Relative improvements in endurance performance with age: evidence from 25 years of Hawaii Ironman racing.

Romuald Lepers, Christoph A. Rüst, Paul Stapley, Beat Knechtle

Relative in performance with age: evidence from 25 years of Hawaii Ironman racing

Romuald Lepers [1 *] **, Christoph A. Rüst** [2] **, Paul Stapley** [3] **, Beat Knechtle** [2 4]

[1] *Motricité - plasticité INSERM : U887 , Université de Bourgogne , Esplanade Erasme, 21078 Dijon, FR*

[2] *Institute of General Practice and Health Services Research University of Zurich , Rämistrasse 71, 8006 Zürich, CH*

[3] *School of Health Sciences University of Wollongong, Faculty of Health and Behavioural Sciences , Northfields Ave, Wollongong NSW 2522, AU*

[4] *General Practice Gesundheitszentrum St. Gallen , Vadianstrasse 26, 9000 St. Gallen, CH*

* Correspondence should be addressed to: Romuald Lepers <rlepers@u-bourgogne.fr >

Abstract

Despite of the growth of ultra-endurance sports events (of duration > 6h) over the previous few decades, the age-related declines in ultra-endurance performance have drawn little attention. The aim of the study was to analyze the changes in participation and performance trends of older (> 40 yrs of age) triathletes between 1986 and 2010 at the Hawaii Ironman triathlon consisting of 3.8 km swimming, 180 km cycling and 42 km running. Swimming, cycling, running and total times of the best male and female triathletes between 18 and 69 yrs of age who competed in the Hawaii Ironman triathlon were analyzed. The relative participation of master triathletes increased during the 1986–2010 period, while the participation of triathletes younger than 40 yrs of age decreased. Linear regression showed that males older than 44 yrs and females older than 40 yrs significantly improved their performances in the three disciplines and in the total time taken to complete the race. Gender differences in total time performance significantly decreased in the same time period for all age groups between the 40–44 yrs and 55–59 yrs ones. The reasons for these relative improvements of Ironman athlete performances in older age groups remain, however, unknown. Further studies investigating training regimes, competition experience or socio-demographic factors are needed to gain better insights into the phenomenon of increasing participation and improvement of ultra-endurance performance with advancing age.

Author Keywords Master athletes, Endurance, Gender differences. Triathlon, Swimming, Cycling, Running, Aging.

Introduction

Anecdotal reports show that some older athletes nowadays can achieve very high levels of ultra-endurance performance (defined as performance exceeding 6 h, Zaryski & Smith 2005). For example, an 81-year-old male athlete was able to finish a 100-km ultra-marathon in a time of 19 h 44 min (Knechtle et al. 2009). In the field of multi-sport events, an 80 year old male triathlete also finished the 2010 Hawaii Ironman Triathlon consisting of 3.8 km swimming, 180 km cycling and 42 km running, in less than 16 h (http://ironmanworldchampionship.com/results/). That same year, and at the same event, a 75 year old female triathlete finished the race in 16h 20min. These unique older athletes have begun to push the limits of the interaction between aging and human endurance. They represent a positive example of healthy aging and provide unique insights into a person's ability to maintain physical performance and physiological function with advancing age (Tanaka and Seals 2008).

Age-related declines in endurance performance have been well described in the literature for running (Trappe 2007, Leyk et al 2009, Lepers & Cattagni 2011), swimming (Tanaka & Seals 2008) and triathlon (Bernard et al. 2010, Baker et al. 2010). Changes in performance across the ages have also been examined for ultra-endurance events, including running events of 50-km to 161-km (Hoffman & Wegelin 2009, Hoffman et al. 2010, Knechtle et al. 2011) and Ironman distance triathlons (Lepers et al. 2010, Lepers & Maffiuletti 2011). Endurance and ultra-endurance performance, in terms of the overall time taken, appears to be maintained until approximately 35–40 years of age, followed by modest decreases until 50 years of age, with a progressive decrease in performance thereafter with the greatest declines occurring after the age of 70 years. Physiological factors, both central (maximum heart rate; maximum stroke volume; blood volume) and peripheral (muscle mass; muscle fiber composition, size and capillarization; muscle enzyme activity), contribute to age-related declines in endurance performance in older athletes. However, these physiological factors can be regulated by changing the intensity and volume of the older endurance athletes' training (Reaburn & Dascombe 2008, Tanaka & Seals 2008) and there is obviously an interaction between training behaviour and performance in older athletes (Maharam et al. 1999).

Previous observations have suggested that the endurance performance of elite athletes (age < 40 yrs old) had plateaued (Sparkling et al. 1998, Lepers 2008, Lepers & Cattagni 2011, Knechtle et al. 2011). In contrast, recent studies showed an improvement in endurance running performance of master athletes (age > 40 yrs old) over the past few decades. For example, analysis of performance trends at the ' New-York City Marathon' showed that the running times of masters athletes significantly decreased, for both males and females over the last three decades (Jokl et al. 2004, Lepers & Cattagni 2011). To our knowledge, only two studies have focussed upon the ultra-endurance participation and performance trends of masters athletes. An increase in participation of both male and female athletes older than 40 yrs has been reported for 161-km ultra-marathons in North America over the past 30 years (Hoffman et al. 2010) and for 100-km running in Switzerland (Knechtle et al. 2011) during the last ten years, but no data are available for a multi-sport ultra-endurance event, such the Ironman triathlon. An increased participation of masters athletes in such ultra-endurance events may inevitably be linked to an increase in training volume, and could be interpreted as a possible strategy for maintaining good health during old age; these older athletes being conscious that regular physical activity may increase life expectancy.

Ironman triathlon represents an intriguing model to analyse age-related declines in ultra-endurance performance. Indeed, the age-related declines in performance can be analyzed in the same subjects collectively, and also for three modes of locomotion (swimming, cycling and running) separately (Bernard et al. 2010, Lepers et al. 2010, Lepers & Maffiuletti 2011). It has been shown for example, that age-related declines in cycling performance were less pronounced compared to running, presumably due to the non-weight bearing aspect and the concentric type of muscle action during cycling. According to previous investigations on the participation trends conducted on ultra-endurance running events (Hoffman et al. 2010, Knechtle et al. 2011), we would also expect an increase in the participation of masters triathletes in an ultra-endurance competitions such Ironman triathlon since the emergence of this sport in the 1980's (Lepers 2008). In accordance with this expected increase in participation, it may also be interesting to see if older Ironman triathletes have shown improvements in their swimming, cycling and running performance over the past 3 decades.

