

Sprint and endurance power and ageing: an analysis of master athletic world records

Jörn Rittweger^{1,*}, Pietro Enrico di Prampero², Nicola Maffulli³
and Marco V. Narici¹

¹*Institute for Biomedical Research into Human Movement and Health, Manchester Metropolitan University, All Saints Campus, Manchester M15 6BH, UK*

²*Department of Biomedical Sciences, University of Udine, Ple M. Kolbe 4, 33100 Udine, Italy*

³*Department of Trauma and Orthopaedic Surgery, Keele University School of Medicine, University Hospital of North Staffordshire, Stoke on Trent ST4 7LN, UK*

Human physical performance is notably reduced with ageing. Although the effects of ageing are often compounded by disuse, the study of master athletes provides an opportunity for investigating the effects of ageing *per se*. It is often held that sprinting is more affected than endurance performance. However, past analyses of master athletic world record data have yielded opposite observations. We argue here that our understanding of these data improves by considering how, biomechanically, metabolic power is related to athletic performance. In line with earlier studies, our analysis showed that running speed declines with age in a more pronounced way for endurance events than for sprinting events, confirming former studies. However, when assessing the metabolic power required to achieve the running world records, sprint and endurance events show a relatively uniform decline with age across the different events. This study has reconciled formerly conflicting scientific results and improves our understanding of the ageing process. However, it is unclear as to which are the governing mechanisms that cause the different systems in our body, responsible for sprinting and for endurance performance, to be affected by ageing in a remarkably uniform way.

Keywords: master athletes; veteran athletes; maximum performance; sport; exercise

1. INTRODUCTION

(a) *The significance of world record data*

Records in sports offer the unique opportunity to study physical performance of humans at optimum. World records, in particular, can be regarded as results of one of the largest human experiments ever accomplished, taking into account the large underlying sample group, the well-defined criteria and the meticulous surveillance involved. The analysis of records has been intriguing to many researchers, mainly because the errors due to ‘experimental’ variation are impressively small for these extremes of human performance (Hill 1925; di Prampero 1985; di Prampero *et al.* 1993).

Important insights into the understanding of human performance in highly trained athletes can be, and have been, gained through the analysis of world records. Using Wilkie’s equation that relates mechanical power to time during exhausting exercise (Wilkie 1980; di Prampero 1985), successful predictions of running and cycling performance have been made (di Prampero *et al.* 1993; Capelli *et al.* 1998; di Prampero 2003). Moreover, records have been used to compare different groups of athletes, for example males and females (Chatterjee & Laudato 1995), or athletes of different disciplines or different age. The latter are of particular interest, because the ageing athlete may be regarded as a model for ‘successful’ ageing (Tanaka & Seals 2003; Rittweger *et al.* 2004; Lazarus & Harridge 2007). Indeed,

so-called master athletes typically train for 10 hours or more per week, and they often do so over decades. Moreover, they show no (Pollock *et al.* 1987; Tanaka *et al.* 1997) or only minute (Wiswell *et al.* 2001) age-related trends in body mass or body composition. Master athletes can consequently be regarded as a ‘model population’ for the study of ageing, as they allow assessment of the relative contribution of senescence (i.e. an irreversible biological process) as opposed to sedentarism or co-morbidity, two other common factors that engender age-related functional declines.

In this sense, record data from master athletes can be regarded as a ‘virtual’ cross-sectional study that can provide important insights into the ageing process. A previous analysis of track and field regional records from different age classes (Shepard *et al.* 1974) yielded an exponential decline of running speed with age (Moore 1975). Performance for shot put and discus throwing declines more rapidly with age than that for running disciplines. Furthermore, within the different running disciplines, the decline is more rapid for the speed over 200 m than that in the marathon run. It was concluded from this that ‘strength deteriorates faster than stamina’. Conversely, studies by Baker *et al.* (2003) on masters’ running world records and by Stones & Kozma (1980) on regional running records suggest that performance in distance events would decline more rapidly with age than sprinting performance. In line with these observations, master swimmers seem to have a greater decline of performance in long-distance events than in

* Author for correspondence (j.rittweger@mmu.ac.uk).

short-distance events (Tanaka & Seals 1997; Donato *et al.* 2003). Taken together, these observations seem to suggest that endurance performance is indeed more affected by age than sprinting.

