INVITED REVIEW

Ageing, aerobic capacity and insulin sensitivity in masters athletes: endurance and speed-power training benefits

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Introduction. Aerobic capacity, insulin sensitivity and other cardiovascular and metabolic characteristics determine our health and quality of life. Masters athletes may be regarded as a model population for the assessment of the age-related functional decline, due to their chronic physical activity and lack of factors associated with secondary ageing. So far, ageing studies have concentrated on endurance-trained athletes. Masters speed-power athletes have not been the focus of attention as regards successful ageing and health. This review presents health outcomes in speed-power athletes (SP) with long-standing competitive sport participation compared to endurance-trained athletes (ER) and untrained subjects (UT). **Results.** SP show a lower level of maximal and submaximal aerobic capacity than ER, but significantly higher than UT. Insulin sensitivity and β-cell function in SP are relatively stable across a wide age range (20−90 years) and comparable to these parameters in ER, whereas in UT glucose metabolism visibly deteriorates with age. Some effects of speed-power training are more beneficial than endurance training. These are a slower rate of decline in aerobic capacity and some cardiorespiratory parameters, especially after the age of 50, and a more stable β-cell function. Moreover, master sprinters have better neuromuscular function, higher bone mineral density and lean body/muscle mass than endurance athletes. At the same time, SP's lipid profile is normal and the risk connected with overload of ligaments and tendons seems to be similar to that in ER. Long-term intensive endurance training, in turn, may induce deleterious changes in the cardiovascular system and increase the risk of some types of heart arrhythmias. Moreover, speed-power training may facilitate the adherence to physical activity. **Conclusions.** The "speed-power model" of lifelong physical activity should be considered an alternative proposal to support recommended levels of aerobic capacity, insulin sensitivity and other health characteristics with ageing.

KEYWORDS: maximal oxygen uptake, gas exchange threshold, homeostatic model assessment, β-cell function, physical activity, successful ageing.

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What is already known on this topic?

The positive effect of endurance sports on age-related changes in aerobic capacity and insulin sensitivity has been well known. However, these important health-related characteristics have not been explored in master speed-power athletes in the context of ageing.

Introduction

Aerobic capacity is commonly viewed as an important physiological determinant of human functional efficiency and health. It can be measured (i) as maximal (or peak) oxygen uptake ($\dot{V}O_2$max) for the upper limits of aerobic physical fitness of the individual; or (ii) as various kinds of "anaerobic thresholds" for the assessment of the ability to continue submaximal intensity exercise and fixing the point above which cardiovascular system does not fully meet the oxygen supply requirements. These two indicators provide independent information [1] but both characterize cardiorespiratory fitness, the deterioration of which is connected with increased mortality risk (cardiovascular

diseases, cancer, all causes), diseases of affluence (e.g. hypertension, diabetes, metabolic syndrome) and, finally, with poor life quality, dependence and disability [2, 3]. The prevalent low level of cardiorespiratory fitness also generates, in consequence, social and financial problems due to disability pensions and early retirement [4]. The range of 15–18 ml·kg^{-1}·min^{-1} for $\dot{V}O_2$max seems to be a boundary between independent living and disability [5, 6].

Insulin resistance and raised blood glucose are the key features of Type 2 diabetes. This type accounts for over 90% of diabetes cases globally and is considered one of the main health- and life-threatening diseases of the 21st century, rightly called an epidemic [7]. The prevalence of raised fasting blood glucose ($\geq$ 126 mg·dl^{-1}) among adults aged $\geq$ 25 years reached globally 9.5% (~640 million) in 2008 [8]. The global prevalence of diabetes in adults aged 20−79 years is projected to rise from 382 million (8.3%) in 2013 to 592 million (10.1%) in 2035 [9]. It is associated with increasing average life duration, resulting in ~15% of world population aged 80+ years afflicted with this disease [10].

The aim of this review is to concisely describe the effects of a long-term participation in competitive sport on two important health outcomes: aerobic capacity and insulin sensitivity. Two distinct training models will be contrasted: (i) based on speed-power exercise; and (ii) based on endurance exercise, both represented by competitive athletes in a wide age range up to 90 years.