A previous study conducted on the Hawaii Ironman triathlon showed that gender differences in total performance time were stable until 55 yrs of age but increased thereafter (Lepers & Maffiuletti 2011). However, this study focused only on a recent three-year period (2006–2008) and did not examine the possible differences between the genders with age since the beginning of the event in the early 1980's. If the changes in age-related decline in performance differed between males and females over the past three decades, we would also expect some change in the difference between gender performances across the ages.

Previous studies have focussed mainly upon declines in overall performance with age by comparing older age group performances with younger ones, but have not really investigated if performances within each older age group have increased relatively over the years. To date, no data exist regarding the participation and performance trends of masters athletes in a multi-sport ultra-endurance event such as the Ironman triathlon in the last 25 years. Accordingly, the first purpose of this large cross-sectional study was to examine the changes in participation and performance of masters triathletes at the Ironman triathlon World Championship over the last 25 years (from 1986 to 2010). A secondary purpose was to analyze the gender differences in Ironman triathlon performance as a function of age across the same 1986–2010 period. In this study, we focused on the performance of the best master triathletes of each age-group (i.e. the top 10 performer of each 5-year age-group) because these athletes present a unique model for studying the effects of high levels of physical training in older age.

Methods

Approval for this study was obtained from the Burgundy University Committee on Human Research. It involved the analysis of publicly available data so content was waived. Age and time performance data for all triathletes completing the Hawaii Ironman Triathlon from 1986 to 2010 were obtained through the Hawaii Ironman Triathlon web site: http://ironmanworldchampionship.com/results/ . In the present paper, we focus our attention on the Hawaii Ironman Triathlon, which has become the Ironman World Championship i.e. the premier race in the field of long distance triathlon (Lepers 2008). In order to participate at the Hawaii Ironman Triathlon, all triathletes must earn a qualifying slot at one of the qualifying Ironman triathlons held worldwide during the previous year (http://ironman.com/events). The number of slot allocations for each age-group at qualifying events is distributed according to the number of age group starters in each category. For example, if 5% of the age group starters are female 40–44 yrs, then 5% of the total slots are allocated to the best female of the 40–44 yrs category. The number of total slots attributed depends on the qualifying events and ranges from 50 to 100. This mode of qualification makes the Hawaii Ironman Triathlon the most competitive long distance triathlon in the world.

Although there is no consensus in the literature about the definition of a masters athlete, in the present study we defined masters triathletes as those equal to or older than 40 yrs. For male and female athletes younger than 40 yrs including elite and non-elite triathletes, we considered only one age group 18–39 yrs. To focus more on changes in participation and performance in masters triathletes, we considered age groups 5 years in length for males and females older than 40, as follows: 40–44 yrs, 45–49 yrs, 50–54 yrs, 55–59 yrs, 60–64 yrs, and 65–69 yrs. Due to the very small number of finishers in the age-groups 70–74 yrs and 75–79 yrs, we did not consider these age groups.

To analyze the changes in participation across the years, we quantified the number of female and male finishers in each age-group category annually from 1986 to 2010. We considered only the age groups with at least 10 finishers per annum for the analysis of performances. Averaged swimming, cycling, running and total time performances of the top 10 finishers of each age group for both females and males were analyzed from 1986 to 2010. Taking the top 10 performers in the master categories gave a better comparison with higher performing younger athletes.

In order to limit the influence of environmental conditions and small changes in the courses in the comparison of performance, the swimming, cycling, running and overall time performances of each triathlete finishing in the top 10 of each age group were divided by the mean time performance of the top 10 overall finishers. We considered the mean performance of the top 10 overall finishers (whose age was always comprised between 18 and 39 years old) as the reference for calculating the relative performance ratio for the master age-groups. Thus, the age-related declines in performance were expressed using a performance ratio calculated between the individual and the mean time performances of the top 10 overall finishers for each mode of locomotion and total event time (Lepers et al 2010). This normalization procedure assisted the comparison of age-related declines in performance across the years for both males and females.

The magnitude of gender differences in total time performance of each age group was examined by calculating the difference in total times between the top 10 males versus females as a percentage of the average time for the top 10 males for each year from 1986 to 2010.

Statistical analysis

Data is reported as means ± SD in the text. Linear regressions analyses were used to estimate changes in the selected variables in each year of the race. Pearson's correlation coefficients were used to assess the association between various variables using Statsoft (Version 6.1, Statistica, Tulsa, OK, USA). Linear regression analyses were used to assess changes in the percentage of finishers in the different age-groups for both sexes across the years, the mean performance ratios for swimming, cycling, running and total event times, for males and females within the different age-groups, and gender differences in total time performances. A significance level of $P < 0.05$ was used to identify statistical significance.

Results

Participation trends

From 1986 to 2010, there were a total of 35,293 finishers (7,825 females and 27,468 males) at the Hawaii Ironman triathlon. The number of finishers during the studied period is shown in Figure 1. During these years, the average number of finishers per year was 1,099 ± 93 [range: 950–1,299] for males and 313 ± 90 [range: 218–469] for females. Females accounted on average for 22 ± 3% [range: 18–28%] of the field over the 25-year period.

In 1986, masters triathletes (i.e. > 40 yrs) represented 31% of the total field for the males and 23% of the total field for females, while in 2010 master triathletes represented 56% of the total field for males and 47% of the total field for females. The changes in the percentage of finishers in different age-groups for both sexes are presented in Figure 2. For both females and males, there was a significant rise in relative participation among age-groups ≥ 40 yrs. In contrast, relative participation significantly decreased among both males and females < 40 yrs, especially for the youngest age-groups 18–29 years.

Performances trends

Total time records and corresponding split times for male and female age-groups at the Hawaii Ironman Triathlon are presented in Table 1. The results clearly show that the best master age-group performances have been set during the last decade, and eight of them have been set in 2010. An exceptional performance can be seen in the male 40–44 yrs total time record that was been set by the 6 times Hawaii Ironman triathlon winner, Dave Scott, who returned to competition in 1994 at 40 years of age, after several years break from the race. Figure 3 shows the trends in swimming, cycling, running and total performance ratios for the top 10 male finishers subdivided into the different age groups across the years 1986 through 2010. There were no significant changes across years within age group 40–44 yrs, for any mode of locomotion and total time. In contrast, the average performance ratios improved between 1986 and 2010 in age groups 45–49 yrs and older.