Short-term muscle power (within tens of seconds) depends on the degradation of ATP and its replenishment from phosphocreatine (PCr) (di Prampero 1981). The rate of both processes is comparatively high, but as PCr stores are limited (sufficient for approx. 100 contractions; McMahon 1984), and need to be replenished by the slower, oxidative metabolism, the high phosphate-based power can be sustained only for a limited time. Therefore, sprinting performance basically relies upon 'anaerobic' mechanisms, whereas endurance performance is usually thought to be limited by 'aerobic' power. Within skeletal muscle, power generation in sprinting performance is mainly by type II muscle fibres, which are specialized in anaerobic power generation, whereas type I fibres are responsible for the aerobic power generation in endurance events.

In the light of these considerations, the finding of a more pronounced decline in endurance as compared with sprinting performance with age may initially seem striking. This is because data from cross-sectional studies suggest a slight increase in the proportion of type I fibres when older individuals in their late sixties or early seventies are compared with young people in their twenties (Larsson 1978, 1983). However, other cross-sectional studies did not find differences in muscle composition between old and younger people (cf. Lexell (1995) and Porter *et al.* (1995) for reviews). Furthermore, in a fairly recent longitudinal, rather than cross-sectional, study in which fibre-type proportion in the same individuals at 65 years and then at 75 years was assessed, a decrease from 60 to 40% of type I content has been found (Frontera *et al.* 2000). Thus evidence of a selective loss of type II fibres with old age seems rather weak and is challenged by this more recent observation of longitudinal nature. As far as the maximum shortening velocity (V_0) of skinned single muscle fibres is concerned, the available data are also somewhat contradictory. For instance, while D'Antona *et al.* (2003) reported lower V_0 values in old than young adults, Trappe *et al.* (2003) did not do so. Inconsistencies seem also to exist when considering the intrinsic speed of the myosin molecule (V_f) assessed with *in vitro* motility assays: whereas lower V_f values have been reported for muscles of older individuals by D'Antona *et al.* (2003) and by Hook *et al.* (2001), Canepari *et al.* (2005) did not find any differences. However, one important issue that could account for these apparent contrasting findings is the physical activity level of the elderly people considered in these studies. Indeed, D'Antona *et al.* (2007) have shown that fibre contractile properties in old age are modulated by physical activity. It thus seems an arduous task to dissociate the effects of ageing alone from those of physical activity when addressing contractile properties at the level of single muscle fibres. It would therefore be desirable to investigate muscle fibre properties in physically active elderly people, e.g. master athletes. Unfortunately, there are few studies available on muscle function in master athletes at the fibre level (Widrick *et al.* 1996; Korhonen *et al.* 2006), and no single study has directly compared distance and sprint athletes. Therefore, we propose here that analysis of world record data could provide insight

into the relative importance of the rates of decline in aerobic versus anaerobic power and thus provide information upon the ageing process under 'ideal' conditions.

2. ASSESSMENT OF METABOLIC POWER FROM RUNNING SPEED

Past studies have analysed record data mainly in terms of athletic performance, e.g. time or speed. However, the relationship between athletic performance and the underlying physiological mechanisms is often nonlinear. Therefore, when inferring such mechanisms from athletic performance, mathematical transformations are needed before speculating on physiological mechanisms. Here, we provide a transformation for running speed for which the relationship between performance (i.e. speed) and its physiological basis (metabolic power) is probably best understood.

The metabolic cost of running over distance D depends on three terms, two of which increase with the square of the running speed, and one of which is independent of speed. More specifically, the cost of running (CR) can be broken down as

$$CR = CR_{NA} + k \cdot v^2 + v^2 / (2 \cdot \text{Eff} \cdot D), \quad (2.1)$$

where CR_{NA} is the non-aerodynamic cost of running at constant speed, $k \cdot v^2$ is the energy spent against the wind per unit of distance D , and the third term takes into account the energy spent to accelerate the runner's body from zero to speed v , and where all terms are expressed per unit body mass and distance.

