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Elite triathletes in 'Ironman Hawaii' get older but faster

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Abstract The age of peak performance has been well investigated for elite athletes in endurance events such as marathon running, but not for ultra-endurance (>6 h) events such as an Ironman triathlon covering 3.8 km swimming, 180 km cycling and 42 km running. The aim of this study was to analyze the changes in the age and performances of the annual top ten women and men at the Ironman World Championship the 'Ironman Hawaii' from 1983 to 2012. Age and performances of the annual top ten women and men in overall race time and in each split discipline were analyzed. The age of the annual top ten finishers increased over time from 26±5 to 35±5 years (r^2=0.35, P<0.01) for women and from 27±2 to 34±3 years (r^2=0.28, P<0.01) for men. Overall race time of the annual top ten finishers decreased across years from 671±16 to 566±8 min (r^2=0.44, P<0.01) for women and from 583±24 to 509±6 min (r^2=0.41, P<0.01) for men. To conclude, the age of annual top ten female and male triathletes in the 'Ironman Hawaii' increased over the last three decades while their performances improved. These findings suggest that the maturity of elite long-distance triathletes has changed during this period and raises the question of the upper limits of the age of peak performance in elite ultra-endurance performance.

Keywords Aging · Swimming · Cycling · Running · Age of peak performance · Ultra-endurance

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Introduction

Age has been reported as an important predictor variable for endurance performance (Donato et al. 2003). Generally, peak endurance performance is achieved between 20 and 55 years for recreational athletes (Donato et al. 2003; Leyk et al. 2007, 2009; Tanaka and Seals 1997). After the age of 55 years, a modest decrease in performance until the age of 70 years followed. After the age of 70 years, the decrease in performance became more pronounced (Donato et al. 2003; Leyk et al. 2007, 2009; Tanaka and Seals 1997).

In recent years, there has been an increasing interest in investigating the effects of aging on endurance performances in master athletes (Knechtle et al. 2011; Lepers and Cattagni 2012; Lepers and Maffiuletti 2011; Tanaka and Seals 2003; Wright and Perricelli 2008). Several studies investigated the age-related decline in performance for different endurance disciplines such as swimming (Donato et al. 2003; Tanaka and

Seals 1997), running (Leyk et al. 2007) and triathlon (Lepers et al. 2010, 2012; Stiefel et al. 2012). However, differences appeared between the lengths of the different endurance disciplines. For example, the age-related performance decline in an Olympic distance triathlon covering 1.5 km swimming, 40 km cycling and 10 km running started at the age of 55 years for age-group athletes, whereas in an Ironman triathlon covering 3.8 km swimming, 180 km cycling and 42.195 km running, the decline in performance started already at the age of 50 years (Lepers et al. 2010).

For athletes and coaches, the age of peak endurance performance might be more important than the age-related performance decline, as they can plan a career more precisely with this knowledge. The age of peak endurance performance seemed to differ between different sports disciplines such as swimming and running (Schulz and Curnow 1988). In freestyle swimming, men achieved peak swim performance at the age of ~20 years in distances over 100, 400 and 1,500 m, respectively. However, women were ~20, ~17 and ~16 years old, respectively (Schulz and Curnow 1988). In running, the age of peak performance seemed to increase with the increasing length of the running distance (Berthelot et al. 2011; Eichenberger et al. 2012; Hoffman and Wegelin 2009; Hunter et al. 2011; Schulz and Curnow 1988). The age of peak running performance was ~22 years for male short-distance runners competing in 100 and 200 m (Schulz and Curnow 1988), ~23.5 years for 10,000-m runners (Berthelot et al. 2011), ~29 years in marathoners (Hunter et al. 2011) and in the upper thirties in ultra-marathoners (Eichenberger et al. 2012; Knechtle et al. 2011; Hoffman and Wegelin 2009).

