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Age-Related Decline in Olympic Triathlon Performance: Effect of Locomotion Mode

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AGE-RELATED DECLINE IN OLYMPIC TRIATHLON PERFORMANCE: EFFECT OF LOCOMOTION MODE

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This study describes the decline in performance with age during Olympic triathlon Age Groups World Championships among the different locomotion modes. Mean performance of top 10 performers were analyzed for each group of age using the exponential model proposed by Baker, Tang,

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and Turner (2003, Experimental Aging Research, 29, 47–65). Comparison in performance decline was done between locomotion modes. Decline in performance in triathlon as a function of age follows an exponential model. A significant interaction effect between age and locomotion mode was observed on performance values. In swimming, a significant decrease was observed close to 5% per year after 45 years. Decline in performance was less pronounced in cycling until 60 years. Analysis of the effect of age in the different locomotion modes of a triathlon could provide information for maintaining quality of life with aging.

In recent years there has been an increased interest in issues related to the enhancement of performance of master athletes (Tanaka & Seals, 2008). Many of the changes in physiological functional capacity related to aging have been found to be the result of long-standing sedentary lifestyle (Maharam, Bauman, Kalman, Skolnik, & Perle, 1999; Wright & Perricelli, 2008). This reduction in physical capacity with aging is related to reduction in physical activity as well as to changes in body composition or development of clinical diseases. Within this framework, studies on master athletes' performance have shown that master athletes are able to maintain their performance despite the structural changes in muscle classically described with aging. Over the last decade, the participation of master athletes has increased, especially in long distance events. In the marathon, for example, the performance of masters has significantly improved, with 70-year-old athletes running it in less than 3 h (e.g., Trappe, 2007). Since the early work of Hill (1925), the study of the performance record has often been used in the literature to study the mechanisms of physiological adaptation, and more recently the impact of the aging process on these mechanisms (Baker, Tang, & Turner, 2003; Balmer, Bird, & Davison, 2008; Tanaka & Seals, 2003, 2008; Wright & Perricelli, 2008). They have shown a small decline in performance between 30 and 50 years, followed by a more pronounced decline in performance from 50 to 60 years and a significant alteration from 70 years. In the literature, several methods and models have been used to describe the decline. On the one hand, for athletic events (including races, jumping, throwing, and walking), several authors have compared different mathematical models to describe the relationship between age and performance (Baker et al., 2003; Moore, 1975; Stones & Kozma, 1986; Tanaka & Seals, 2003, 2008). In this context, Baker et al. (2003) have normalized the best performance for each age group, with the best performance of athletes below

30 years. The decline is represented by a ratio that decreases exponentially $[Y = 1 - \exp(T - T_0)/\tau]$ for running and linearly $[Y = \alpha(T - T_0)]$ for jumping or walking. On the other hand, with the increased participation of masters athletes in long distance events such as the marathon or half marathon, quantitative approaches have identified a breaking point in the evolution of performance. Recently, Leyk et al. (2007) have statistically analyzed the results of 65 semimarathons and 69 marathons using the average performance from the first 10 athletes (TOP 10) for every 10-year age group. Even though not record performances, the results presented confirm previous observations and indicate a decline in performance of 2.6% to 4.4% per decade between 50 and 69 years (Leyk et al., 2007). Classically the decline in performance is related to changes in cardiovascular and muscular systems with age (e.g., Tanaka & Seals, 2008). With aging, a vicious circle is established between the reduction of activity, changes in body composition, and cardiovascular disorders or reduced respiratory function (Maharam et al., 1999). In recent reviews on this topic, Tanaka and Seals (2003, 2008) have observed that the alteration of performance with age was different between running and swimming and seems specific to the exercise task characteristics.