Masters athletes as a model population
Until recently, scientists have focused exclusively on general population or simply sedentary individuals in their search of factors contributing to the inevitable functional decline with age. Today, however, the opinion which receives more recognition is that highly physically active and trained subjects should serve as a model population, and that they are the best control group in research on human age-related decline in physical fitness, in order to separate the effect of "pure" senescence (inherent ageing) from secondary factors associated with lifestyle. Competitive masters athletes meet such requirements because they continuously maintain a higher-than-average, mostly extraordinary, level of physical activity and fitness [3] over decades filled with 3−6 sessions (several hours of intense exercise) each week [11]. Consequently, factors confounding the "natural" picture of ageing affect the results of studies on masters athletes to a much lesser extent than studies on general population. The undesirable phenomena untrained/sedentary individuals are exposed to include e.g. increased body fatness, reduction in muscle mass, co-morbidity [3, 12, 13], incidence and risk of cardiovascular diseases, hypertension, diabetes, and a proportion of smokers [14, 15]. Masters athletes not only rate their health level higher than their untrained or sedentary peers [14], but they also reach the upper limits of human physical performance [16, 17]. They are, as suggested, an adequate model to study the physical dimension of "successful ageing" [18].

The effect of physical activity
It seems that chronic physical activity is a normal state because during the evolution of human metabolic pathways genes were selected to support physical activity that was obligatory for survival [19]. Competitive athletes are similar in this respect to the Paleolithic and still existing here and there hunter-gatherer societies that lack tobacco, rarely have hypertension and lead lives characterized by considerable exercise [21]. It is suggested that the so-called hypertrophy of skeletal muscle and the "athlete's heart" are not adaptations to increased physical activity but a desirable norm, whereas sedentary control subjects in exercise studies represent, in fact, pathological effects of activity shortage [20, 22, 23]. Lifetime physical inactivity accelerates secondary ageing (caused by diseases of affluence and environmental factors) and shortens average life expectancy [24].

In apparently healthy untrained individuals, a decline in aerobic capacity with ageing has been consistently observed by numerous researchers, who studied both maximal aerobic capacity [2, 9] as well as "threshold" (submaximal) aerobic capacity using various methods [25, 26, 27]. Also in the case of insulin sensitivity, the unfavourable age-related changes seem to be inevitable [28] with a peak at about 80 years [29]. This can be, however, prevented or at least substantially delayed by lifetime physical activity. There are many clear and persuasive arguments supporting the thesis that secondary ageing develops much faster with progressive and prolonged inactivity accompanied by deterioration in physiological functions [24]. According to existing evidence, it is unhealthy lifestyle (resulting, e.g., in insufficient physical activity, gaining fat mass, illnesses, medication), rather than ageing itself, which significantly affects the deterioration of cardiorespiratory function and the decrease in insulin sensitivity [2, 30, 31, 32].

Early studies initiated in the 1960s showed that maximal aerobic capacity in middle-aged and older masters athletes could be maintained on a high level; or that the decline considerably decelerated in 10-, 22-, 25- or even 33-year periods, if subjects adhered to regular endurance training programme as opposed to their peers who dropped out or were inactive [13, 33, 34, 36, 44]. Similarly, also submaximal aerobic capacity can be preserved in the elderly, as demonstrated in physically active octogenarians who showed higher measured than predicted levels of ventilatory threshold [37]. It was revealed that not only competitive sport but also simple exercise habits (e.g. 30-min sessions twice a week over a few months) resulted in increased ventilator threshold in adult individuals [38]. In the case of highly-trained male athletes, a considerably elevated and unchanging absolute ventilatory threshold was observed up to 50 years old [39]. As for the glucose regulation, its deterioration was shown to be effectively prevented in ageing endurance-trained athletes [30, 32, 40, 41, 42, 43].

