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ORIGINAL ARTICLE

Age-related changes in conventional road versus off-road triathlon performance

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Abstract The aims of this study were: (i) to analyze age-related declines in swimming, cycling, and running performances for road-based and off-road triathlons, and (ii) to compare age-related changes in these three disciplines between road-based and off-road triathlons. Swimming, cycling, running and total time performances of the top five males between 20 and 70 years of age (in 5-year intervals) were analyzed for short distance road-based (1.5 km swim, 40 km cycle, and 10 km run) and off-road (1.5 km swim, 30 km mountain bike, and 11 km trail run) triathlons at the 2009 World Championships. Independently of age, there was a lesser age-related decline in cycling performance ($P < 0.01$) compared to running and swimming for road-based triathlon. In contrast, age-related decline did not differ between the three locomotion modes for off-road triathlon. With advancing age, the performance decline was less pronounced ($P < 0.01$) for road-based than for off-road triathlon in swimming (≥65 years), cycling (≥50 years), running (≥60 years), and total event (≥55 years) times, respectively. These results suggest that the rate of the decline in performance for off-road triathlon is greater than for road-based triathlon, indicating that the type of discipline (road vs. mountain bike cycling and road vs. trail running) exerts an important influence on the magnitude of the age-associated changes in triathlon performance.

Keywords Master athlete · Swimming · Cycling · Mountain biking · Running · Xterra®

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Introduction

The age-related decline in endurance running performance up to the marathon distance has been well documented (e.g., Trappe 2007; Tanaka and Seals 2008). In general, peak endurance performance is maintained until ~35 years of age, followed by modest decreases until 50–60 years of age, and a progressively steeper decline thereafter (Tanaka and Seals 2008). In contrast, less is known about the age-related decline in performance of other modes of locomotion such as swimming (Donato et al. 2003) and cycling (Balmer et al. 2008a, b). The nature and the type of muscular contractions differ between the three modes of locomotion (swimming, cycling, and running). For example, cycling is a non-weight bearing activity that employs predominantly concentric muscle activation compared with the stretch–shortening activity and eccentric activations during running. Swimming involves mostly the upper body musculature with no mechanical constraints. Therefore, questions about whether age-related declines in performance differ between the modes of locomotion may be raised.

Triathlon, involving successive swimming, cycling, and running bouts of exercise, represents an interesting model to examine the age-related changes in endurance performance in these different locomotion modes (Bentley et al. 2002). It has been shown that the age-related declines in performance times were specific for each locomotion mode. For example, there is a lesser age-related decline in cycling performance compared with running and swimming performances for both short (1.5 km swim, 40 km cycling, and 10 km running), and long (3.8 km swim, 180 km cycling, and 42.2 km running) distance triathlons (Bernard et al. 2010; Lepers et al. 2010). One explanation for the different age-related declines in cycling and running may involve the mechanical power required by these disciplines. Mechanical power output in running depends on the velocity ($P = k \cdot V$) while it depends on third power of velocity in cycling ($P = k \cdot V^3$). If we assume that the changes in aerobic capacity (e.g., VO_2 max) with age are directly related to the decline in mechanical power, a similar reduction in power output for running and cycling with advancing age would induce a lower reduction in cycling velocity than running velocity (Lepers et al. 2010). This may explain, in part, why the magnitude of the decrease in cycling performance with age was less than that for running. In addition, the lesser decline in cycling performance with advancing age could also be due to a lesser reduction in lactate threshold and/or economy compared with running.

In addition, it has been shown that in contrast to swimming, the magnitude of the declines in cycling and running performances with age in short distance triathlon were less pronounced than for long distance races (Lepers et al. 2010). Greater neuromuscular fatigue, greater muscle damage, and changes in substrate availability and utilization with age could explain the task duration effect on triathlon performances at least in cycling and running.