A sex difference in the age of peak endurance performance has been described (Hunter et al. 2011; Knechtle et al. 2012b; Schulz and Curnow 1988). In swimming, women tended to be 2 years younger at the age of peak performance compared to men (Schulz and Curnow 1988). The age of peak swim performance over longer distances such as 400 and 1,500 m freestyle was associated with younger ages for women, but not for men (Schulz and Curnow 1988). In contrast, elite female marathoners with ~29.8 years seemed slightly older than elite male marathoners with ~28.9 years (Hunter et al. 2011). In half-Ironman triathlon, women achieved their best performance between 25 and 39 years, whereas men attained their fastest race times between 18 and 39 years (Knechtle et al. 2012b).

Previous observations suggested that the age of peak endurance performance tended to increase over time in ultra-endurance events these last decades. For example, the age of the top five overall runners in the 'Western States 100-Miles Endurance Run' increased between 1978 and 2007 from the early thirties to the upper thirties (Hoffman and Wegelin 2009). The age of peak performance in multi-sports disciplines such as long-distance duathlon or triathlon has also been investigated (Knechtle et al. 2012a, b; Rüst et al. 2012, 2013). In long-distance duathlon, the age of peak performance was between 25 and 39 years for both women and men (Rüst et al. 2013). In ultra-distance triathlons covering the Triple Iron ultra-triathlon distance of 11.4 km swimming, 540 km cycling and 126.6 km running and the Deca Iron ultra-triathlon distance of 38 km swimming, 1,800 km cycling and 420 km running, the age of peak performance was between 25 and 44 years (Knechtle et al. 2012a). The mean age of the finishers was significantly higher for Deca Iron ultra-triathletes with 41.3±3.1 years compared to Triple Iron ultra-triathletes with 38.5±3.3 years. For the Ironman triathlon, Lepers (2008) investigated the changes in performance of elite triathletes over time in 'Ironman Hawaii', but the age of the elite triathletes in 'Ironman Hawaii' had not been investigated. In 'Ironman Switzerland', one of the European qualifiers for 'Ironman Hawaii', the age of the top ten triathletes was 34±4 years for women and 33±3 years for men (Rüst et al. 2012). The age of peak Ironman performance remained unchanged for men over the last 17 years, but increased for women from 30±4 years in 1995 to 36±5 years in 2011. Both the annual top ten women and men improved overall race performance over time (Rüst et al. 2012).

In the present study, we focus our attention on 'Ironman Hawaii' because this race has become the Ironman World Championship, i.e. the premier race in the field of long-distance triathlon. Therefore, the aim of the present study was to examine the changes in performance and age of elite female and male triathletes in 'Ironman Hawaii' between 1983 and 2012. Referring to findings in 'Ironman Switzerland' as a qualifier for 'Ironman Hawaii', we hypothesized that elite female triathletes would become older but both female and male elite triathletes would improve their performance in overall race performance and in the three disciplines over time.

Materials and methods

This study was approved by the Institutional Review Board of St. Gallen, Switzerland, with waiver of the requirement for informed consent given that the study involved the analysis of publicly available data. The data set for this study was obtained from the race website of 'Ironman World Championship' (www.ironmanworldchampionship.com). All triathletes who ever finished 'Ironman Hawaii' between 1983 and 2012 were analyzed regarding race time and age. Due to the high number of missing or incomplete data of the age of the athletes between the first race in 1978 and 1982, data before 1983 were excluded from analysis. Data from 41,463 finishers in the 'Ironman Hawaii' between 1983 and 2012 were available and analyzed. For each year, the age and the performance times of the ten fastest female and male triathletes for total race time and split discipline were analyzed (30 years × total race + three split times × two sexes × ten athletes = n=2,400).