Neglected research on speed-power athletes
For certain reasons, in principle, only endurance runners [13, 36, 44, 45, 46] and other endurance-trained athletes [33, 35, 41, 47, 48] have been the focus of studies on ageing-related changes in maximal aerobic capacity. Research in this particular area that would include speed-power masters athletes has been scarce [49, 50, 51, 52] and laden with imperfections precluding a deeper analysis of the age-related decline such as narrow age ranges, small number of subjects, lack of control untrained groups, and not so strictly speed-power character of competition. In terms of different manifestations of the "anaerobic threshold" (lactate, ventilatory or gas exchange thresholds), it is virtually an unsurveyed area in the context of ageing speed-power athletes. To our best knowledge, no research papers have been published so far, except for the one written by our team [53] that describes age-related long-term changes in the "anaerobic threshold" in sprint-trained athletes. This lack is in part explainable by the fact that indices of maximal and submaximal aerobic capacity are not used as speed-power (sprint) performance parameters. Also, only the effect of chronic endurance exercise on insulin sensitivity preservation across a wide age range has been well described [30, 32, 40, 41, 42, 43]. Sparse studies tackling insulin sensitivity in sprint-trained

athletes include solely young participants [54, 55, 56]. Analogous studies on age-related changes in older speed-power athletes are practically non-existent.

Training models
In principle, training modalities of speed-power and endurance-trained athletes differ considerably. On the other hand, the physical preparation of a speed-power athlete requires, paradoxically, a substantial volume of low-intensity exercise, the duration of which reaches, e.g., over 80% of the total net training time or about 50% of total energy spent in a one-year cycle of a young sprinter [57]. In masters speed-power track and field athletes, endurance improvement still takes up from 10 to 50% of training duration (0.6–2.0 training sessions per week) in different periods of the year [11]. This results from the necessity of using essential training components like warm-up, drills for technique perfection and active recovery after high-intensity exercise or competition. Apart from this, sprint-trained masters athletes develop, of course, speed and speed-endurance abilities, jumping ability and strength as their leading fitness characteristics, directly determining sport performance. In general, training loads of an ageing speed-power athlete are characterized by a quite large qualitative diversity [11].

What is more, the effects of sprint interval and endurance training may be surprisingly similar in some aspects. Admittedly, the available research includes only young adults (20–30 years old), but it suggests the potential of high-intensity training as an alternative exercise model for the improvement of vascular and metabolic health, comparable with conventional endurance training, also in older populations. In young, recreationally active individuals, short sprint interval training increased muscle oxidative potential and doubled endurance capacity during intense aerobic cycling [58, 59]. Such training substantially improved a number of metabolic and vascular risk factors in overweight/obese young sedentary men: $\dot{V}O_2$max, mean Wingate power, insulin sensitivity index, resting fat and carbohydrate oxidation rate in the fasted state, systolic blood pressure, waist and hip circumferences [60]. It was also reported that "anaerobic threshold" may be as or more effectively elevated by high-intensity interval training compared to high-volume low-intensity endurance training [61]. Moreover, not only traditional endurance training but also high-intensity sprint interval training improves insulin sensitivity in sedentary or recreationally active

humans [62, 63]. These experimental data are supported by observations of young sprint-trained athletes who are characterized by better insulin sensitivity than an untrained group [56] as well as similar [55] or only somewhat lesser [54] insulin sensitivity in comparison with endurance-trained peers. The analysis of medicines taken by former elite sprint-trained athletes aged from 36 to 89 years revealed that they are less exposed to diabetes than power athletes (e.g. weightlifters) and untrained subjects [64].

The speed-power model of training seems to be interesting in the context of health and fitness preservation in a long-term perspective due to beneficial adaptations that match up to those resulting from the endurance model. Based on studies done so far, one may expect that speed-power athletes practicing competitive sport on a regular basis will maintain a relatively high level of aerobic capacity and insulin sensitivity across the lifespan. Some crucial questions should be posed here. Is the level of aerobic capacity in ageing speed-power athletes comparable to that of endurance runners? Does the rate of decline in maximal and submaximal aerobic capacity differ significantly between these two groups? Do sprint-trained athletes show stable insulin sensitivity and β-cell function comparable to those of endurance-trained peers across a wide age range? Are other functional and structural parameters in master speed-power athletes optimal for health?

Participants and methods

Our three latest studies elucidated in part the relationship between speed-power training model and ageing-related changes in aerobic capacity and insulin sensitivity – two manifestations of systemic cardiovascular and metabolic mechanisms that are not only related to sport performance, but are, first of all, crucial to support individual health in a lifetime perspective [53, 65, 66]. We examined in total 203 men: track and field speed-power (sprint-trained) athletes aged 20–90 years, endurance-runners aged 20–80 years and untrained participants aged 20–70 years. In athletes, their training history was 30.4 (8–77) years in the speed-power group and 27.4 (7–66) years in the endurance group; weekly training time was 8.1 ± 2.7 and 9.0 ± 3.5 hours, respectively. The most important assumption was that highly-trained athletes are functionally and metabolically adapted for their specific exercise training and, thus, are representative of many years' speed-power or endurance training modality.