In the field of endurance multisport, off-road triathlon (also named Xterra®) combining swimming, mountain biking (MTB) and trail running represents another interesting model to examine the age-related changes in endurance performance in different locomotion modes. Since 1996, the world's premier off-road triathlon, also named the Xterra® World championship, has comprised a 1.5 km swim, a 30 km MTB ride, and a 11 km trail run, and has taken place on the island of Maui (Hawaii, USA), (Lepers and Stapley 2010). In contrast to conventional (road-based) triathlon, cycling and running parts of off-road triathlon take place on trails, with frequently significant ascents in the cycling leg of the race. The major difference between off-road and conventional triathlon is found in the cycling discipline, which is performed as MTB during off-road triathlon. Physiological and technical requirements of mountain biking differ in many points from road cycling. Factors other than aerobic power and capacity such as off-road cycling economy, anaerobic power and capacity, and technical ability might influence off-road cycling performance (Impellizzeri and Marcora, 2007). Similarly, running on trails is specific and also requires more technical ability than road running (Anderson et al. 2009, Hoffman and Wegelin 2009). During off-road triathlon, the age-related declines in cycling and running performances maybe greater because the physiological and mechanical stresses that occur during off-road triathlon are much greater compared to those encountered during road-based triathlon.

Therefore, the purposes of this study were: (1) to determine if there was a reduced rate of decline in cycling performance with advancing age compared to running and swimming for the off-road triathlon, as has been previously shown for road-based triathlons (Bernard et al. 2010; Lepers et al. 2010), and (2) to compare age-related changes in swimming, cycling, and running performances between the road-based and off-road triathlons. Due to the nature of the disciplines with stochastic efforts (i.e., with a greater anaerobic component), mountain biking and trail running require different physiological and technical aptitudes compared to conventional triathlon cycling and running. We therefore hypothesized that age-related declines in cycling and running performance would be greater for off-road than for conventional road-based triathlon.

Methods

Approval for the project was obtained from the Burgundy University Committee on Human Research. This study involved the analysis of publicly available data so content was waived.

Averaged swimming, cycling, and running and overall time performances of the top five amateurs of ten male age groups were analyzed for road-based (short distance) and off-road triathlon World Championships in 2009. The age groups distinguish the categories for each period of 5 years as follows: 20–24, 25–29, 30–34, 35–39, 40–44, 45–49, 50–54, 55–59, 60–64, and 65–69 years.

For the road-based short distance triathlon, the data set was obtained from the 2009 World Championships web site (http://www.worldtriathlongoldcoast.com/). This race took place at the Gold Coast, Australia; the road-based World Championships was a point-to-point race, combining a 1.5 km swim in the ocean with wetsuit (Water temperature: 21°C), a 40 km (2 laps of 20 km) road bike ride almost flat (altitude change <5 m) and a 10 km flat run on the road along the ocean. The race took place on September 12, 2009; during the race, ambient temperature and relative humidity were about 22°C and 65%, respectively.

For the off-road (Xterra) triathlon, the data set was obtained from the Xterra triathlon World Championships web site: http://www.xterraplanet.com/maui/past.html. Since 2005, the Xterra World Championships has taken place in Makena, Maui (Hawaii, USA) and held each year in October with only minor changes to the course. The championships is a point-to-point race, combining a 1.5 km swim in the Pacific ocean without wetsuit (water temperature: 28°C), a 30 km MTB ride that involves a total altitude change of 915 m on rocky, dirt-strewn trails on the lower slopes of Haleakala Volcano, and a 11 km trail run along the beaches and lava formations along south Maui's scenic south shore (total altitude change of 346 m) (Lepers and Stapley 2010). The Xterra Maui triathlon is the last in a series of nearly 20 off-road triathlons held in the world that serve as qualifying races. The race took place on October 25, 2009; during the race, ambient temperature and relative humidity were about 28°C and 60%, respectively.

For both road-based short distance and off-road triathlons, the swimming, cycling, running, and overall time performances of each triathlete finishing in the top five of each age group was normalized to the mean time performance of the top five of the best performing age group. Thus, the age-related declines in performance were expressed using a ratio calculated between the individual and the mean time performances of the best performing age group for each mode of locomotion and total event time.

Statistical analysis

Data are reported as means ± SD in the text and table and displayed as means ± SE in the figures. A two-way ANOVA with repeated measures on locomotion mode was used to compare performance ratio between modes of locomotion across ages for road-based and off-road triathlons. For each mode of locomotion and total time performance, a two-way ANOVA (age × type of triathlon) was used to compare performance ratios between road-based versus off-road triathlon across age. Post-hoc analysis (Tukey) was used to test for differences within the ANOVAs when appropriate. A significance level of $P < 0.05$ was used to identify statistical significance.