The efficiency value (Eff) in the third term is introduced to transform the kinetic energy per unit of distance ($v^2/2D$) into the corresponding metabolic cost. CR_{NA} is essentially independent of the speed (e.g. see Margaria *et al.* 1963; Minetti *et al.* 2002), amounting to approximately $3.8 \text{ J kg}^{-1} \text{ m}^{-1}$ (di Prampero *et al.* 1993) and k can be estimated at approximately $0.01 \text{ J s}^2 \text{ m}^{-3} \text{ kg}^{-1}$ (Pugh 1971). Importantly, evidence suggests that CR_{NA} is unaffected by age in male and female distance runners (Allen *et al.* 1985; Wells *et al.* 1992), and we see no reason to assume an age effect upon k .

Therefore, if we are prepared to use the average speed to calculate the kinetic energy and to assume $\text{Eff}=0.25$, as observed during uphill running (Minetti *et al.* 2002), equation (2.1) becomes

$$CR = 3.8 + 0.01 \cdot v^2 + 2 \cdot v^2 / D. \quad (2.2)$$

The metabolic power required for running at speed v (ER, W kg^{-1}) is the product of the energy cost of running per unit of distance (CR, $\text{J kg}^{-1} \text{ m}^{-1}$) and the speed (v , m s^{-1}),

$$ER = CR \cdot v. \quad (2.3)$$

Hence, from equations (2.2) and (2.3), it follows that

$$ER = 3.8 \cdot v + 0.01 \cdot v^3 + 2 \cdot \frac{v^3}{D}. \quad (2.4)$$

3. AGEING AND RUNNING SPEED

The track and field world records were obtained from the World Association of Veteran¹ Athletes (WAVA, <http://www.world-masters-athletics.org>) in June 2007. The records for the 100 m, 200 m, 400 m, 800 m,

Table 1. Men's running world records (in s) as of June 2007.

age	100 m	200 m	400 m	800 m	1500 m	3000 m	5000 m	10 000 m	marathon
40	10.42	20.64	47.81	110.7	226.7	485.1	823.1	1710.9	7726
45	10.72	22.13	50.20	114.2	238.3	507.7	863.6	1802.6	8151
50	10.95	22.58	51.39	118.6	245.2	529.2	893.2	1856.1	8369
55	11.50	23.36	52.24	123.7	252.5	537.3	937.0	1947.7	8756
60	11.70	24.00	53.88	130.4	267.6	569.5	972.6	2054.9	9495
65	12.53	25.46	56.37	134.3	279.9	587.4	998.8	2082.2	9717
70	12.77	26.71	60.77	140.5	297.7	642.4	1113.4	2284.1	10 488
75	13.61	27.97	65.34	156.3	322.7	670.4	1147.0	2365.2	11 315
80	14.35	30.89	72.85	173.5	359.1	790.5	1317.9	2669.4	13 142
85	16.16	34.41	84.18	206.6	423.1	964.6	1547.5	3170.8	16 495
90	17.83	40.00	98.69	268.2	520.0	1116.0	1885.5	4167.5	20 401

1500 m, 3000 m, 5000 m, 10 000 m and marathon events were analysed for men (see table 1) and women for outdoor competitions.² World records exist for age classes of 5 years, starting with the age of 35. However, since world records were unavailable for many distances beyond the age of 90, and given that some of the running records in the age class of 35 are held by professional runners (rather than by amateurs as for all the older ages), we have restricted the analyses to the age range of 40 to 90 years. Moreover, because the main effects of age were comparable between male and female records, and because participation in veteran athletics is still considerably smaller in women as compared with men, we are reporting here only the results obtained from the men's records.

The processing of data was performed with the MATHEMATICA v. 4.1.2 software package (Wolfram Research, www.wolfram.com). To model the running speed for distance D as a function of age A , a third-order polynomial, $v_D(A)$, was fitted for each event (see figure 1a). Third-order polynomial functions yielded considerably better fit, with adjusted R^2 values (Zar 1999) between 0.991 and 0.999, than second-order polynomials, for which adjusted R^2 ranged only between 0.980 and 0.995. Choosing higher orders, however, did not further improve the fitting.