These studies have mainly considered single-sport performance such as running, and more recently cycling or swimming performance. During the last decade, triathlon, involving successive swimming, cycling, and running sessions, has become one the most popular multidisciplinary event. Studies focusing on factors affecting performance during a triathlon have clearly identified differences with single performance, indicating that the effect of previous locomotion mode on subsequent exercise was the main factor explaining changes in performance (Bentley, Millet, Vleck, & McNaughton, 2002; Bernard et al., 2007; Hausswirth & Lehénaff, 2001). Therefore the adaptation of triathletes must be considered as unique and relatively specific to the constraints activity (race profile, swim-cycle and cycle-run transitions, intensity, and exercise duration). Within this framework, the decline in performance could be different than those reported in single sports. Furthermore, these events have seen a significant increase in master participation. When comparing the participation of the Triathlon World Championship in age groups over a period of 4 years, between 2004 (Madeira) and 2007 (Hamburg), the number of masters triathletes "finishers" has increases by 30% (Figure 1). To our knowledge, no study has described the impact of aging on Olympic distance triathlon performance, which involves 1500-m swimming, 40-km cycling, and 10-km

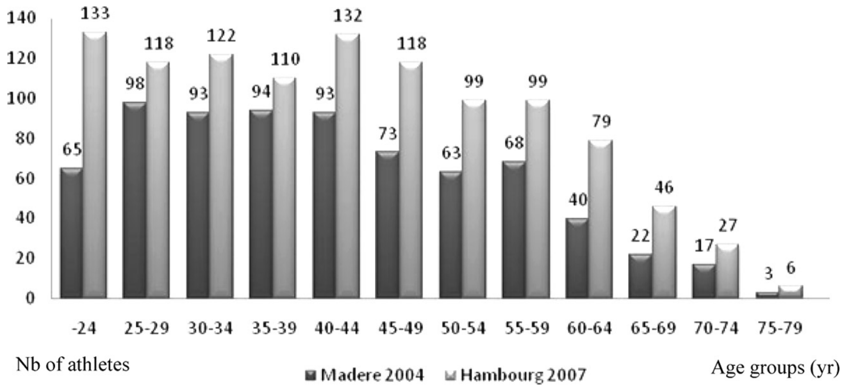

Figure 1. Participation of the Triathlon World Championship in age groups over a period of 4 years, between 2004 (dark bars, Madeira) and 2007 (grey bars, Hamburg).

running. The objective of this study was to describe the evolution of Olympic triathlon performance with age for each mode of locomotion and overall race. Similarly to Tanaka and Seals (2003, 2008), we hypothesize differences in decline of performance with age among the different locomotion modes.

METHODS

The Olympic triathlon world championship by "age groups" was chosen as a model for this study. During the world championship, each nation's "elite" athletes can compete for a world title in his/her age category. Competitors in the same age category are grouped in a single wave of departure. The race is an individual event; the 40-km cycling is performed without drafting (i.e., pedaling in the slipstream of the previous rider). Data were assessed only during the last two world championships, Lausanne 2006 and Hamburg 2007, because they presented a similar participation of masters' athletes.

Subjects

In these two world championships, 1710 male athletes were considered as finishers. The age groups are defined by the international federation and distinguish the categories for each period of 5 years. In our study, age groups are codified in the following manner: $\leq$24 years, 25–29 years, 30–34 years.... The last group was 75–80 years.

The age categories below 50 years were the most represented, and included more than 100 competitors for each event. Beyond 50 years, a significant decline of the population by age group is recorded; however, the proportion of masters still represents more than 50% of men. Within this framework, in order to compare the age groups, the 10 best performers in each category are identified and overall performance as well as performance in each locomotion mode was recorded (Leyk et al., 2007).

Decline in Performance

The decline in performance is assessed by calculating a ratio between the best individual performance of the total population and the performance of each age group according to the methodology proposed by Baker et al. (2003). The best individual time in overall triathlon and for each locomotion mode was used to normalize the performance. A ratio equal to 1.00 represents the best performance. Based on these data, the best adjustment is calculated from the following exponential equation:

$$Y = 1 - \exp(T - T_0)/\tau$$

Where Y is the performance expressed as a ratio, τ a time constant representative of the decline of performance, T the age, and T_0 the age for which the theoretical performance equated with a performance of zero.