Results

At the road-based triathlon World Championship, there were 1,537 finishers: 925 males (60%) and 612 females (40%), and the finishing rate was 97.4%. At the off-road triathlon World Championships, there were 486 finishers: 336 males (69%) and 150 females (31%), and the finishing rate was 94.5%.

Swimming, cycling, running, and total time performances for each age group for both road-based and off-road triathlons are presented in Table 1. The relative contribution of each part of the overall performance remained constant across the ages but differed slightly between the two triathlon types. For off-road triathlon, the relative contribution of the swim part was lower, while the cycle part was greater compared to road-based triathlon. For road-based triathlon, the 1.5-km swimming, 40-km cycling, and 10-km running represented on average 17.3 ± 0.8, 49.1 ± 1.2, 31.2 ± 1.2% of the total time, respectively. For off-road triathlon, the 1.5-km swimming, 30-km mountain biking, and 11-km running represented on average 12.7 ± 1.2, 57.8 ± 1.9, 29.4 ± 2.0% of the total time, respectively.

Standard deviations of mean values for each locomotion mode and for total time performances were greater for off-road triathlon compared to road-based triathlon, suggesting that the density of the top five was lower for off-road triathlon.

For both road-based and off-road triathlons, the performance ratios for each mode of locomotion decreased in a curvilinear manner with advancing age (Fig. 1a, b). For road-based triathlon (Fig. 1a), there was a locomotion mode effect ($F = 12.9$, $P < 0.0001$) for performance ratio. Independently of age, both swimming and running performance ratios were lower ($P < 0.01$) than cycling performance ratios. In addition, independently of locomotion mode, performance ratio differed between the age groups ($F = 117.2$, $P < 0.0001$). Performance ratio was significantly lower ($P < 0.01$) for age groups 45–49 years and above compared to all age groups between 20–24 yrs and 35–39 years. Finally, there was a significant interaction between age and mode of locomotion for performance ratio ($F = 2.5$, $P < 0.002$).

For off-road triathlon, however, there was no interaction between age and mode of locomotion ($F = 1.45$, $P = 0.13$), and there was no locomotion mode main effect ($F = 0.29$, $P = 0.74$) for performance ratio. However, independently of locomotion mode, performance ratio differed between the age groups ($F = 31.9$, $P < 0.0001$). Performance ratio was significantly lower ($P < 0.01$) for age groups 55–59 years and above compared to all previous age groups comprised between 20–24 and 40–44 years.

Comparisons of age-related declines in swimming, cycling, running, and total performance for road-based and off-road triathlons are shown in Fig. 2. There was a significant interaction between age and type of triathlon for swimming ($F = 2.85$, $P = 0.01$), cycling ($F = 10.03$, $P < 0.0001$), running ($F = 5.36$, $P < 0.0001$), and total event ($F = 12.04$, $P < 0.0001$) performance ratio. Age-related declines in performance were less pronounced for road-based compared to off-road triathlon for swimming for age group 65–69 years, for cycling for age groups 50–54 years and above, for running for age groups between 60–64 and 65–69 years and for total time for age groups 55–59 years and above, respectively.

Table 1 Swimming, cycling (road cycling or mountain biking MTB), running, and total performance times for the top five males in each age group at the short distance road-based world triathlon championships (Gold Coast, Australia) versus off-road world triathlon championships (Maui, Hawaii, USA) in 2009