Figure 1a gives the results of these computations, showing the decline in running speed with age in absolute terms for the men's outdoor world records. Clearly, the relationship between speed and age is curvilinear, with a more pronounced decline after age 75.

To investigate this age-related decline in relative terms, the relative running speed $\omega_D(A)$ was defined for each distance D in proportion to the 100 m sprinting event, as

$$\omega_D(A)_j = s \cdot v_D(A) / v_{100\text{ m}}(A), \quad (3.1)$$

where s is the ratio of the speeds of the records over 100 m to that over the distance D at age 40. Hence, s serves as a scaling factor to unify all ω_D functions at point (40 years, 1). By definition, $\omega_{100\text{ m}}$ equals 1 for all ages. For the other distances, a value greater than 1 in ω_D implies, with regards to the 100 m event, a smaller age-related decline. Conversely, whenever ω_D attains values less than 1, then the relative decline is larger than for the 100 m distance.

Figure 1b gives the relative decline in running speed. With the exception of the 100 m and the 200 m events, all curves remain below 1 beyond age 40, demonstrating that the age-related decline in running speed is more

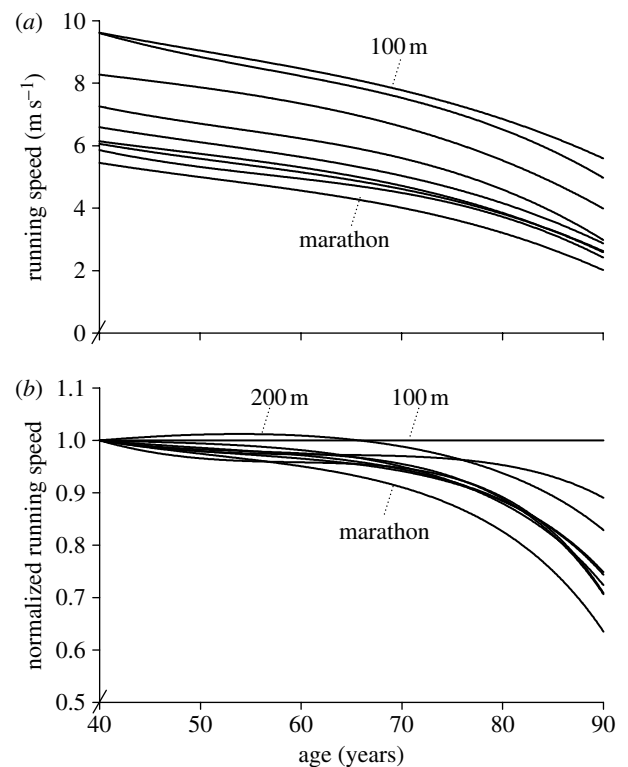


Figure 1. World record running speed as a function of age for the men's outdoor events. (a) Polynomial fits of mean running speed v . A clear-cut decline in v can be appreciated for all running distances, which seems to be aggravated beyond the age 70. (b) Relative running speed ω , i.e. speed relative to the age-specific world record for 100 m. By definition, $\omega_D(A)=1$ for 100 m at all ages A , and also $\omega_D(A)=1$ for all distances D at age 40. Curves for 400 m and longer races are always below 1. This decline becomes more prominent with age, suggesting that endurance performance is affected by age more than sprinting.

pronounced for long distances than for sprinting events, which is in agreement with earlier studies (Stones & Kozma 1980; Baker et al. 2003). As can also be seen from the figure, the discrepancy between sprinting and long-distance speed seems to be aggravated with increasing age. For example, the grand average of ω for the 400 m and longer events is 0.98 for the age range 40–69 years, indicating a relative difference of only 2.2 per cent between sprint and longer distance events. However, for the age range 70–84 years, the grand average of ω is 0.90, and it is 0.73 at age 90.