Statistical analysis

In order to increase the reliability of the data analyses, each set of data was tested for normal distribution and for homogeneity of variances in advance of statistical analyses. Normal distribution was tested using a D'Agostino and Pearson omnibus normality test, and homogeneity of variances was tested using a Levene's test in case of two groups and with a Bartlett's test in case of more than two groups. To find significant changes in the age and performance of the annual top ten female and male triathletes across years, linear regression was used. To find differences between the age of peak performance in the different disciplines between women and men, a two-way analysis of variance (ANOVA) with sex × discipline was performed with subsequent Bonferroni post-hoc analysis. Effect size (ω^2) was inserted to show the strength of an association for the two-way ANOVA. Statistical analyses were performed using IBM SPSS Statistics (Version 19, IBM SPSS, Chicago, IL, USA) and GraphPad Prism (Version 5, GraphPad Software, La Jolla, CA, USA). Significance was accepted at $P<0.05$ (two-sided for t tests). Data in the tables are given as mean ± standard deviation (SD). Data in the figures are presented as individual data in plots with regression lines.

Results

Changes in performance between 1983 and 2012

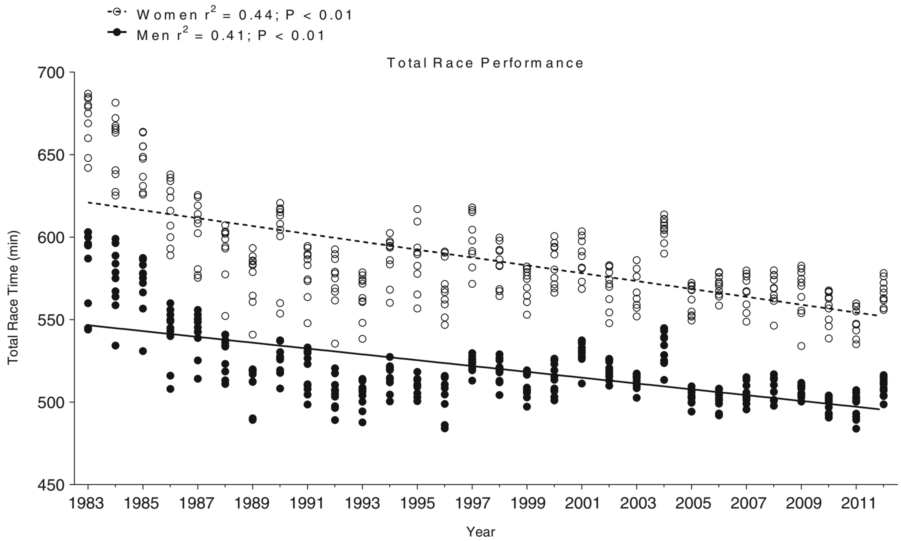
Race times of the annual overall top ten finishers decreased for both women (r^2=0.44, $P<0.01$) and men (r^2=0.41, $P<0.01$) across years (Fig. 1 and Table 1). Regarding the split disciplines (Fig. 2), split times decreased in swimming for men from 56±3 to 52±2 min (r^2=0.17, $P<0.01$), but not for women (r^2=0.01, $P>0.05$; Fig. 2a). In cycling (Fig. 2b) and running (Fig. 2c), split times decreased for both women and men. For women, the cycling split times decreased from 368±8 to 309±5 min (r^2=0.36, $P<0.01$); for men, the cycling split time decreased from 321±10 to 276±2 min (r^2=0.48, $P<0.01$). In running, the split times decreased for women from 223±13 to 184±3 min (r^2=0.47, $P<0.01$) and for men from 192±8 to 171±3 min (r^2=0.45, $P<0.01$).