	Age groups (years)									
	20–24	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69
Road-based triathlon										
1.5 km Swim (min:s)	19:31 ± 0:26	19:49 ± 0:43	19:39 ± 0:43	21:24 ± 0:56	20:09 ± 0:52	21:07 ± 1:05	22:04 ± 0:52	21:53 ± 1:32	23:39 ± 1:49	24:32 ± 1:08
40 km Cycle (h:min:s)	0:57:31 ± 0:29	0:57:09 ± 0:26	0:57:55 ± 0:42	0:58:17 ± 0:33	0:57:34 ± 0:52	0:59:23 ± 0:14	1:00:28 ± 0:57	1:03:25 ± 1:33	1:06:13 ± 2:58	1:09:06 ± 3:03
10 km Run (min:s)	34:55 ± 0:46	35:16 ± 0:53	35:45 ± 0:33	36:05 ± 0:15	35:12 ± 0:42	36:50 ± 1:41	39:02 ± 1:03	41:17 ± 1:23	44:51 ± 2:31	48:11 ± 1:42
Total (h:min:s)	1:54:21 ± 0:47	1:54:49 ± 0:34	1:55:52 ± 0:56	1:58:28 ± 0:55	1:55:31 ± 0:43	2:00:07 ± 0:49	2:04:35 ± 2:03	2:09:56 ± 1:13	2:18:45 ± 3:59	2:26:06 ± 3:35
Off-road triathlon										
1.5 km Swim (min:s)	23:41 ± 1:45	22:40 ± 1:05	24:23 ± 3:32	22:51 ± 0:59	25:17 ± 2:01	26:16 ± 1:37	26:46 ± 4:53	27:08 ± 1:21	35:07 ± 7:35	36:22 ± 5:17
30 km MTB (h:min:s)	1:46:33 ± 5:12	1:43:49 ± 3:44	1:48:37 ± 4:31	1:49:37 ± 2:58	1:50:47 ± 4:44	1:53:46 ± 2:46	2:03:09 ± 6:00	2:10:17 ± 11:49	2:28:39 ± 19:42	2:50:18 ± 15:53
11 km Run (h:min:s)	0:54:19 ± 1:57	0:54:43 ± 3:45	0:54:02 ± 2:12	0:52:46 ± 1:57	0:53:21 ± 3:07	0:56:38 ± 2:21	0:57:46 ± 4:41	1:07:11 ± 5:30	1:22:30 ± 11:37	1:36:44 ± 17:16
Total (h:min:s)	3:04:34 ± 5:43	3:01:12 ± 5:54	3:07:02 ± 6:42	3:05:14 ± 3:59	3:09:25 ± 7:58	3:16:40 ± 1:32	3:27:41 ± 8:50	3:44:57 ± 16:38	4:26:16 ± 34:39	5:03:24 ± 32:53

Values are mean ± SD

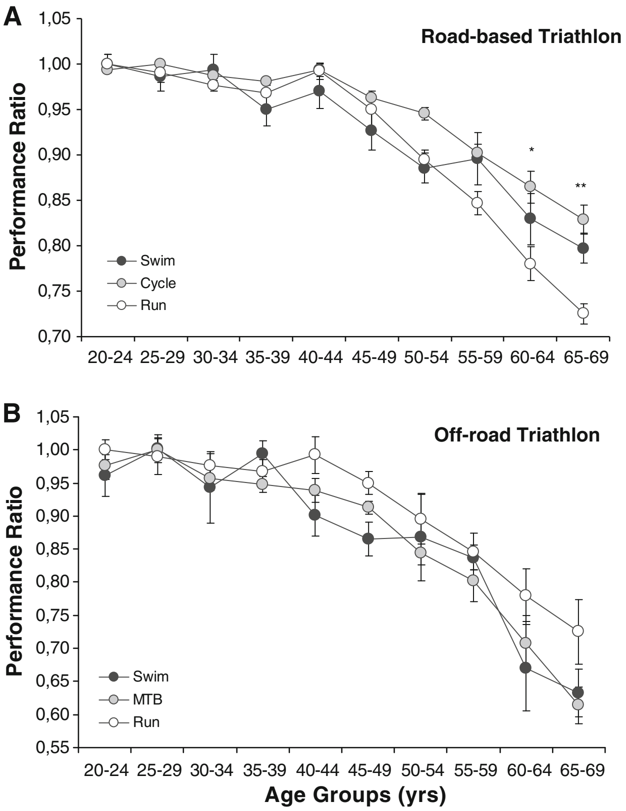

Fig. 1 Age-related declines in swimming, cycling, and running performances for road-based (**a**) and off-road triathlons (**b**), (mean ± SE). For road-based triathlon, the swimming performance ratio for age groups 45–49 years and above was significantly different from the best age group (i.e., 20–24 yrs). The cycling performance ratio for age groups 55–59 years and above was significantly different from the best age group (i.e., 25–29 yrs). The running performance ratio for age groups 50–54 yrs and above was significantly different from the best age group (i.e., 20–24 yrs). For off-road triathlon, performance ratio differed between the age groups, independently of locomotion mode. Performance ratio was significantly lower for age groups 55–59 years and above compared to all previous age groups comprised between 20–24 and 40–44 years. $^{*}P < 0.05$, $^{**}P < 0.001$: cycling significantly different from running