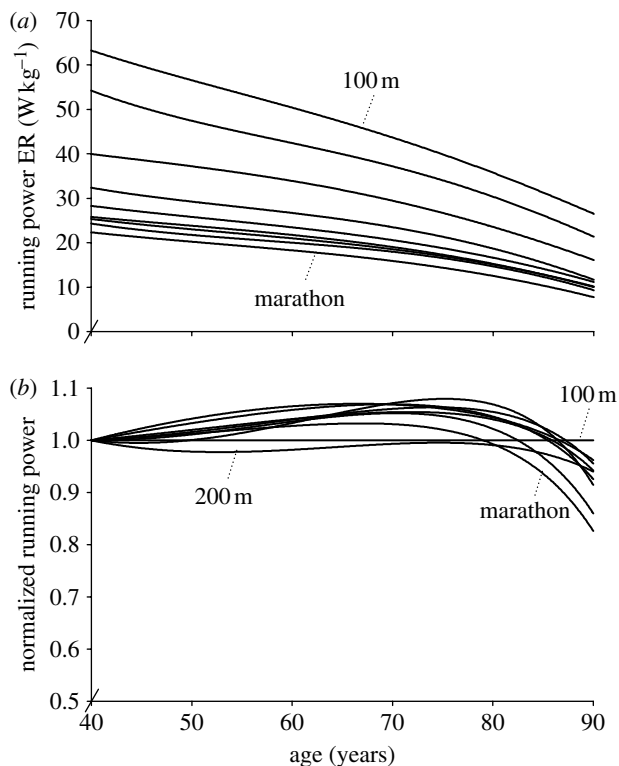


Figure 2. Metabolic power required to achieve the running velocities in figure 1, again as a function of age in the men's outdoor world records. (a) Metabolic power (ER) in absolute terms. The curves were computed from the curves in figure 1a applying equation (2.4). As in figure 1a, there is a clear cut decline of ER with increasing age for all distances, but here the decline appears to be almost linear. (b) Relative metabolic power ε , which, by analogy with figure 1b, gives ER relative to the age-specific ER for 100 m. Up to the age of 80, and contrasting with figure 1b, values for middle- and long-distance events are slightly greater than 1, suggesting a moderate sparing effect for endurance power up to the age of 80, and conversely beyond that age.

4. METABOLIC POWER AND AGE

The polynomial relationships between running speed and age allowed us to calculate, over each distance, the functions relating metabolic power requirement ER, as from equation (2.4), to age. They are reported in figure 2a. Similar to running speed (figure 1a), ER declined steadily with age. Inspection of figure 2a, however, does not show any clear-cut breaking point for the sprint events. This impression is reinforced by fitting a linear function to $ER_{100\text{ m}}$ data which yields an adjusted R^2 value of 0.998, whereas the same kind of fit for $v_{100\text{ m}}$ yielded an adjusted R^2 value of only 0.972. The same procedure yields an adjusted R^2 value of only 0.953 for v_{marathon} , but a value of 0.999 for ER_{marathon} . The age-related declines in sprinting power (100, 200 and 400 m) and endurance power (5000 m or above) therefore seem to follow a linear trend, which parallels with the linear decline in peak jumping power reported by Runge *et al.* (2004), while the decline in running speed with age seems to be more aggravated with increasing age.

In analogy to the computation of ω in equation (3.1), and in order to investigate the relative decline in metabolic power relative to the 100 m sprint, $\varepsilon_D(A)$ was computed as

$$\varepsilon_D(A) = u \cdot ER_D(A) / ER_{100\text{ m}}(A), \quad (4.1)$$

where u is the ratio of ER over 100 m to ER over the distance D at age 40. Therefore, as was the case for s in equation (3.1), u is a scaling factor unifying all ε_D values at age 40. Similar to the interpretation of ω in equation (3.1), the age-related decline in metabolic power over the distance D is equal, in relative terms, to that over the 100 m sprint when $\varepsilon = 1$; it is greater when $\varepsilon < 1$.

The results of this computation are reported in figure 2b. At variance with the values for ω (figure 1b), ε is greater than 1 for all events longer than 200 m between ages 40 and 80, and dip only thereafter. For example, the grand average of ε for events longer than 200 m yielded 1.031 between ages 40 and 69, and 1.044 for ages 70–84. This implies that the required metabolic power was slightly better preserved for endurance events than for the 100 m sprint up to age 85.