Changes in age between 1983 and 2012

Between 1983 and 2012, the age of the annual overall top ten triathletes increased for both women and men (Fig. 3 and Table 2). For men, the age increased from 27±2 to 34±3 years (r^2=0.28, $P<0.01$); for women, the age increased from 26±5 to 35±5 years (r^2=0.35, $P<0.01$). Considering the split disciplines (Fig. 4), age increased for both women and men in all three disciplines (Table 2). In swimming (Fig. 4a), age increased from 24±3 to 34±3 years in women (r^2=0.29, $P<0.01$) and from 26±4 to 33±4 years in men (r^2=0.15, $P<0.01$). In cycling (Fig. 4b), age increased for women from 27±4 to 34±5 years (r^2=0.33, $P<0.01$) and for men from 27±4 to 33±4 years (r^2=0.10, $P<0.01$). In running, age increased from 27±5 to 34±5 years for women (r^2=0.13, $P<0.01$) and from 28±4 to 32±3 years in men (r^2=0.13, $P<0.01$).

During the 1983–2012 period, the mean age of the best triathletes was not significantly different between men (33±4 years) and women (30±3 years) for overall race time, and both swimming (30±8 years for men and 28±4 years for women) and cycling (33±5 years for men and 34±3 years for women) split times. However, the best male runners were significantly older (36±8 years) than the best female runners (30±3 years; $P<0.05$). For women, the best swimmers were significantly younger (28±4 years) than the best cyclists (34±3 years; $P<0.05$). There was a significant interaction between discipline and sex (ω^2=13.7, P=0.01).

Fig. 1 Changes in overall race time across years of the annual top ten women and men. Values are presented as individual data with linear regression



Discussion

The aim of the present study was to examine the changes in performance and the age of peak performance for the annual top ten female and male triathletes in 'Ironman Hawaii' between 1983 and 2012. The results showed that both female and male elite triathletes improved their performance in cycling, running and overall race time during the studied period. In addition, they became older over time.

Change in triathlon performance

The decrease of overall race times was associated for both sexes with an improvement in both the cycling and running splits. In swimming, only men improved the split time. Overall race times in Ironman triathlon decreased rapidly in the beginning of 'Ironman Hawaii', but remained stable since the late 1980s, except in the running and cycling splits where small improvements were observed (Lepers 2008). The considerable improvement in the first few years in 'Ironman Hawaii' might be explained by the increasing number of athletes which was probably also due to improvements in training, nutrition and experience-related pacing strategies (Lepers 2008).