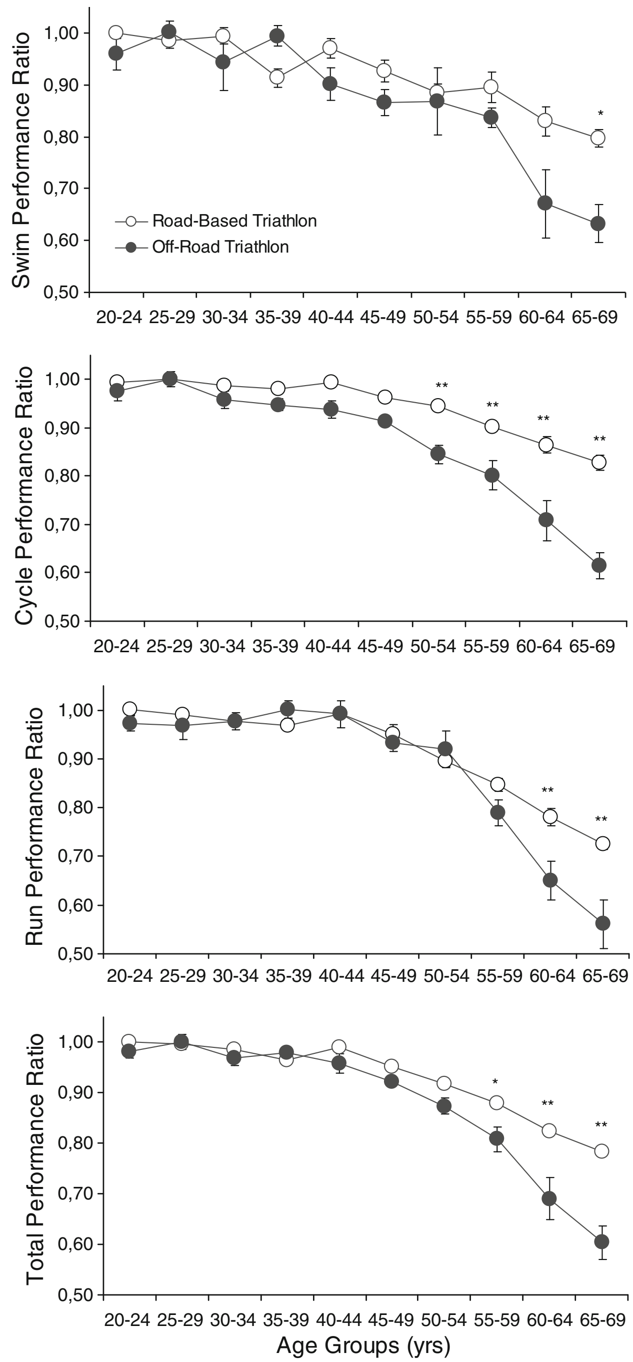

Fig. 2 Age-related declines in swimming, cycling, running, and total performances for road-based and off-road triathlons (mean ± SE). Age-related decline in swimming, cycling, running, and total performance was less pronounced for road-based triathlon. $^{*}P < 0.05$; $^{**}P < 0.01$: Significantly different from off-road triathlon for the same age group

Discussion

The main findings of the present study were (i) a reduced age-related decline in cycling performance compared to running and swimming performances for road-based triathlon but not for off-road triathlon, and (ii) a smaller effect of age on swimming, cycling and running performances for road-based compared to off-road triathlon.

Methodological considerations

With endurance events, the environment (temperature, humidity, precipitation) affects the outcome of the results. For road-based triathlon taking place on the Gold Coast (Australia), the temperature was around 22°C, whereas during the off-road triathlon taking place in Hawaii (USA), the temperature was around 28°C. Thus, the hotter conditions for the off-road triathlon may have more greatly affected performance than for the road-based triathlon. However, by normalizing the individual time performance by the mean time performance of the top five of the best performing age groups for both type of triathlons, the influence of environment was minimized when comparing road-based and off-road triathlon performances.