Maximal oxygen uptake ($\dot{V}O_2max$) and oxygen uptake at gas exchange threshold ($\dot{V}O_{2GET}$) [67] were obtained during an incremental treadmill test until exhaustion. The homeostatic model assessment (HOMA2) was used to determine insulin sensitivity (HOMA-%S), β-cell function (HOMA-%B) and insulin resistance from paired fasting glucose and insulin levels [68]. The main strengths of the studies were: (1) an unprecedently wide age range of speed-power athletes compared to earlier studies on aerobic capacity and insulin sensitivity; (2) participation of elite-level athletes and thus separation of strongly pronounced distinct training models; (3) avoiding the effect of seasonal changes in parameters analyzed due to testing in the competition period; (4) a quite large number of speed-power athletes in spite of non-standard exercise test during important championships; and (5) participation of untrained subjects.

Maximal aerobic capacity

Some earlier studies that included smaller numbers of masters athletes and encompassing narrower age ranges [49, 50, 52] showed a lower average level of maximal aerobic capacity in speed-power than endurance master athletes. In our research, we compared two groups of masters athletes as regards $\dot{V}O_2max$ and its contribution to the age-related decline [65]. Like in former studies, endurance-trained athletes surpassed sprint-trained athletes (~58 v. ~47 ml·kg^{-1}·min^{-1}, respectively); however, the level of the speed-power group was still considerably above that of the untrained group (~41 ml·kg^{-1}·min^{-1}). Admittedly, some researchers revealed that $\dot{V}O_2max$ may be higher in young untrained individuals than in non-endurance athletes (bobsledders), but the results could be biased by age differences (untrained controls were ~8 years younger), moreover, the aerobic capacity changed in favour of bobsledders after a 15-year follow up [51].

One feature seems to be distinctive for the speed-power athletes, according to our research: the rate of cross-sectional decline in $\dot{V}O_2max$, expressed both as body mass-adjusted and percent values, is smaller in sprint-trained athletes (0.31 ml·kg^{-1}·min^{-1} per year, 5.6% per decade) than in endurance runners (0.46 ml·kg^{-1}·min^{-1} per year, 6.6%) and untrained participants (0.35 ml·kg^{-1}·min^{-1} per year, 7.0%) groups [65]. In support of this outcome, other scientists reported a slower longitudinal 15-year rate of decline in $\dot{V}O_2max$ in sprint compared to endurance athletes

[51]. Furthermore, the age of 50 seems to be crucial in this respect. Above this age, the rate of decline in $\dot{V}O_2$max in older sprinters remains similar to that of younger ones (0.19 ml·kg^{-1}·min^{-1} per year for both age groups), whereas in older untrained and endurance-trained subjects the decline in $\dot{V}O_2$max "escalates" to 0.50 and 0.63 ml·kg^{-1}·min^{1} per year, respectively. This is the reason why the difference in average levels of aerobic capacity between sprinters and endurance runners virtually disappears about the age of 80 years [65]. In contrast, endurance-trained subjects usually reduce their maximal aerobic capacity faster with age [45, 46] or at a similar rate at best [69] in comparison with their untrained peers.

The strongest central factor that determines the slowest reduction of $\dot{V}O_2$max in speed-power athletes is probably maximum heart rate, because it declines most slowly in this group, whereas the reduction is most rapid in endurance runners. At the same time, maximal oxygen pulse (indirectly reflecting stroke volume) and haemoglobin concentration change similarly with age in all groups [65].

Significant positive correlations between variables describing aerobic capacity and weekly training volume were found in athletes. The weekly training volume was the primary predictor of $\dot{V}O_2$max (~29% of explained variance) and maximal distance (~53% of explained variance) in both the sprint- and the endurance-trained groups, complemented by haemoglobin level and body mass or body mass index [65].