5. DISCUSSION AND CONCLUSION

We have investigated the decline of running performances with age in terms of metabolic power requirement, rather than speed. A crucial assumption of this study is that the energy cost of running per unit of body mass and distance is indeed as described by equation (2.2). The third term in this equation is the cost to accelerate the body from a stationary start to final speed (di Prampero *et al.* 1993). In turn, the final speed was assumed to coincide with the average speed and the efficiency of transformation of metabolic energy into kinetic energy during the acceleration phase was assumed to be 0.25, i.e. equal to that observed during uphill running at slopes 25 per cent or above. The greater the role of the kinetic energy term of equation (2.2), the shorter the distance and the larger the speed. It accounts for approximately 33 and 16 per cent of the overall power requirement over 100 and 200 m at age 40, and is reduced to approximately 15 and 6 per cent over the same distances at age 90. For distances of 800 m or above, it becomes 3 per cent or less of the overall power requirement.

Recently, di Prampero *et al.* (2005) have estimated the energy cost of sprint running using a novel approach based on the equivalence of an accelerated frame of reference, centred on the runner, with the Earth's gravitational field. Therefore, accelerated running on flat terrain can be viewed as analogous to uphill running at constant speed, the slope being dictated by the forward acceleration. Since the energy cost of running uphill at constant speed is fairly well known (Minetti *et al.* 2002), the energy cost of accelerated running was estimated by assessing the time course of speed and acceleration over the first 30 m of a 100 m sprint. The data reported by di Prampero *et al.* (2005) allow us to calculate the average energy cost of running for the 100 m sprint at a speed equal to that applied for the 40-year-world record. It amounts to $6.1 \text{ J kg}^{-1} \text{ m}^{-1}$, to be compared with $5.4 \text{ J kg}^{-1} \text{ m}^{-1}$, as obtained from equation (2.2). It can therefore be concluded that the two approaches for estimating the energy cost of sprint running yield comparable results. This suggests that the metabolic power requirement, as calculated in this study, does indeed represent a fair estimate of the 'true' metabolic power, even over the shorter distances and greater speeds.

The different decline with age of the record speeds and of the metabolic power over the different distances can

be explained in the light of the role played by the kinetic energy term in setting the metabolic power requirement as a function of the distance (and speed). A few calculations follow. Consider, for instance, the fall of the 100 m record speed from age 40 (9.65 m s^{-1}) to age 90 (5.09 m s^{-1}). This brings about a substantial decline of the energy cost and power from $6.29 \text{ J kg}^{-1} \text{ m}^{-1}$ and 60.7 W kg^{-1} to $4.58 \text{ J kg}^{-1} \text{ m}^{-1}$ and 23.3 W kg^{-1} . Thus, whereas at age 90 the metabolic power output over the 100 m sprint has fallen to approximately 38.4 per cent, the speed over the same distance has declined only to 52.7 per cent (of the values at age 40). On the contrary, speed and metabolic power over the marathon at age 90 are reduced to the same extent, i.e. to approximately 35 per cent of the corresponding values at age 40.

Thus, the ‘speed sparing’ effect over the short distances is entirely due to the kinetic energy term, the weight of which on the power requirement increases with the cube of the speed and declines linearly with the distance. This is because, over the short sprint distances, small declines of speed are associated with substantial reductions of metabolic power, whereas over the longer distances, the effects of the kinetic energy term become evanescently small, so that speed and metabolic power decline hand in hand. It should be pointed out that the energy spent to overcome wind resistance (second term in equation (2.2)) plays a similar (albeit much smaller) role, in so far as it also increases with the cube of the speed. However, (i) its contribution to the metabolic cost is much smaller (equation (2.2)), and (ii) it is independent of the distance, so that for all practical purposes the speed sparing effect can be attributed exclusively, or very nearly so, to the kinetic energy term.