Statistical Analysis

Values were described mean $\pm$ *SD*. A first analysis of variance was conducted to identify an effect of age (independent variable) on overall performance. Then the effect of age and locomotion mode on performance was analyzed using a two-way analysis of variance with repeated measures (ANOVA2 R) (age versus locomotion mode) with performance scores as dependent variables. When F values were statistically significant, post hoc test of Newman-Keuls was conducted to identify differences between two age groups or for the same age group between swimming cycling and running. The level of significance was set at $p < .05$.

RESULTS

Modeling the Decline in Performance in Olympic Triathlon

Times of each group for overall triathlon and for each locomotion mode are presented Table 1. In both groups, the relationship between performance and age is modeled according to an exponential curve. The parameter values T_0, τ, and the minimizing least squares parameter (ESS) are shown Table 2. The model used by Baker et al. (2003) not only represents the best fit of the observed values for the overall performance (Figure 2), but also for each mode of locomotion.

The values of performance decline (in percent of the best performance) as a function of age for each locomotion mode and overall triathlon are presented Table 3. A significant effect of age on performance is observed on the overall performance and whatever the locomotion mode. In addition, a significant interaction between age and locomotion mode was observed on performance values (Figure 3).

A significant difference was observed between swimming, running, and cycling. The decline in performance was more pronounced during swimming and running, whereas performance remains stable longer during cycling. In swimming, a significant decrease was observed after 40 years, with a decrease close to 5% per year after 45 years. In cycling, decline in performance was not significant until 55 years and less than 3% per year until 60 years. From 40 years old, performance in swimming was significantly lower than performance in running or cycling for all age group; furthermore, a significant difference between running and cycling was observed only after 55 years of age.

The relative contribution of each part on overall performance was independent of age until 70 years old. Cycling time represents 49.1% ± 2.3% of overall performance time, whereas performance in swimming, running, and transition time represent, respectively, 17.9% ± 1%, 28.2% ± 1%, and 4.7% ± 0.5%. After 70 years of age, a slight but significant increase in the role of swimming and running time was observed, which represents, respectively, 19.5% ± 1.2% and 31% ± 0.9% of overall performance time.

Table 1. Times of each group for overall triathlon and for each locomotion mode

	Age groups (years)											
	≤24	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70–74	75+
Overall triathlon	2 h 01 min ± 1 min 44 s	2 h 02 min ± 1 min 06 s	2 h 02 min ± 1 min 22 s	2 h 05 min ± 1 min 11 s	2 h 04 min ± 44 s	2 h 07 min ± 1 min 31 s	2 h 13 min ± 1 min 43 s	2 h 20 min ± 13 min 21 s	2 h 26 min ± 5 min 22 s	2 h 38 min ± 3 min 43 s	2 h 54 min ± 9 min 19 s	3 h 33 min ± 23 min 29 s
Swimming	20 min 08 s ± 1 min 10 s	21 min 40 s ± 56 s	20 min 48 s ± 1 min 12 s	22 min 28 s ± 1 min 32 s	22 min 14 s ± 37 s	22 min 27 s ± 46 s	24 min 42 s ± 1 min 16 s	26 min 14 s ± 1 min 59 s	26 min 48 s ± 2 min 06 s	28 min 39 s ± 3 min 15 s	34 min 39 s ± 3 min 50 s	41 min 09 s ± 6 min 13 s
Cycling	1 h 08 s ± 55 s	1 h 21 s ± 48 s	1 h 01 min ± 1 min 01 s	1 h 01 s ± 55 s	59 min 36 s ± 44 s	1 h 01 s ± 53 s	1 h 03 s ± 1 min 43 s	1 h 05 s ± 1 min 31 s	1 h 07 s ± 2 min 30 s	1 h 14 s ± 3 min 13 s	1 h 16 s ± 4 min 13 s	1 h 30 s ± 9 min 41 s
Running	34 min 54 s ± 1 min 06	34 min 52 s ± 1 min 20 s	34 min 55 s ± 1 min 17 s	35 min 15 s ± 1 min 19 s	36 min 19 s ± 40 s	37 min 21 s ± 54 s	38 min ± 1 min 28 s	40 min 51 s ± 1 min 24 s	44 min 08 s ± 2 min 39 s	46 min 59 s ± 2 min 30 s	52 min 36 s ± 3 min 35 s	1 h 08 min 54 s ± 12 min 57 s

Table 2. Modeling the decline in performance in Olympic Triathlon

	ESS	τ	$T_{0\ (yrs)}$
Swimming	0.0067	16.93	90
Cycling	0.0024	12.29	90
Running	0.0038	14.44	89
Overall performance	0.0014	14.20	89.8

Note. ESS represents the minimization least squares parameter (value of zero is the best adjustment), τ is a time constant representative of the decline of performance, and T_0 the age for which the theoretical performance equated with a performance of zero.