Figure 4 shows the trends in performance ratios for the top 10 female finishers subdivided into the different age groups across the studied period. The average performance ratios for each mode of locomotion and total time improved between 1986 and 2010 in all age groups from 40–44 yrs to 60–64 yrs. The r^2, P and slopes values of the linear regressions corresponding to the Figure 3 and 4 are presented in the Table 2.

Gender differences trends

The changes across the years in total time gender differences between the top 10 female and top 10 male subdivided by different age groups are presented in Figure 5. There was no significant change in gender difference across the years within the age group 18–39 yrs ($r^2 = 0.09$, $P = 0.13$). In contrast, the gender difference significantly ($P < 0.001$) decreased between 1986 and 2010 in age groups comprised between 40–44 yrs and 55–59 yrs. Surprisingly, the gender difference for age group 60–64 yrs did not significantly change between 1999 and 2010 ($r^2 = 0.06$, $P = 0.42$). In 2010, the gender difference in total time was 11.8%, 11.9%, 11.3%, 14.4%, 12.7% and 17.8% for age groups 18–39 yrs, 40–44 yrs, 45–49 yrs, 50–54 yrs, 55–59 yrs and 60–64 yrs, respectively.

Discussion

The main findings of the present study were first that the participation of masters triathletes at the Hawaii Ironman triathlon increased during the 1986–2010 period. Second, during that period, female triathletes older than 40 years and male triathletes older than 44 years significantly improved their swimming, cycling, running and total time performances in the most recent years, relative to performances recorded at the beginning of the time period studied. Third, gender differences in total Ironman triathlon time decreased over the last 25 years for masters age-groups while it remained stable for the young age-group, 18–39 yrs.

Increase in participation of masters Ironman triathletes

Despite the rapid growth of triathlon since the early 1980's (The first Hawaii Ironman triathlon took place in 1978), the number of total male and female finishers has slightly increased (~34%) over the last 25 years. This could be explained by the fact that, for safety reasons, the race organisation of the Hawaii Ironman has imposed limits on the number of entries accepted since 1985, by creating a qualification system that requires all triathletes wanting to participate to earn a qualifying slot at one of the qualifying Ironman triathlons held worldwide (except for some limited slots offered by lottery). In 2010, it was estimated that around 50,000 triathletes had finished an Ironman distance triathlon in the world, either at one of the 23 qualifying races (http://ironman.com/events/) or at another non-qualifying event (http://www.k226.com/). Because the number of slot allocations for each age-group at qualifying events is distributed according to the relative number of age group starters in each category, the percent of finishers in each age group at the Hawaii Ironman triathlon represents a good picture of the age and gender of Ironman triathletes in the world.

Independently of the age, the female field has increased from 19 % to 27 % of total finishers over the past 25 years. Female participation at such an ultra-endurance event remains slightly lower compared to traditional endurance events such as marathon running, but greater than ultra-endurance events such as a 161-km ultramarathon. Indeed, Lepers & Cattagni (2011) showed that the relative participation of females at the New-York City Marathon increased over the last 30 years from 17% to 33% of the total field. In contrast, females accounted for 20 % of the finishers in the same time period at 161-km ultramarathons in North America (Hoffman et al. 2010).

In addition, the relative proportion of masters triathletes in the total field has also increased for both males and females over the last 25 years while those of male triathletes younger than 40 yrs of age decreased during the same period. In 2010, master triathletes represented 56% of male finishers and 47% of female finishers, respectively. This finding corroborates previous observations for marathon and ultramarathon running (Jokl et al. 2004, Lepers & Cattagni 2011, Hoffman et al. 2010). The growth of female and masters age groups in worldwide marathon and ultra-marathon racing has been particularly startling over the last 20 years (Burfoot 2007, Knecthle et al. 2011). Our data suggest that similar trends have occurred in Ironman triathlon racing over the last 10 years and we can expect that the participation of female master will continue to increase in the future to soon reach half of the total female field.

Different factors could be used to explain the increase in participation of masters Ironman triathletes. With the increase in life expectancy and training facilities, such as specific masters programs, the increased participation of older athletes described may be a reflection that these athletes, who are perhaps retired, have more available time and resources at their disposal to train and therefore to compete. The relative increase in participation of older Ironman triathletes could result from a relative decrease in Ironman triathletes in the younger age groups (18–39 years). Younger triathletes maybe more and more attracted by shorter distances such as short distance and half-Ironman distance triathlons. Indeed, since 2000 short distance triathlon (1.5km swim, 40 km cycle and 40 run) became an Olympic sport and it may have increased the popularity of the short distance especially in the young triathlete field. With advancing age, athletes naturally move towards longer distances where endurance capacities play a greater role in performance than maximal oxygen consumption. It has been suggested that enjoyment, health, fitness benefits, and social factors are the primary drivers for sport involvement with advancing age (Shaw & Ostrow 2005). For masters triathletes that are more achievement-oriented, there is no doubt that competition, personal challenge and skill development may also be strong reasons for their participation in ultra-endurance events. However, among older triathletes, the distinction between people who started training in triathlon later in life (i.e. after 40 yrs age) and people who participated in triathlon at a younger age is not known.

Performances of masters triathletes

The present results show that swimming, cycling, running and total performance times decreased over the 25-year periods studied for male triathletes older than 44 yrs age and female triathletes older than 40 yrs age. Several reasons may explain the improved performance of masters triathletes, such as a greater participation of the older age groups, which would increase the probability of finding better triathletes in these age groups, increased training facilities for older people, and increases in the competitive spirit in these older groups.

These last years, the age-related declines in total Ironman triathlon performance with advancing age until 70 yrs of age was about 12–13% per decade for males and 14–15% per decade for females, respectively. These values are in accordance with those found by Lepers & Cattagni (2011) for the New-York marathon running, but appear greater compared to those found in 100-km ultra-marathon running (7–8% per decade for males and 9–10% per decade for females), by Knechtle et al. (2011). These findings may be explained by the shorter duration of 100-km running compared to Ironman triathlon, and the different level of competitiveness between the two events: regional one for the 100-km running *vs.* World Championship for Ironman triathlon. Our data also confirm previous observations (Bernard et al. 2010, Lepers et al. 2010) showing a lesser age-related decline in cycling performance compared with running and swimming performances in triathlon. Physiological (e.g. concentric muscle contractions) and mechanical (e.g. relation between mechanical power output and velocity, non-weight bearing aspect) specificities of cycling compared with the two other disciplines may be explained by the lower age-related decline in cycling performance (Bernard et al. 2010, Lepers et al. 2010). In the context of health promotion, this finding suggests that cycling may represent an optimal activity with advancing age.