Submaximal aerobic capacity

In one of our studies we showed that also $\dot{V}O_{2GET}$, reflecting submaximal aerobic capacity, may be effectively maintained across a wide age range in sprint-trained athletes [53]. Admittedly, their levels of $\dot{V}O_{2GET}$ were clearly lower compared to endurance-trained athletes but, at the same time, much higher than those observed in untrained individuals. The differences were visible regardless of the type of measure: absolute, body mass-adjusted or relative (%$\dot{V}O_2$max). The linear regression analysis showed that the rate of decline in $\dot{V}O_{2GET}$ is slower in sprinters (0.38 ml·kg^{-1}·min^{-1} per year) than in endurance runners (0.56 ml·kg^{-1}·min^{-1} per year) and slowest in the untrained group (0.22 ml·kg^{-1}·min^{-1} per year); however, the percentage changes were similar in the three groups (about 8% per decade). Interesting results were obtained when data were analyzed separately for subgroups below and above 50 years

of age. In the endurance-trained and untrained groups, the loss of $\dot{V}O_{2GET}$ was considerably more pronounced in older than in younger subjects (0.65 vs 0.42 and 0.21 vs 0.17 ml·kg^{-1}·min^{-1} per year, respectively). In contrast, the rate of decline was uniform across the whole age range in speed-power athletes (0.24 ml·kg^{-1}·min^{-1} per year, regardless of the age group). Also, the percent decline in $\dot{V}O_{2GET}$ after the age of 50 was visibly smaller in speed-power athletes (7.2% per decade) than in endurance-trained athletes (13.4%) and untrained participants (10.2%). The discrepancy in age-related changes made the two groups of athletes very similar as regards the average level of $\dot{V}O_{2GET}$ at the advanced age of about 85 years.

The multiple regression analysis revealed that it is not the age as such but the age-related changes in cardiorespiratory characteristics that contribute to the decline in submaximal capacity [53]. The strongest predictor of $\dot{V}O_{2GET}$ was oxygen pulse at gas exchange threshold which explained over 90% of variance. The greater $\dot{V}O_{2GET}$ and its slower decline with age in sprint-trained than untrained subjects may be explained by either a greater stroke volume or O_2 extraction, since other cardiovascular factors (heart rate at gas exchange threshold, haemoglobin and haematocrit) were similar. A significant positive relation was revealed between weekly training volume and $\dot{V}O_{2GET}$ in the combined group of speed-power and endurance athletes, indicating the crucial role of physical activity in maintaining the level of submaximal aerobic capacity.

Insulin sensitivity

In another study we showed some basic parameters of glucose metabolism against age in ageing subjects representing different training modalities and levels [66]. The most important result was that speed-power athletes maintained a relatively stable insulin sensitivity and β-cell function with age. Their levels of HOMA-%S and HOMA-%B were similar to those of endurance-trained athletes in the age range from 20 to 90 years. Admittedly, impaired fasting glucose was somewhat more frequent in speed-power athletes than in endurance runners. With age, untrained individuals showed a rapid increase in fasting insulin and β-cell activity accompanied by a relatively rapid decrease in insulin sensitivity. Thus, athletes maintained the balance between insulin secretion and insulin sensitivity, whereas lower physical activity status was connected with age-related intensifying of β-cell activity to compensate decreasing insulin sensitivity.

Speed-power athletes were characterized by the smallest age-related cross-sectional rate of increase in fasting glucose (0.07 mmol·l⁻¹ per decade) when compared to endurance runners (0.12 mmol·l⁻¹ per decade) and untrained controls (0.08 mmol·l⁻¹ per decade). Both speed-power and endurance athletes did not show any significant correlation between fasting insulin and age. In contrast, this relationship was strong in the untrained group ($r = 0.78$) in which the rate of increase in insulin level was 7.6 pmol·l⁻¹ per decade. Additionally, lower fasting glucose and insulin as well as higher insulin sensitivity (but not β-cell function) were associated with higher levels of $\dot{V}O_2$max ($r = -0.29$, -0.59 and 0.58, respectively).