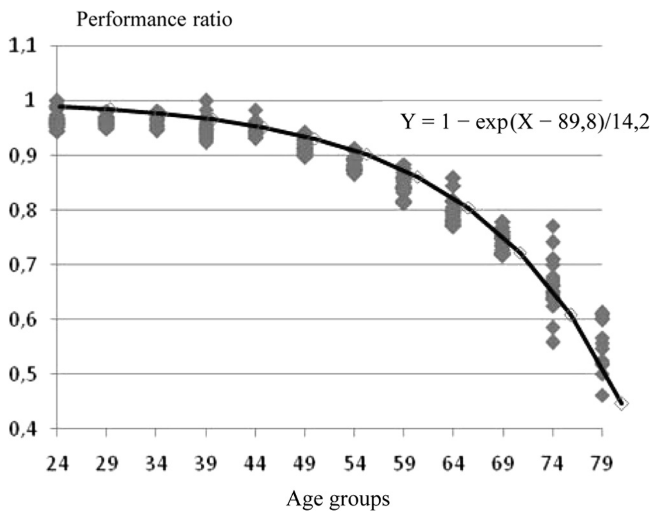

Figure 2. Overall performances in triathlon and predicted values calculated from the exponential model described by Baker et al. (2003). Performance ratio: A value of 1 represents the best performance.

Table 3. Decline in performance as a function of age expressed as percent of the best performance

	Age groups (years)											
	≤24	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70–74	75+
Overall triathlon	1	0	1	2	2	5	9	13	18	23	32	47
Swimming	0	2	2	3	5*	9	14*	20*	22	25*	40*	52*
Cycling	2	0	1	1	1	2	4	8*	13*	20*	23	41*
Running	2	1	0	1	3	4	8*	13*	21*	26*	35*	49*

*A significant difference with the previous age group was observed ($p < .05$).

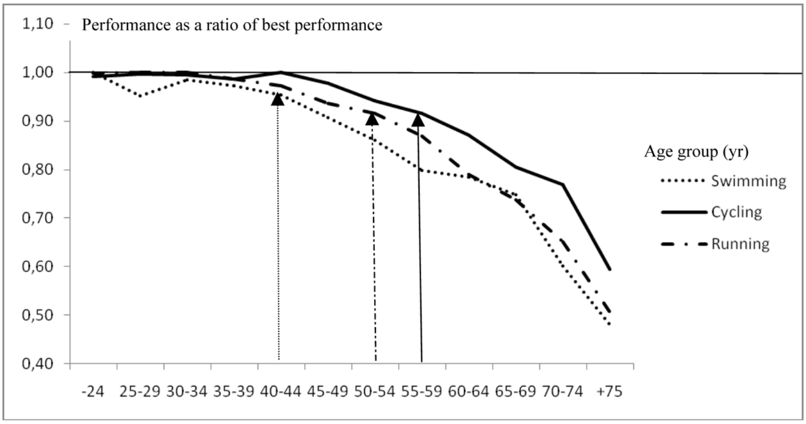

Figure 3. Decline in performance with age for each locomotion mode of the triathlon. Arrows indicate significant beginning of the decline in performance (i.e., significantly different from the previous age group, $p < .05$).

DISCUSSION

The main result of the present study indicated a significant effect of locomotion mode on decrease in performance with age in master athletes. Within this framework, decline in performance during cycling is less pronounced than during running and swimming.

In our study, the results show that the decline in performance in triathlon as a function of age (and for each mode of locomotion) follows the exponential model proposed by Baker et al. (2003) during athletics running events.