This paper focuses on the performances of male triathletes only. Potential differences in age-related decline in triathlon performance between male and female may also occur (e.g., Vleck et al. 2008; Lepers and Maffiuletti 2011), so it could be interesting to verify if similar results are obtained for female triathletes. However, for off-road triathlon, data for female triathletes older than 55 years of age are limited. Moreover, unpublished data from our laboratory suggest that similar findings are observed for female triathletes, i.e., a reduced age-related declines in cycling performance compared with running and swimming performances for road-based triathlon, but not for off-road triathlon and a greater magnitude of age-related decline in performance for the off-road triathlon than for the road-based triathlon.

This data do not include performance of elite/professional triathletes. This is because differences existed between the race formats for off-road and road events. At the World off-road triathlon Championships, elite and age grouper triathletes raced the same course at the same time; at the World road-based short distance triathlon Championships, elite triathletes raced a different course with different rules (drafting allowed for the elite athletes and forbidden for the age groupers).

Age-related differences in triathlon performance differ between road-based versus off-road triathlon

Age-related declines in swimming, cycling, and running performances were lesser for road-based triathlon than for off-road triathlon. Lepers et al. (2010) found that age-related changes in swimming performance were not influenced by task duration; indeed the magnitudes of decreases in swimming performance were similar for short distance versus long distance triathlon. The swimming distance was similar between road-based and off-road triathlon (i.e., 1.5 km), but for road-based triathlon wetsuits were permitted, while for off-road triathlon they were forbidden as the water temperature was close to 28°C. The use of wetsuits may explain firstly the fastest swimming times at the road-based triathlon than at the off-road triathlon World Championships (see Table 1), and secondly the lower declines in performance at older ages for road-based triathlon. Indeed, wearing a wetsuit improves swimming performance and propulsion efficiency, but also reduces gross energy consumption in the swimming portion of triathlon races (Tomikawa et al. 2008). We unfortunately had no possibility of testing the swimming abilities of road-based and off-road triathletes. However, if one assumes that the advantage of wearing a wetsuit may be greater for slower swimmers (and therefore oldest swimmers) compared to the faster (younger) ones, this could explain the lower declines in swimming performance at older ages for road-based triathlon where wetsuits were used. On average, for off-road triathlon swimming performance (without wetsuits), declined by ~16% at 55-years-old, and reached ~37% by 65 years of age. The present decline is somewhat greater than those found by Tanaka and Seals (1997) (~32% at 65 yrs age) at the same distance swum in a swimming pool. The lower performance declines observed by these authors for the same age compared with the triathlon data might be due the differences between the water conditions: calm in swimming pool versus stochastic in open water for triathlon.

For road-based short distance triathlon, there was a lesser age-related decline in cycling performance compared to running and swimming performances. Similar findings have been already documented by Bernard et al. (2010) for short distance triathlon and by Lepers et al. (2010) for long distance triathlon. In contrast, for off-road triathlon, cycling (mountain biking) performance declined with advancing age in the same manner to that seen in swimming and running. The absence of relative preservation of cycling performance with advancing age for off-road triathlon suggests that the effect of age on cycling performance is amplified for mountain biking compared to road cycling.

Indeed, the magnitude of the declines in cycling performance with advancing age for road-based triathlon was less pronounced than for off-road triathlon. It has been shown that task duration in triathlon exerts an influence on age-related declines in triathlon performance. Lepers et al. (2010) showed that age-related decline in cycling performance was greater for long distance triathlon (180 km cycle) compared to short distance triathlon (40 km cycle). For example, these authors found that cycling performance declined by ~20% for short distance triathlon and by 26% for long distance triathlon at 65 years, respectively. In this study, cycling performance declined by ~17% at 65 years for short distance triathlon and by 39% for off-road triathlon, respectively. The longer duration of mountain biking part of off-road triathlon (~2 h) compared to road cycling part at short distance triathlon (~1 h) may not totally explain the greater decline in cycling performance in off-road triathlon with advancing age. The nature of the discipline may better explain the greatest part of that difference.