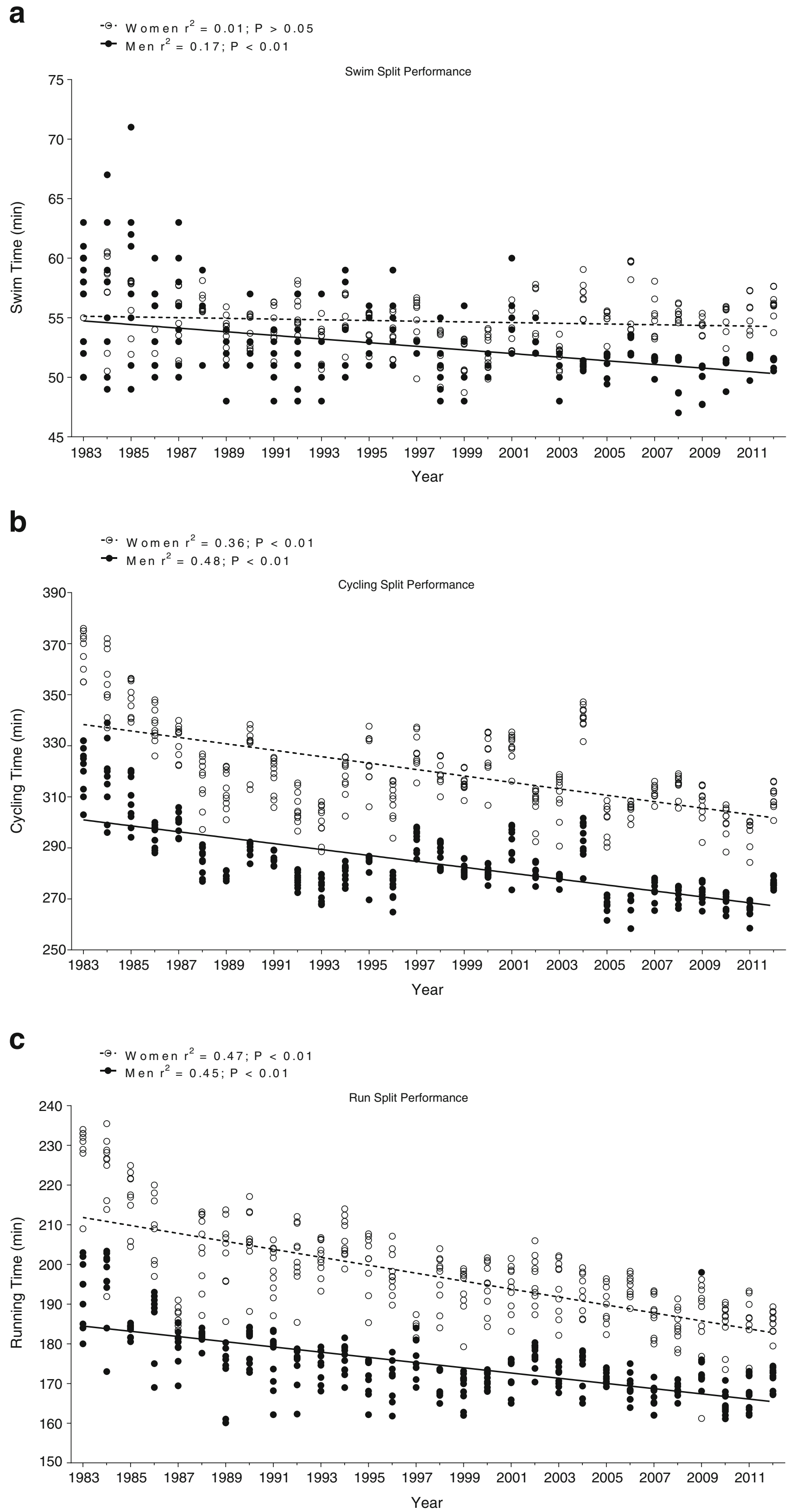
During the last century, there has been a continuous decrease in performance times in different sports disciplines such as track and field and swimming (Berthelot et al. 2010; Schulz and Curnow 1988). Again, there seemed to be differences for various endurance disciplines. Elite performances in running disciplines have been stagnating since the late 1980s, while swimming performances were still improving

Table 1 Change in overall and split times in 'Ironman Hawaii' between 1983 and 2012 for the overall top ten women and men

	1983	2012	Change	Significance
Women				
Overall race time (min)	671±16	566±8	−16 %	*P*<0.01
Swimming split time (min)	57±3	56±1	–	*P*>0.05
Cycling split time (min)	368±8	309±5	−16 %	*P*<0.01
Running split time (min)	223±13	184±3	−17 %	*P*<0.01
Men				
Overall race time (min)	583±24	509±6	−13 %	*P*<0.01
Swimming split time (min)	56±3	52±2	−5 %	*P*<0.01
Cycling split time (min)	321±10	276±2	−14 %	*P*<0.01
Running split time (min)	192±8	171±3	−11 %	*P*<0.01

Values are presented as mean (±SD)

Fig. 2 Changes in split times across years in swimming (**a**), cycling (**b**) and running (**c**) of the annual top ten women and men. Values are presented as individual data with linear regression