The question of whether the masters triathletes have reached their limits in Ironman triathlon performance can therefore be raised, at least for the age-group categories studied (i.e. between 40–69 yrs for males and 40–64 yrs for females). For marathon running, it has been recently suggested that male (> 65 years) and female (> 45 years) master runners should still improve their performances in the future (Lepers & Cattagni 2011). All these data suggest that older athletes have probably not yet reached their limits in endurance and ultra-endurance performance. The new generation of well-trained masters triathletes will move progressively into the older age group competitions. In addition to better performances for older triathletes, an increase in density of the top 10 spreads of each age group may also be expected in the future. Moreover, the expected arrival of previous elite triathletes to the youngest masters age-group category i.e. 40–44 yrs (The Hawaii Ironman triathlon male winner was 37 years old in 2010) in the near future will result in a need to redefine the notion of masters triathletes, regarding the decline in their performance.

Gender differences in total time

The current Hawaii Ironman triathlon record is 8:54:202 for females and 8:04:08 for males (see Table 2), corresponding to a gender gap of 10.3%. The present results showed that for masters triathletes, the gender differences in Ironman triathlon performance times decreased over the last 25 years, suggesting that masters females have reduced the gap to males. During these last years, gender differences in total event performance times remained slightly greater for age groups > 54 yrs compared to youngest age groups. This finding corroborates the results of Lepers & Maffiuletti (2011) who showed that gender differences in Ironman triathlon performance times analyzed from 2006 to 2008 increased with advancing age from 55 yrs. In contrast, it has been shown that gender difference in New-York marathon running performances did not significantly change across this age group over the past decade (Lepers & Cattagni 2011). Ironman triathlon is a newer ultra-endurance event with less participants compared to the NYC Marathon, which may explain why gender differences across the ages groups in Ironman triathlon are currently similar to those that were observed for marathon 30 yrs ago. There is no doubt that gender differences for older Ironman triathletes would still diminish in the future as it has been observed for marathon running because there is no real evidence that the age-related declines in physiological function differ between males and females. Age-related changes in the physiological determinants of endurance and ultra-endurance performance (e.g. maximal oxygen uptake, lactate threshold, and running economy) between males and females have not received considerable attention. For example, Holloszy and Kohrt (1995) suggested that the relative rates of decline in maximal oxygen consumption with age are similar between the sexes. However, further investigations are required in order to analyse the age-related declines in other physiological parameters such lactate threshold and running economy in males and females.

Practical applications

Most healthcare providers would agree that racing an Ironman triathlon after 50 years of age is not good for the body. But most older Ironman triathletes will say that training for an Ironman triathlon is one of the healthiest things they can do (Wortley & Islas 2011). Where should the limits be set? If masters athletes performed at such a high-level for so long, it is reasonable to expect that those destined to maintain that intensity could do so because they remained largely injury-free (Knobloch et al. 2008). The exponential increase in participation of masters athletes especially in the female field in ultra-endurance sporting events such as Ironman triathlon represents an immense opportunity to learn how the aging process is related to physical performance. However, the remarkable growth in ultra-endurance older athletes and varying levels of fitness also represent unique challenges to sports medicine professionals because these individuals are particularly exposed to overuse injuries (Egermann at al. 2003). A framework for pre-participation evaluation, training program and injury prevention is required to help older athletes reach their participation and performance goals injury free i.e. to maximise the benefits and minimize the risks (Marr 2011). We have much to learn from these ultra-endurance masters athletes that can pursue their passion with greater health and safety once we gain a greater understanding of them (Wortley & Islas 2011).

Conclusion

The participation of older triathletes at the World Ironman triathlon championship has increased over the 1986–2010 period and it will probably still grow in the future in Hawaii and other Ironman triathlons worldwide. During that period master triathletes have shown relative improvements of their performances in the three disciplines and in total event times. The gender differences in Ironman triathlon performance have progressively decreased over the last 25 years for older age-groups suggesting that female masters triathletes have reduced the gap to males. The question whether older triathletes have yet reached limits in their performance during Ironman triathlon should therefore be raised. Further studies investigating training regimes, competition experience or socio-demographic factors are needed to gain better insights into the phenomenon of the relative improvement in ultra-endurance performance with advancing age.

Acknowledgements:

No funding has been received for this work from the NIH, Wellcome Trust, HHMI or others.

Footnotes:

The authors have no conflict of interests to report.

References:

- Baker AB , Tang YQ . 2010 ; Aging performance for masters records in athletics, swimming, rowing, cycling, triathlon, and weightlifting . Exp Aging Res . 36 : 453 - 77
- Bernard T , Sultana F , Lepers R , Hausswirth C , Brisswalter J . 2010 ; Age related decline in Olympic triathlon performance: effect of locomotion mode . Exp Aging Res . 36 : 1 - 15
- Burfoot A . 2007 ; The history of the marathon . Sports Med . 37 : 284 - 287
- Egermann M , Brocai D , Lill CA , Schmitt H . 2003 ; Analysis of injuries in long-distance triathletes . Int J Sports Med . 24 : 271 - 276
- Hoffman MD , Wegelin JA . 2009 ; The Western States 100-Mile Endurance Run: participation and performance trends . Med Sci Sports Exerc . 41 : 2191 - 2198
- Hoffman MD , Ong JC , Wang G . 2010 ; Historical Analysis of Participation in 161 km Ultramarathons in North America . Int J Hist Sport . 27 : 1877 - 1891
- Holloszy JO , Kohrt WM . 1995 ; Exercise . Bethesda, MD Handbook of Physiology Aging Am Physiol Soc . 633 - 666
- Jokl P , Sethi PM , Cooper AJ . 2004 ; Masters's performance in the New York City marathon 1983–1999 . Br J Sports Med . 38 : 408 - 412
- Knechtle B , Wirth A , Knechtle P , Kohler G . 2009 ; Change of body composition in an 81 year old runner in a 100 km run . Praxis (Bern 1994) . 98 : 143 - 149
- Knechtle B , Rüst CA , Rosemann T , Lepers R . 2011 ; Age-related changes in 100-km ultra-marathon running performances . Age (Dordr) . in press 10.1007/s11357–011–9290–9
- Knobloch K , Yoon U , Vogt PM . 2008 ; Acute and overuse injuries correlated to hours of training in master running athletes . Foot Ankle Int . 29 : 671 - 676
- Lepers R . 2008 ; Analysis of Hawaii ironman performances in elite triathletes from 1981 to 2007 . Med Sci Sports Exerc . 40 : 1828 - 1834
- Lepers R , Sultana F , Bernard T , Hausswirth C , Brisswalter J . 2010 ; Age-related changes in triathlon performances . Int J Sports Med . 31 : 251 - 256
- Lepers R , Maffiuletti N . 2011 ; Age and gender interactions in ultra-endurance performance: insight from triathlon . Med Sci Sports Exerc . 43 : 134 - 139
- Lepers R , Cattagni T . 2011 ; Do older athletes reach limits in their performance during marathon running? . Age (Dordr) . in press 10.1007/s11357-011-9271-z
- Leyk D , Erley O , Gorges W , Ridder D , Rüther T , Wunderlich M , Sievert A , Essfeld D , Piekarski C , Erren T . 2009 ; Performance, training and lifestyle parameters of marathon runners aged 20–80 years: results of the PACE-study . Int J Sports Med . 30 : 360 - 365
- Maharam LG , Bauman PA , Kalman D , Skolnik H , Perle SM . 1999 ; Masters athletes: factors affecting performance . Sports Med . 28 : 273 - 285
- Marr DS . 2011 ; Care of the multisport athlete: lessons from Goldilocks . Br J Sports Med . 45 : 1086 - 1087
- Reaburn P , Dascombe B . 2008 ; Endurance performance in masters athletes . Eur Rev Aging Phys Act . 5 : 31 - 42
- Shaw KL , Ostrow A . 2005 ; Motivation and psychological skills in the senior athlete . Eur Rev Aging Phys Act . 2 : 22 - 34
- Sparkling PB , O'Donnell EM , Snow TK . 1998 ; The gender difference in distance running performance has plateaued: an analysis of world rankings from 1980 to 1996 . Med Sci Sports Exerc . 30 : 1725 - 1729
- Tanaka H , Seals DR . 2008 ; Endurance exercise performance in Masters athletes: age-associated changes and underlying physiological mechanisms . J Physiol . 586 : 55 - 63
- Trappe S . 2007 ; Marathon runners. How do they age ? . Sports Med . 37 : 302 - 305
- Wortley G , Islas AA . 2011 ; The problem with ultra-endurance athletes . Br J Sports Med . 45 : 1085 -
- Zaryski C , Smith DJ . 2005 ; Training principles and issues for ultra-endurance athletes . Curr Sports Med Rep . 43 : 165 - 70

Fig. 1

Total number of finishers at the Hawaii Ironman Triathlon and number of finishers of each sex from 1986 to 2010.

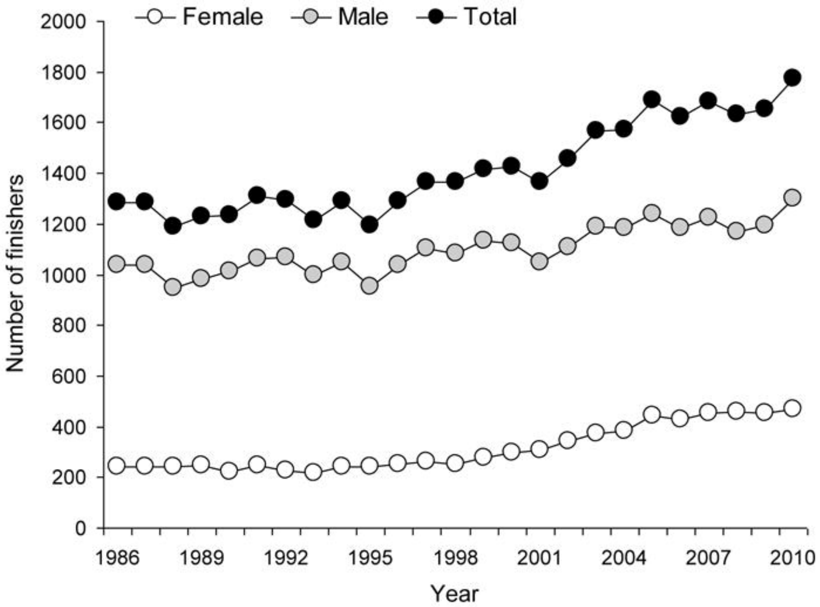


Fig. 2

Linear regressions defining the percentages of finishers within different age groups across the period of 1986 through 2010, for females (Panel A) and for males (Panel B). All the slopes of the linear regressions were significantly different (P < 0.01) from zero.