Indeed, mountain biking differs in many respects from road cycling. The duration of the MTB leg (~2 h) of the off-road triathlon is very similar to that of a cross-country MTB race for which it has been shown that more than 80% of the time is spent above lactate threshold (Impellizzeri et al. 2002). This very high intensity (i.e., above lactate threshold) is related in particular to climbs, forcing off-road cyclists to expend most of their effort going against gravity, greater rolling resistance associated with the difficult terrain conditions, and the isometric contractions of arm and leg muscles necessary for bike handling and stabilization. Therefore, a known decrease in power-to-weight ratios with advancing age (Bonnefoy et al. 1998; Kostka 2005) inevitably leaves older off-road triathletes with a disadvantage in the climbs compared to flat sections. Secondly, lower arm and leg muscle strength in older athletes (Faulkner et al. 2008) may also mean that they possess a reduced bike stabilisation capacity during the descents, even if decreases in muscle strength may be reduced in older athletes compared to sedentary persons of the same age (McCrory et al. 2009). Older triathletes even if they compete in off-road triathlon may probably be less experienced off-road cyclists compared to older mountain bikers. Finally, age-related changes in technical ability to control and stabilize the bicycle, if it exists (Sturnieks et al. 2008), could be another factor explaining the greater decline in MTB performance compared to road cycle performance.

The age-related declines in running performance were greater for off-road triathlon than for road-based triathlon. It has been suggested that in older athletes, skeletal muscle continues to have high aerobic potential, while declines in muscle size and contractile performance are apparent (Trappe 2007; Tanaka and Seals 2008). These changes in the skeletal muscle profile may contribute partly to the alterations in running performance seen with increasing with age, but the difference in age-related changes in performances between trail versus road running remains unclear. Lepers et al. (2010) showed that the magnitude of the decline in running performance with advancing age was greater for long distance triathlon (42 km run) compared to short distance triathlon (10 km run). Indeed, running performance declined by ~27% for short distance triathlon and by 33% for long distance triathlon at 65 years, respectively. In this study, running performance declined by ~22% at 65 years for short distance triathlon and by 35% for off-road triathlon. As for cycling, the longer duration of the trail running part during off-road triathlon (~1 h) compared to the road running part during short distance triathlon (~40 min) may explain only in part, the greater decline in running performance in off-road triathlon with advancing age.

Age-related changes in trail running performance have been few investigated and for distances much greater than 11 km. For example, Easthope et al. (2010) showed that performance of masters athletes (~45 years of age) during a 55 km trail running race did not differ from those of young athletes (~30 years of age), and that both group of athletes showed similar fatigue and muscle damage after the race even if recuperation seemed slower in masters athletes. Hoffman and Wegelin (2009) found that the finish times of a 161 km trail running race were about 40% longer for athletes of age 60–69 years compared to fastest athletes of age 30–40 years.

The specificity of the 11 km trail run for the off-road triathlon with running part along the beaches and lava formations with a total altitude change of 346 m affected more the running performance compared to a 10 km flat road run but the reasons are unclear. Lower capacity to assimilate the variation in running intensity and lower ability to change the biomechanics of running (foot support, stride frequency) due to the changes in surface (sand, rocks, etc.,…) may explain the lower running performances of older triathletes during off-road triathlon compared to road-based triathlon.

Conclusion

This cross sectional study found that the magnitudes of age-related declines in triathlon performance for off-road triathlon are greater than for road-based triathlon, suggesting that the type of discipline (swimming with or without wetsuit, road vs. MTB cycling, and road vs. trail running) exerts an important influence on the age-associated changes in triathlon performance. The specific aspects of mountain biking and trail running may explain why age-related decline in off-road triathlon is more pronounced for off-road compared to conventional on road triathlon. Further studies examining the changes in training volume and physiological characteristics of older road-based and off-road triathletes are required to better understand the age-associated changes in triathlon performance and will provide valuable information for understanding the way to maintain physical capacity and performance with advanced age. In addition, future analysis of the age-related changes in performance for other endurance or ultra-endurance single discipline events, such as mountain bike races and trail or road running races, may also provide valuable insights into the maintenance of performance in older athletes.

Conflict of interest The authors have no conflict of interests to report.

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