Comparing other health effects
As shown above, the speed-power model of lifelong physical activity is comparable to the endurance model in regard to health-related levels of aerobic capacity and insulin sensitivity. This comparison may be extended to other significant health qualities. The results of our and other studies suggest that speed-power training is beneficial to several aspects of the broadly understood physical fitness and activity in the context of ageing. Apart from above described effects, this training modality practiced on a lifetime basis seems to be associated with, for example, a more optimal blood lipid profile [51, 52] and body composition [49, 70] than observed in untrained individuals, similarly to endurance training. Importantly, ageing speed-power athletes have higher lean body mass than endurance athletes [70], which must be considered advantageous. For both young and older athletes, another advantage of the speed-power over the endurance training is a definitely better effect on bone strength and structure as well as neuromuscular function that are promoted most effectively in high-impact disciplines like sprint, jumping or basketball [71, 72]. This beneficial effect is due to the extremely high mechanical force and power generated in the eccentric phase of muscle activity, stimulating bone strength during specific exercise [73]. As a result, masters sprinters have higher bone mineral density and content than masters endurance athletes [70, 74]. Besides, the latter may have similar bone parameters as untrained individuals at some measured sites [70, 75, 76, 77]. Neuromuscular function tests (e.g. countermovement jump, multiple one-leg hopping and grip force) not only show the advantage of speed-power training over endurance training but also demonstrate that masters endurance athletes may be, surprisingly, less fit than the general population in this respect [72]. Furthermore, in spite of the common view, sprint training does not seem to be more hazardous for tendons and ligaments (due to mechanical overload or inflammation) than endurance exercise, as was shown in our two recent studies [78, 79]. However, it must be openly said that, in general, the tendon rupture risk is higher in masters track and field athletes, regardless of specialization, than in untrained individuals [14]. On the other hand, also individuals who do not practice competitive or any other sports suffer from such ailments [80].

To be fit and healthy, one must be physically active. All competitive masters athletes are highly motivated, however, certain factors induce them to practice a specific discipline. This may be, e.g., somatic and mental predispositions, personal inclinations, exercise perception or simply available leisure time. The speed-power training model may be preferred for some reasons. Reportedly, endurance exertion is perceived as more strenuous than sprint exercise [81], thus, many years' adherence to training based on short-term exercise may be easier, as it was exemplified by comparison of the duration of competitive sport history in masters speed-power (25–34 years) and endurance (16–18 years) athletes [11]. Moreover, the link between personality traits and favourite sport/physical activity has been well known [82, 83]. Thus, speed-power sports are chosen by a specific group of people who satisfy their personal needs. Finally, lack of time is the most common subjective barrier to preclude adults from participation in physical activity [60, 84]. In this light, short-duration high-intensity exercise may be an alternative solution that has been recently recommended [85]. It seems that speed-power training is less time- and energy-consuming [62] and, despite this, as efficacious as endurance training regarding some key health outcomes [60, 63].

Endurance training is commonly associated only with positive effects in masters athletes, especially for heart structure and function [50, 86], aerobic capacity and related characteristics. Recently, some controversies emerged about the health-related value of the many years' endurance training. Surprisingly, some researchers, based on well-designed studies,

indicated that the long-term high-intensity endurance exercise may result in harmful functional and structural alterations, e.g. higher incidence and risk of heart arrhythmias [87] or specific damages and malfunctions in the cardiac, peripheral and cerebral vascular system [88]. It is not known whether the long-term speed-power training is less risky for the cardiovascular system, because of lack of research in this area. Beyond a doubt, health benefits outweigh the risk associated with regular sport practice (if reasonably programmed), regardless of training profile.

It is clear that extreme caution should be exercised when recommending or prescribing high-intensity training to beginners or people with specific disorders, especially cardiovascular and metabolic. However, some researchers demonstrated that interval training of increased or high intensity, may be safely and effectively administered in patients with metabolic syndrome [89, 90], type 1 diabetes [91], cardiovascular diseases, heart failure [92, 93] or in post-surgical rehabilitation in individuals with coronary artery disease [94]. Currently, even in patients undergoing heart transplantation, specific adapted forms of such training have been seriously discussed with growing consensus that it produces greater benefits than moderate-intensity continuous training [95, 96, 97].

To be a speed-power athlete or not to be?