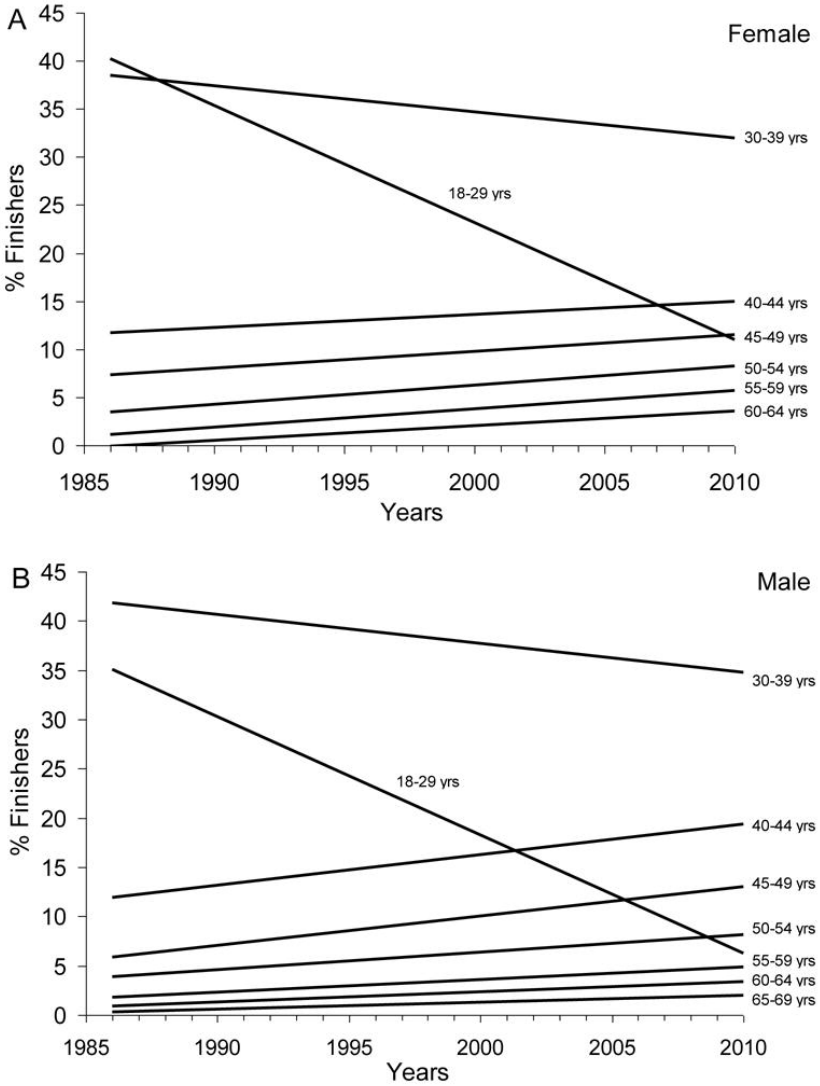
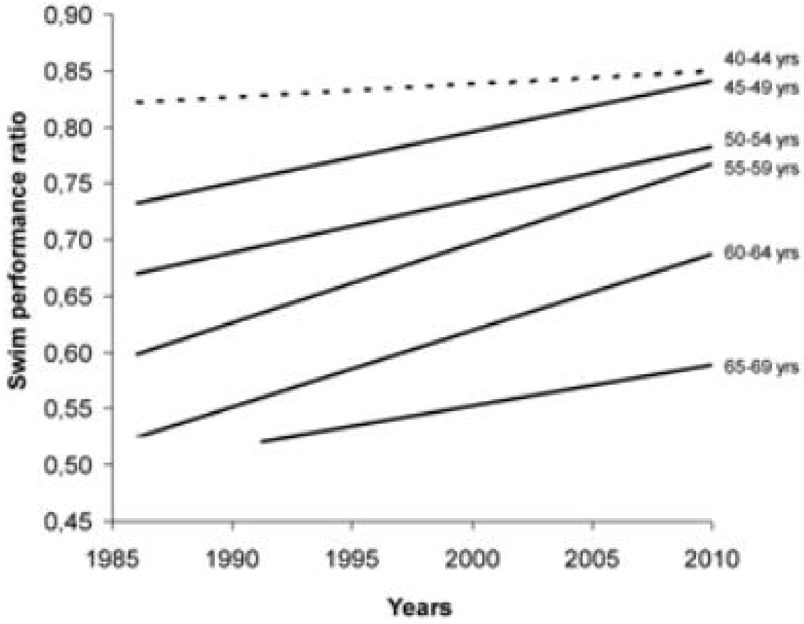


Fig. 3

Changes in performance ratios for swimming, cycling, running and total times across the years for top 10 finishers in each male age group. A performance ratio equal to 1 corresponded to the performance of the top 10 finishers of the 18–39 year age group. Solid lines represent conditions where the slopes of the linear regressions were significantly different (P < 0.01) from zero. Dashed lines indicate the slopes of the linear regressions were not significantly different from zero. Lines cross only the range of years for which data were considered.