Decline in Performance With Age in Master Triathletes

In our work, the significant decline in performance with age for the triathlon begins at 45 years for masters subjects. These values are higher than those previously reported in the literature in single sport, which shows a significant decrease in running performance from 35 years (Leyk et al., 2007; Tanaka & Seals, 2003, 2008; Wright & Perricelli, 2008), suggesting that alternating different locomotion mode during the triathlon may help to delay the first significant decline in performance by allowing athletes to specifically manage their physiological capabilities. After 50 years of age, when looking at the percentage of decline per decade, our results are comparable to those of previous studies indicating a decrease in performance of

8%, to reach 32% after 70 years old. During triathlon, performance depends on classical endurance qualities (Bentley et al., 2002; Hausswirth & Lehénaff, 2001), such as the maximum aerobic capacity, the aerobic-anaerobic threshold, and the efficiency of each locomotion mode. In an Olympic triathlon, the distance in each locomotion mode is for swimming, 1.5 km; cycling, 40 km; and running, 10 km. In similar single-sport performance, Tanaka and Seals (2003, 2008) studied the contributions of these physiological factors to explain the decline in performance in endurance running (10 km) and swimming (1500-m swim free). According to these authors, the decline in performance with age is mainly linked to a decrease in maximum aerobic power ($VO_{2\ max}$) and secondly to a shift of the aerobic-anaerobic threshold towards lower intensities (aerobic capacity). With age, it has been reported in the scientific literature that $VO_{2\ max}$ values declined by 10% per decade from 45 to 70 years and 15% per decade beyond 70 years (Fitzgerald, Tanaka, Tran, & Seals, 1997; Hawkins & Wiswell, 2003; Rosen, Sorkin, Goldberg, Hagberg, & Katzel, 1998; Trappe, 2007). A larger decrease is observed for sedentary subjects (15% per decade), and it is suggested that regular endurance training can reduce this decline to 5% to 7% per decade before reaching 70 years (Hawkins & Wiswell, 2003; Trappe, 2007). It is interesting to observe that these values are higher than those reported in the present study before 70 years and lower after this age. This observation suggests that other factors specific to triathlon performance could explain the decline in performance in this sport. Among them, the specificity of decline for each locomotion mode could be partly responsible for this particular trend.

Decline of Performance With Age Among the Three Locomotion Modes

The major result of this study is that cycling leads to a less pronounced decline than the other locomotion modes, indicating that cycling seems to allow subjects to maintain performance despite classical metabolic changes reported with aging. Success in triathlon events is partly determined by the ability of an athlete to overcome difficulties in the change from one discipline to another. In the scientific literature on triathlon, differences between cycling and running has been widely studied, whereas less is known about differences between swimming and the two other locomotion modes.

Main differences between cycling and running are the change from a non–weight-bearing to a weight-bearing activity and differences in the coordination of leg muscles, with the shift from a predominantly concentric type of muscle action in cycling to a stretch-shortening activity with eccentric contractions in running (Bijker, de Groot, & Hollander, 2002; Heiden & Burnett, 2003). In running, during the landing phase, the active muscles are stretched to decelerate the body mass, whereas during the push off phase, the active muscles are shortening (Bijker et al., 2002). As a result, efficiency during running is greater than during cycling, leading to lower energy expenditure. However, during running, stretch-shortening cycle exercise causes a greater impairment in muscle function, leading to a greater neuromuscular fatigue and structural muscular damage (Gauche et al., 2006; Hausswirth & Lehénaff, 2001). Thus one hypothesis that could explain the more pronounced decrease in performance during running, than during cycling, is that the impairment of muscle function and structure classically described with aging would lead to a greater neuromuscular fatigue during the running part of the triathlon (Place, Lepers, Deley, & Millet, 2004). Classically in the literature when muscle performance of young and old trained subjects are compared, a reduction in isometric muscle strength generally appears after the age of 60 years on quadriceps muscles (Porter et al., 1995) due mainly to a loss of muscle fibers, a change in size of numbers and proportions of muscle fiber type (Lexell, 1995; Porter et al., 1995), a reduction in muscle volume and cross-sectional area (Narici, Maganaris, Reeves, & Capodaglio, 2003), and an alteration in contractile properties (Kent-Braun, Ng, Doyle, & Towse, 2002). Therefore we suggest that the significant difference in performance decline between running and cycling after 55 years of age observed in our study could be attributed to a greater muscular fatigue during running where the alteration in muscular function described with aging is enhanced by muscular damage induced by the repeated stretch-shortening cycle and eccentric contractions. Further studies analysing, for example, long distance triathlon with a 42-km running part are necessary to validate this hypothesis.