So far, priority has been given to endurance training, and its health advantages have been demonstrated repeatedly. However, it has not yet been compared with any other training modality as regards the effects on ageing and health. Most often, *exercise* and *training* are used synonymously with *endurance exercise* and *endurance training* in health and ageing research. However, it seems that this training modality is not the only way to support successful ageing. In a long-run perspective, also the speed-power training model results in aerobic capacity and insulin sensitivity levels comparable with those induced by endurance training, and much better than in untrained individuals, as suggested above. Additionally, speed-power athletes are characterized by slower ageing-related decrease in $\dot{V}O_2max$, maximum and threshold heart rate, oxygen pulse as well as by virtually constant β-cell function across a wide age range. It must be admitted that endurance-trained athletes clearly surpass sprint-trained peers as regards parameters of aerobic capacity

(or cardiorespiratory function in general) and insulin sensitivity. However, speed-power training still ensures health outcomes far above average, and the differences between the two training models decide the question of sport performance, rather than of general health. The advantage of the speed-power model may be that it is beneficial not only to aerobic capacity, cardiovascular fitness and insulin sensitivity, but also to other important health outcomes, often to a greater extent than the endurance model.

Limitations

Surely, one should take into account some assumptions and limitations associated with presented deliberations. The athletes examined by us and others have a very long training history, reaching over 70 years in some cases, and consequently show far better levels of physical fitness and health than the general population. One may say that, in many aspects, they exemplify a model of "successful ageing" based on permanent adherence to sport training, usually undisturbed by factors related to an unhealthy lifestyle. We did not discuss the question of recommendations and interventions in individuals who are chronically inactive, suffer from certain disorders or initiate their competitive sport participation without previous preparation. Nevertheless, it seems that that the speed-power model of physical training, if started early in life or later with appropriate caution and then continued, may be a suitable and useful activity form to support aerobic capacity, insulin sensitivity and other health characteristics.

The available studies are cross-sectional and, thus, only approximate rates and time-course of changes in parameters analyzed have been revealed, whereas there is a quite large variability among subjects of the same age. Admittedly, this approximation seems to be useful since longitudinal studies covering such a large age range are currently unfeasible. We also did not control specific genetic factors that could be associated with presented relationships. It is well known that physical fitness and sport performance are determined by numerous genes, associated with respiratory and cardiovascular function, body build and composition, muscle strength, carbohydrate and lipid metabolism, response to training, exercise (in)tolerance and others [98, 99]. Finally, only men were examined. Undoubtedly, the problem of long-term health effects of speed-power training model deserves more attention in the future.

Conclusions

In the presented review, the issue of effects of many years' speed-power training on the aerobic capacity and insulin sensitivity was raised in the context of ageing. The examination of competitive athletes – in which factors related to an unhealthy and inactive lifestyle affect the ageing process to a small extent – allows a relatively undisturbed comparison between two modalities of lifelong physical activity in a wide age range. The available research provides convincing evidence that older age and poor health are not inseparable. The speed-power model of lifelong physical training may play an important role in maintaining health and physical fitness significantly above population norms for long periods. What is more, high-intensity exercise of short duration must be simply considered indispensable to support some specific health aspects.

Elevated levels of aerobic capacity and insulin sensitivity are prerequisites not only for maximizing sport performance but also for comfortable independent functioning in everyday life and for preventing diseases of affluence, especially in older age. A lifelong training including high-intensity exercise seems to be an effective tool to ensure these goals. It is associated with beneficial physiological and metabolic adaptations, time savings, the possibility to chose preferred activity forms as well as, presumably, longer-term participation in sport.

In conclusion, the existing scientific evidence authorizes us to suggest that not only endurance but also speed-power sports are suitable for maintaining lifelong physical activity, fitness and health. The currently common paradigm which "privileges" endurance training needs revision. Thus, we recommend the "speed-power model" as an alternative activity form to support optimal levels of aerobic capacity, insulin sensitivity and other health outcomes with ageing.

What this study adds?
The speed-power model of lifelong physical activity is associated with high levels of maximal and submaximal ("threshold") aerobic capacity, and their slower rate of age-related decrease than in endurance athletes. It allows maintaining aerobic fitness significantly above values of healthy untrained individuals across the age range of 20–90 years. The increased aerobic fitness is in turn associated with increased insulin sensitivity and its stability with age. Also, a number of other health and physical activity aspects are positively related to speed-power training. Thus, we recommend the "speed-power training model" as an alternative activity form to support optimal levels of aerobic capacity, insulin sensitivity and other health outcomes with ageing.

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