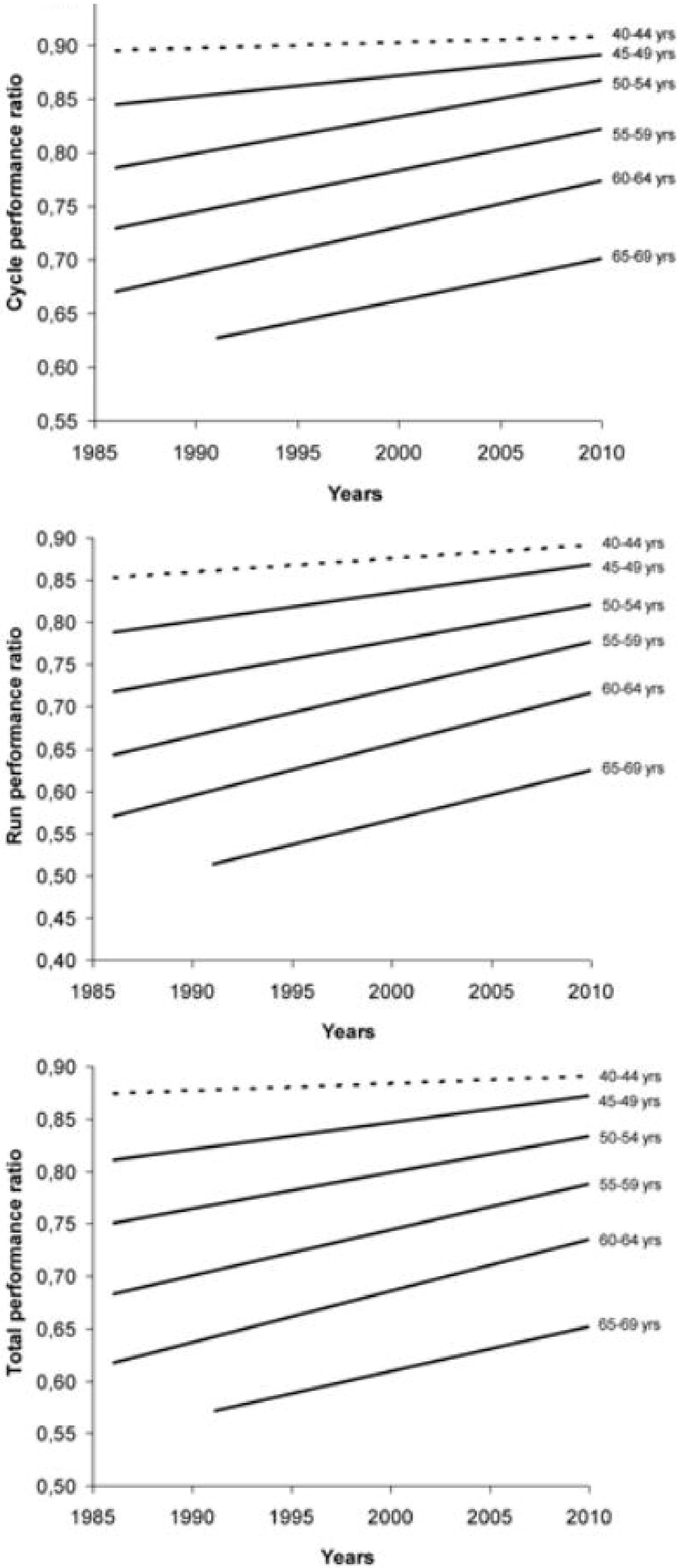
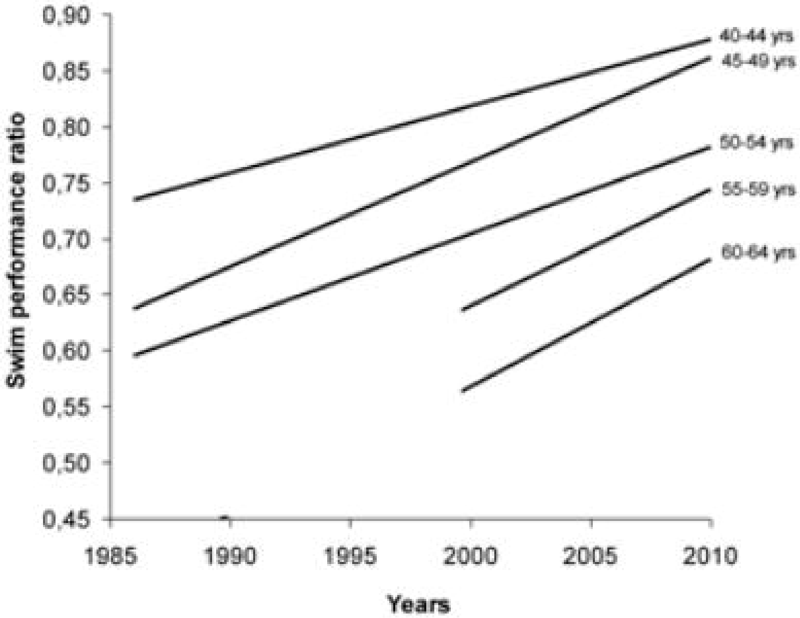
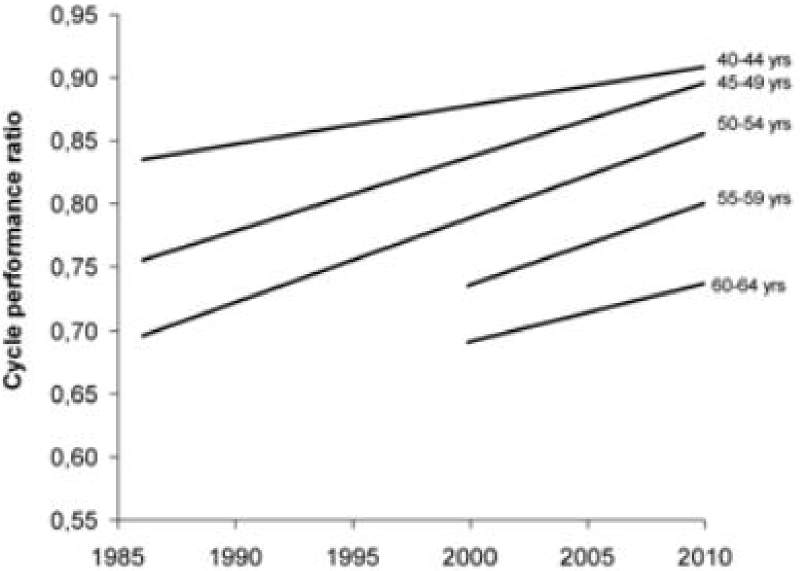
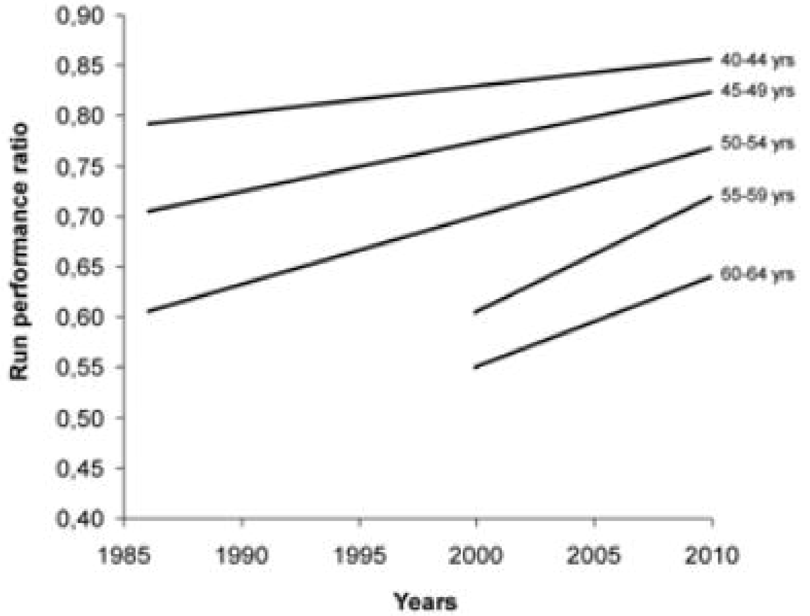

Cycle performance ratio
Years
Run performance ratio
Years
Total performance ratio
Years
40-44 yrs
45-49 yrs
50-54 yrs
55-59 yrs
60-64 yrs
65-69 yrs

Fig. 4

Changes in performance ratios for swimming, cycling, running and total times by year for the top 10 finishers in each female age group. A performance ratio equal to 1 corresponded to the performance of the top 10 finishers of the 18–39 year age group. Solid lines represent conditions where the slopes of the linear regressions were significantly different (P < 0.01) from zero. Dashed lines indicate the slopes of the linear regressions were not significantly different from zero. Lines traverse only the range of years for which data were considered.







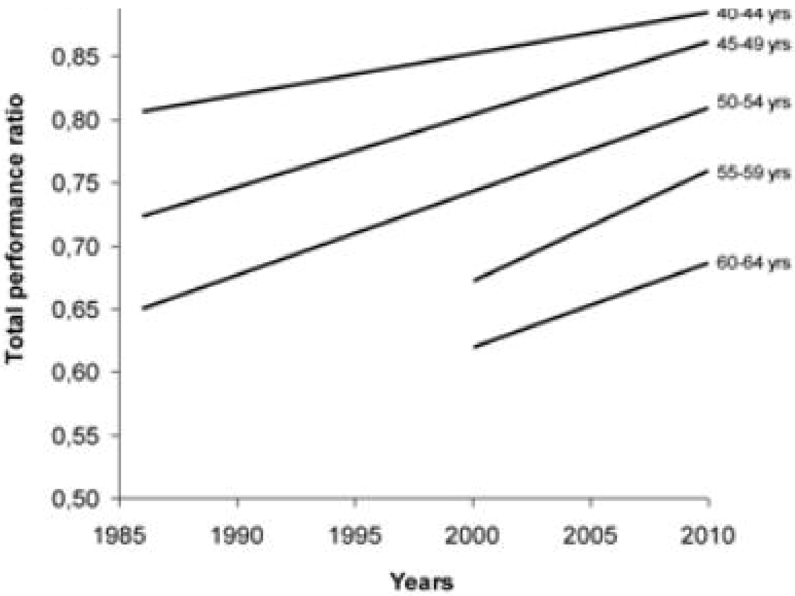


Fig. 5

Linear regressions defining gender differences in total times within different age groups across the period of 1986 through 2010. Solid lines represent conditions where the slopes of the linear regressions were significantly different ($P < 0.01$) from zero. Dashed lines indicate the slopes of the linear regressions were not significantly different from zero. Lines traverse only the range of years for which data were considered.