Sprinting performance is determined by anaerobic capacity at young age. The relative decline in $ER_{100 \text{ m}}$ in the present study is in good agreement with the age-related decline in anaerobic capacity reported in the literature. For example, the estimated metabolic 100 m power declined more or less linearly between ages 40 and 70, namely from 63.3 W kg^{-1} to 43.7 W kg^{-1} , i.e. a loss of 31 per cent (see figure 3). Michaelis *et al.* (2008) have assessed anaerobic capacity by a vertical jumping test in 495 master runners. For the male sprinters, they found a decline in peak jumping power by 30 per cent between the ages of 40 and 70 (see figure 3). Again, a similar loss in jumping power by 35 per cent was found over the same age range in a fit non-athletic population (Runge *et al.* 2004). These findings are in line with the earlier observations of Margaria *et al.* (1966) on the maximum anaerobic power during running at top speed up on a staircase for the ages of 10 to 70+ years, which show an approximately 40 per cent loss of power between 40 and 70 years of age. Hence, there are multiple lines of evidence for a fairly linear loss of anaerobic power, equivalent to 1 per cent of the power of a 40-year-old person per year, from the age of 40 onwards in athletes as well as in a fit elderly population.

Aerobic power ($VO_2\text{max}$) is a major physiological determinant of distance running (Costill 1986). When trying to assess age-related changes in $VO_2\text{max}$ in distance runners, past studies have yielded quite diverging results, with some studies (Heath *et al.* 1981; Fuchi *et al.* 1989; Rogers *et al.* 1990) reporting an age-related decline only half as large as others (Pollock *et al.* 1997; Wiswell *et al.*

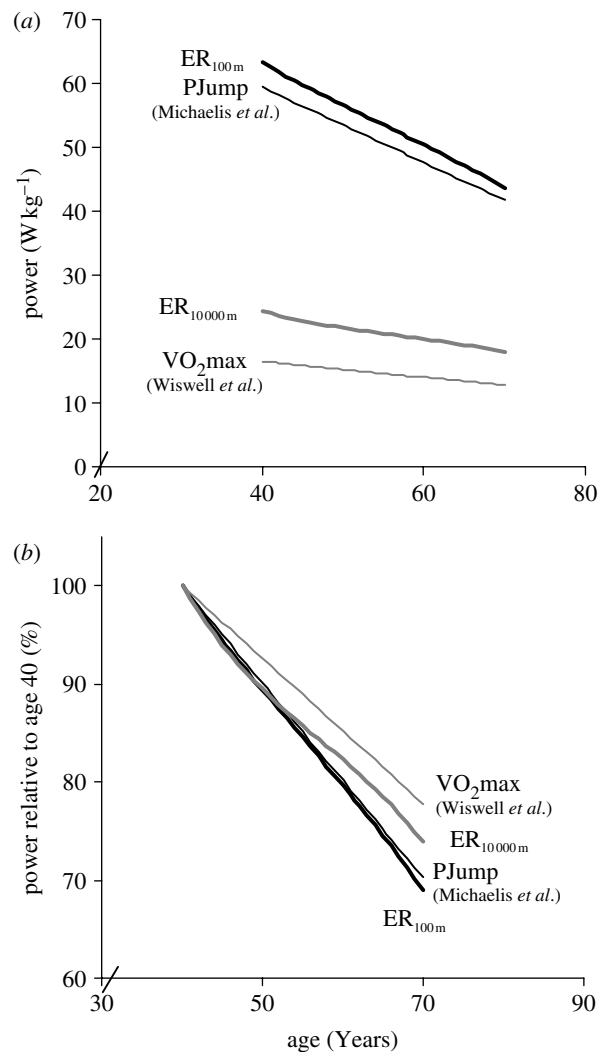


Figure 3. Comparison of the age-related declines in ER and in aerobic and aerobic capacity, displayed in (a) absolute terms and (b) relative terms. Anaerobic capacity was identified as the peak power in a vertical jump test (PJump). Here, we used the regression equation from 126 master sprinters (Michaelis *et al.* 2008). $ER_{100 \text{ m}}$ is the metabolic power required for the 100 m sprint world record. Since PJump is an external mechanical power value, it cannot be compared to $ER_{100 \text{ m}}$ in absolute terms. However, almost identical relative decline rates can be observed between PJump and $ER_{100 \text{ m}}$. $ER_{10000 \text{ m}}$, i.e. the metabolic power involved in the 10 000 m race world record, is consistently above the $VO_2\text{max}$ regression line found by Wiswell *et al.* (2001) in a sample of 146 master runners of mixed athletic capabilities. Values from the latter study have been transformed from $\text{ml O}_2 \text{ kg}^{-1} \text{ min}^{-1}$ to W kg^{-1} , assuming a caloric equivalent of $20 \text{ J ml}^{-1} \text{ O}_2$. Apparently, the relative decline in (b) is somewhat larger for $ER_{10000 \text{ m}}$ than for $VO_2\text{max}$.