One unexpected result of this study is that decline in performance is more pronounced in swimming than during the two other locomotion modes. To the best of our knowledge, change in swimming performance with age has been relatively little studied (Cooper, Powell, & Rasch, 2007; Donato et al., 2003; Fairbrother, 2007; Tanaka & Seals, 2003). Among these studies, Tanaka and Seals (2003) have compared swimming and running performances, indicating on the one hand that reduction in swimming performance was smaller than during running and on the other hand that the age at which the decline begin occurred later with swimming (70 years) compared with running (60 years). The authors indicated that the reasons for this difference were unclear and the main hypothesis raised was that there is a lower incidence of orthopedic injuries during swimming than during running. Our results are not in agreement because decline in swimming performance was more pronounced than both in running and cycling. In earlier studies, Stones and Kosma (1980) have proposed an alternative hypothesis to explain difference in performance decline between sports based on difference in energy cost of locomotion between young and masters athletes. In competition events, the energy cost for a given power output is dependent on both the energy (ATP) needed to overcome the external resistance and the energy used in the production of external energy (internal energy). Consequently, the energy cost of locomotion could be improved by reducing as well external energy and/or internal energy or both (Di Prampero, 1981). On the one hand, our result could be explained by a more important difference in energy cost of locomotion during swimming between young and masters athletes than for the two other modes. Triathlon is a sport that has evolved considerably during the last decades and if we consider training history of these masters triathletes, the skill in swimming is lower than in running or cycling, (Hausswirth & Lehénaff, 2001). On the other hand, one of the main difference between energy cost of locomotion between a triathlon and single sports is the possibility for athletes to use drafting as well during swimming than during cycling or running. While swimming front crawl, the role of drafting, i.e., swimming directly behind or at the side of another swimmer, is important because all subjects are together at the beginning of the race, and this role is enhanced in triathlon by the possibility to wear a wet suit. Recent studies have indicated that drafting and wearing a wet suit allow the swimmer to reduce the energy cost of swimming propulsion for the same speed and increases performance during the subsequent cycling part (Delextrat et al., 2003). Actually, in an elite Olympic distance triathlon, the pacing strategies during the swimming part can influence the energy demands of this section as well as cycling and running strategies. Within this context, focusing on the relative importance of swimming in triathlon performance, recent authors identified that the relationship between overall triathlon performance and performance in swimming is weaker than with performance of the two others disciplines (Bentley et al., 2002). Therefore we could suggest that with decreasing functional capacities, one strategy adopted by masters athletes was to decrease energy cost by using drafting and reducing the speed when swimming in a pack in order to better prepare the cycling or the running part, which are more important for the overall performance.

Furthermore, when comparing aging studies, the use of cross-sectional data rather than longitudinal analysis has many inherent methodological problems that could explain the difference between these studies. Cross-sectional studies are dependent on the criteria used to select each group and among them are several sociological characteristics and training histories specific to each sport. Therefore to assess the potential confounding factor of training status or training pattern in each locomotion mode, further studies including quality of life and training questionnaires on a larger population are necessary to confirm and/or explain this result (Balmer et al., 2007; Tanaka & Seals, 2008; Wright & Perricelli, 2008).

In conclusion, overall triathlon performance times decline with advancing age in a curvilinear manner although the patter of decline is specific to each locomotion mode. Physical functional capacity and performance appear to be more resistant to biological aging in cycling than in the other two sports. As always, data from cross-sectional studies must be considered with caution, but further studies examining and comparing the effect of the aging process on factors affecting performance in the three locomotion modes of a triathlon will provide valuable information for understanding the way to maintain physical capacity and performance with aging.

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