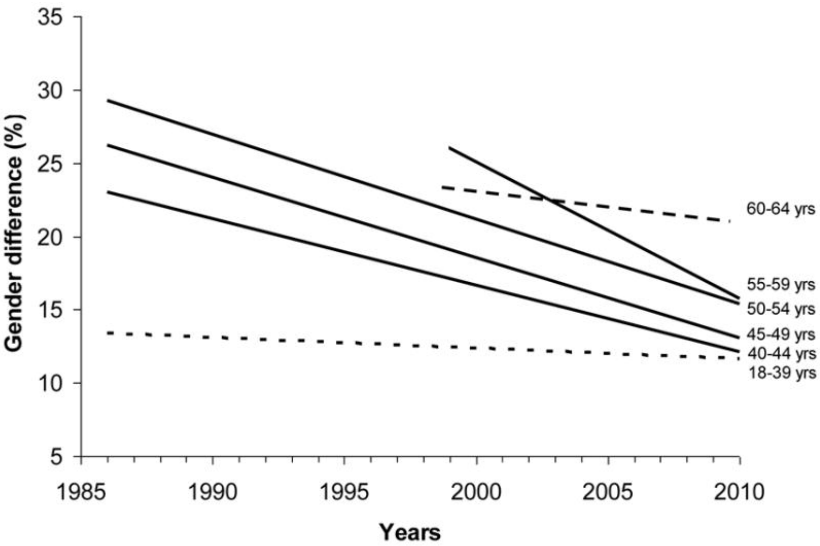


Table 1

Total time records and corresponding splits times for male and female age-groups at the Hawaii Ironman Triathlon.

	Age Groups (years)									
	18–39	**40–44**	**45–49**	**50–54**	**55–59**	**60–64**	**65–69**	**70–74**	**75–79**	**> 80**
Male										
3.8 km Swim (h:min:s)	51:36	51:48	56:55	1:03:32	1:07:09	1:16:20	1:27:36	1:38:05	1:37:47	1:50:11
180 km Cycle (h:min:s)	4:30:44	4:39:16	5:04:47	4:51:44	5:00:17	5:19:17	5:57:30	6:27:39	6:39:35	7:14:10
42 km Run (h:min:s)	2:41:48	2:53:28	3:04:21	3:24:51	3:34:03	3:25:28	3:52:35	4:23:11	4:55:43	6:34:15
Total (h:min:s)	8:04:08	8:24:32	9:11:24	9:26:23	9:47:29	10:08:15	11:29:45	12:41:33	13:27:50	15:48:40
(year)	(1996)	(1994)	(2009)	(2006)	(2005)	(2010)	(2006)	(2010)	(2005)	(2010)
Female										
3.8 km Swim (h:min:s)	54:31	1:13:52	1:04:03	1:08:08	1:06:18	1:32:16	1:21:02	1:37:54	1:45:05	-
180 km Cycle (h:min:s)	4:52:06	5:25:00	5:20:08	5:31:56	5:35:36	6:27:46	6:47:28	7:24:33	7:25:17	-
42 km Run (h:min:s)	3:03:05	3:17:48	3:31:11	3:47:23	4:00:08	4:05:22	4:59:01	6:07:02	6:19:43	-
Total (h:min:s)	8:54:02	10:02:35	10:01:30	10:35:59	10:51:43	12:17:24	13:16:32	15:19:19	15:54:16	-
(year)	(2009)	(2010)	(2010)	(2005)	(2010)	(2010)	(2010)	(2000)	(2005)	

Table 2

Corresponding r^2 , P and slopes values of the linear regressions presented in Figure 3 (Male) and Figure 4 (Female).

	Swim			Cycle			Run			Total		
	r^2	P	Slope. 10^{-2}	r^2	P	Slope. 10^{-2}	r^2	P	Slope. 10^{-2}	r^2	P	Slope. 10^{-2}
Male												
40–44 yrs	0.05	0.26	0.11	0.04	0.29	0.05	0.21	0.02	0.16	0.10	0.12	0.07
45–49 yrs	0.56	< 0.0001	0.45	0.23	0.013	0.19	0.58	< 0.0001	0.33	0.52	< 0.0001	0.26
50–54 yrs	0.59	< 0.0001	0.47	0.44	< 0.001	0.34	0.60	< 0.0001	0.43	0.61	< 0.0001	0.35
55–59 yrs	0.61	< 0.0001	0.70	0.55	< 0.0001	0.39	0.66	< 0.0001	0.55	0.72	< 0.0001	0.44
60–64 yrs	0.76	< 0.0001	0.68	0.58	< 0.0001	0.43	0.57	< 0.0001	0.61	0.62	< 0.0001	0.49
65–69 yrs	0.24	0.034	0.40	0.60	< 0.0001	0.58	0.50	< 0.0001	0.61	0.58	< 0.0001	0.54
Female												
40–44 yrs	0.55	< 0.0001	0.60	0.47	< 0.0001	0.31	0.42	< 0.0001	0.27	0.60	< 0.0001	0.33
45–49 yrs	0.82	< 0.0001	0.93	0.81	< 0.0001	0.59	0.65	< 0.0001	0.49	0.82	< 0.0001	0.58
50–54 yrs	0.54	< 0.0001	0.78	0.70	< 0.0001	0.67	0.69	< 0.0001	0.68	0.76	< 0.0001	0.66
55–59 yrs	0.71	< 0.001	1.04	0.59	0.003	0.65	0.84	< 0.0001	1.14	0.79	< 0.0001	0.88
60–64 yrs	0.34	0.047	1.14	0.31	0.049	0.45	0.67	0.0011	0.90	0.59	0.0034	0.67