal delay between the warm-up and the start of a DHIT session is recommended in order to accelerate the time needed to reach VO_2max with a warm-up intensity <60–70 % vVO_2max[58].

Table 1: Examples of training modalities for continuous and discontinuous training for Masters runners

MODALITY	WORK INTENSITY	WORK DURATION	RECOVERY	RECOVERY DURATION	SERIES & REPS
DHIT Long	≥ 95% vVO_2max **or** v800m SB	2 – 3 min	Passive	≤ 2 min	6 - 10 x 2 min
	≥ 90% vVO_2max **or** 100 – 105% v3000m SB	≥ 3 min	≤ 60 – 70% vVO_2max **or** 60% v3000m	≥ 4 -5 min	5 - 8 x 3 min 4 - 6 x 4 min
DHIT Short	100 – 120% vVO_2max **or** 105 – 120% v800m SB	15 sec ≤ t ≤ 45 sec	Passive **or** ≤ 60 – 70% vVO_2max **or** 60% v3000m	< 15 sec (passive) ≥ 15 sec	2-3 x ≥ 8 min (total work) Rest between series ≥ 4 – 5 min
CON Long	< vLT or 75 – 85% v10km SB	80 – 120 min			
CON Short	vLT or 90 – 95% v10km SB	30 – 50 min			

DHIT (discontinuous high intensity training); CON (continuous low to moderate intensity training); vVO_2max (speed at VO_2max); v800m (speed during 800m race); v3000m (speed during 3000m race); v10km (speed during 10km race); vLT (speed at lactate threshold); SB (seasonal best). From BUCHHEIT & LAURSEN[77] (MODIFIED).

Previous training recommendations suggest that on average a ~48h time period separating DHIT will enable the majority of athletes to properly recover and maximise their performance[77]. In fact, when DHIT sessions are separated by less than two days, a progressive overload is likely to occur. Sometimes this "functional" overload condition is sought by athletes during particular short training periods, however, if the overload is not properly controlled (reduced training or tapering) and maximal efforts are repeated over several days or weeks, DHIT can lead to a non-functional overreaching condition[77].

A functional long-term periodisation for Masters runners should begin with predominant low intensity continuous training in order to elicit cardiovascular, muscular and structural adaptations. After that, the high-intensity training stimulus becomes essential in order to obtain further improvements in endurance performance.

For all these reasons, it is recommended that Masters athletes wanting to improve their performance and/or health status must consult experienced coaches and rely on evidence-based training methods.

Examples of DHIT and CON training sessions are shown in Table 1.

Strength training

An age-related decline in strength has been observed in both sedentary individuals and Masters athletes, suggesting that muscles undergo the same physiological changes in both populations[79], namely, a loss in type 2 motor units is responsible for the decrease in muscle power[80]. This decline in strength accounts for a reduced capacity for muscle to recover. Therefore, part of the training process should focus on the development of neuromuscular properties of the muscles in order to preserve and/or possibly improve the function of the muscle fibres. Both CON training and DHIT, associated with repetitions at high intensity, can preserve and enhance the properties of type 1 fibres[81]. This results in the neuromuscular improvements in both fibre types[82]. However, resistance training is known to affect type 2 versus type 1 fibres more[83].

Being aware of the relationship in young and elite athletes with regard to neuromuscular characteristics and running economy[84], PIACENTINI et al analysed the effect of six weeks of maximal strength training (2 times per week) during the conditioning period in preparation for long endurance events (CON endurance training targeted to increase maximal aerobic power) in Masters athletes. The authors observed that maximal strength training, when performed for a limited amount of time, increased running economy in Masters athletes, similar to younger athletes[85]. This result suggests that resistance training should be integrated in the training programme for older athletes possibly slowing down age-related declines in muscle mass while improving performance. However, further research is needed.

Conclusion

Amongst the main physiological determinants of endurance exercise performance, a progressive reduction in VO_2max appears to be the primary mechanism associated with the decline in endurance performance with increased age. Reductions in lean muscle mass and lactate threshold velocity also contribute to the reduction in endurance performance, although these may be secondary factors. In contrast, exercise economy does not change with age in endurance-trained adults.

High intensity and volume training are important in maintaining or attenuating age-related decreases in VO_2max and endurance performance. However, the greatest challenge to Masters athletes is balancing an adequate physical stimulus for the body while preventing excessive fatigue, which may lead to injury[50, 86]. Moreover, introducing periods of both high-intensity and volume training at the appropriate time in a training programme, in order to achieve an optimal performance[55,] is imperative.

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