2001). Importantly, most of those studies were relatively small, and only the study by Wiswell and colleagues seems to be large enough (146 men) to allow for a generalization. As shown in figure 3b, the results for $VO_2\text{max}$ in that study are, in principle, in agreement with the age-related decline in $ER_{10000 \text{ m}}$ found in this study. In quantitative terms, $ER_{10000 \text{ m}}$ in our study declined by 26 per cent, and $VO_2\text{max}$ in Wiswell's study by 22 per cent between the ages of 40 and 70 (Wiswell *et al.* 2001). The somewhat smaller decline in Wiswell *et al.*'s study is probably due to the fact

that their cross-sectional study sample was of rather mixed athletic capabilities, whereas the world records are, by definition, achieved by the very best athletes.

In conclusion, the present analysis of the age-related decline in metabolic power underlying the running records has yielded a 'sparing' effect in favour of aerobic power. However, it is probably the most important finding of this study that such sparing effect is rather moderate, not amounting to more than 10 per cent (figure 2b). In other words, ageing compromises the ability to generate power in a strikingly similar way in distinctly different athletic categories, distinguished not only by different background skills but also by training-specific adaptations. The important question therefore arises as to why the maximally achievable anaerobic and aerobic powers decline with age in such a similar fashion.

Evidence from past cross-sectional studies has suggested that ageing involves selective atrophy and loss of type II muscle fibres (Larsson 1978; Lexell *et al.* 1988), and one should therefore expect the age-related fall in metabolic power to be more aggravated for sprint rather than for endurance performance. Recent studies, however, have suggested that selective atrophy of type II fibres may be more related to disuse rather than ageing, since it can be reversed by resistive training. Importantly, any loss of muscle fibres due to neuropathic phenomena (Narici & Maganaris 2006) cannot be reversed. Hence, master athletes, having been exposed to lifelong training, do not show any disuse-related fibre atrophy, and from 40 to 80 years of age their fibre size remains constant (Tarpennig *et al.* 2004). The level of physical activity not only affects fibre size but also the maximum shortening velocity of single fibres (V_o), as D'Antona *et al.* (2007) have shown that both type I and type II fibres of immobilized older individuals have higher V_o values than sedentary and endurance-trained elderly subjects. Thus, master athletes, owing to their lifelong physical activity, are expected to show mainly age-related, rather than disuse-related, changes in fibre-shortening velocity, as seems to be confirmed by the finding that both type I and type II fibre V_o values of endurance runners are only slightly lower than those of young sedentary individuals (Trappe 2001; D'Antona *et al.* 2007). In addition to the quite well-preserved fibre-shortening velocities, fibre-type distribution seems to be unaffected by age in master athletes, and co-expression of multiple myosins (so-called 'hybrid fibres') seems to be rare (Trappe 2001; Aagaard *et al.* 2007). Therefore, despite the mandatory loss of muscle fibres due to neuropathic processes, the actual proportion of type I and II fibres seems maintained in lifelong trained athletes, an observation that may partly account for the similar decline in muscle power in endurance and sprint athletes.

In summary, the new approach of this study, by which age-related world records have for the first time been analysed in terms of metabolic power rather than only in terms of performance (i.e. speed or time), has shown that there is a very mild sparing effect of aerobic power generation—as would have been expected by most experts in the field. However, such sparing effect is relatively small, and the most important finding that arises from the present study is that a balanced decline of aerobic and anaerobic power occurs with age.

ENDNOTE

¹The terms 'master' and 'veteran' athlete are used interchangeably.

²Obviously, those records are frequently bettered and some have been bettered since June 2007. These changes have been rather small and occurred at all running distances. It therefore seems unlikely that this will affect our analysis and interpretation systematically.

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