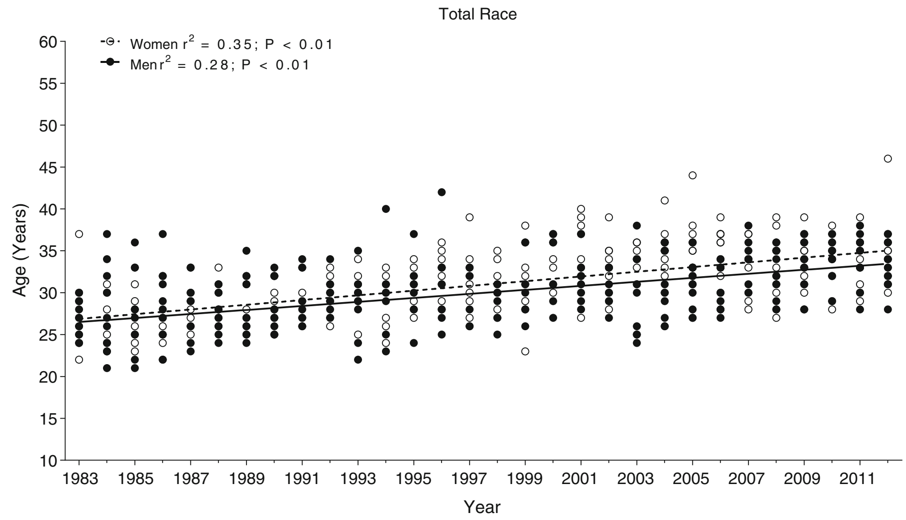


Fig. 3 Changes in the age of the annual top ten women and men over time. Values are presented as individual data with linear regression

(Berthelot et al. 2010). As wetsuits are not allowed in 'Ironman Hawaii' (http://www.ironman.com/triathlon/events/ironman/world-championship/athletes/rules-and-regulations/swim-rules.aspx#axzz2Lk611Dga), no technological advances have been achieved in swimming (Lepers 2008). This might be one reason for the unchanged swim split times over the investigated period for women. In cycling, the improvements in race performance seemed to be more pronounced in the first decade of 'Ironman Hawaii'. This might be surprising as cycling technology is still progressing (Faria et al. 2005). However, as the bike course in 'Ironman Hawaii' is relatively flat and drafting is prohibited due to heavy wind in Hawaii (www.hawaiiweathertoday.com), the air resistance is the primary energy cost factor at high cycling speeds and especially on flat terrain (Faria et al. 2005; Jeukendrup and Martin 2001). This discrepancy can be explained by the fact that improvements in aerodynamics were more important than to reduce bike weight for this particular race. Most probably, aerodynamic techniques were established earlier, whereas nowadays is being focused on reducing bike weight. The constant improvement in marathon split time could be explained by better nutrition and pacing strategies (Abbiss et al. 2006), which are probably more important at the end of an Ironman race.

Table 2 Change in the age of the athletes for overall race time and split times for the overall top ten women and men in 'Ironman Hawaii' between 1983 and 2012

	1983	2012	Significance
Women			
Overall race time (years)	26±5	35±5	*P*<0.01
Swimming split (years)	24±3	34±3	*P*<0.01
Cycling split (years)	27±4	34±5	*P*<0.01
Running split (years)	27±5	34±5	*P*<0.01
Men			
Overall race time (years)	27±2	34±3	*P*<0.01
Swimming split (years)	26±4	33±4	*P*<0.01
Cycling split (years)	27±4	33±4	*P*<0.01
Running split (years)	28±4	32±3	*P*<0.01

Values are presented as mean (±SD)

Age of peak performance in triathletes

The most important finding was that the age of peak performance increased for both women and men while the athletes became faster. The top ten women and men became older in all single disciplines, and tended even to become master athletes since master athletes were generally defined by the age at which the world record in open elite sport peaks, means typically older than 35 to 40 years (Ransdell et al. 2009; Reaburn and Dascombe 2008). These results were expected since it has been reported for ultra-marathoners that top performers became older over time (Eichenberger et al. 2012; Hoffman and Wegelin 2009). For example, the age of the top five runners increased between 1978 and 2007 from the early thirties to the upper thirties in the 'Western States 100-Miles Endurance Run' (Hoffman and Wegelin 2009).

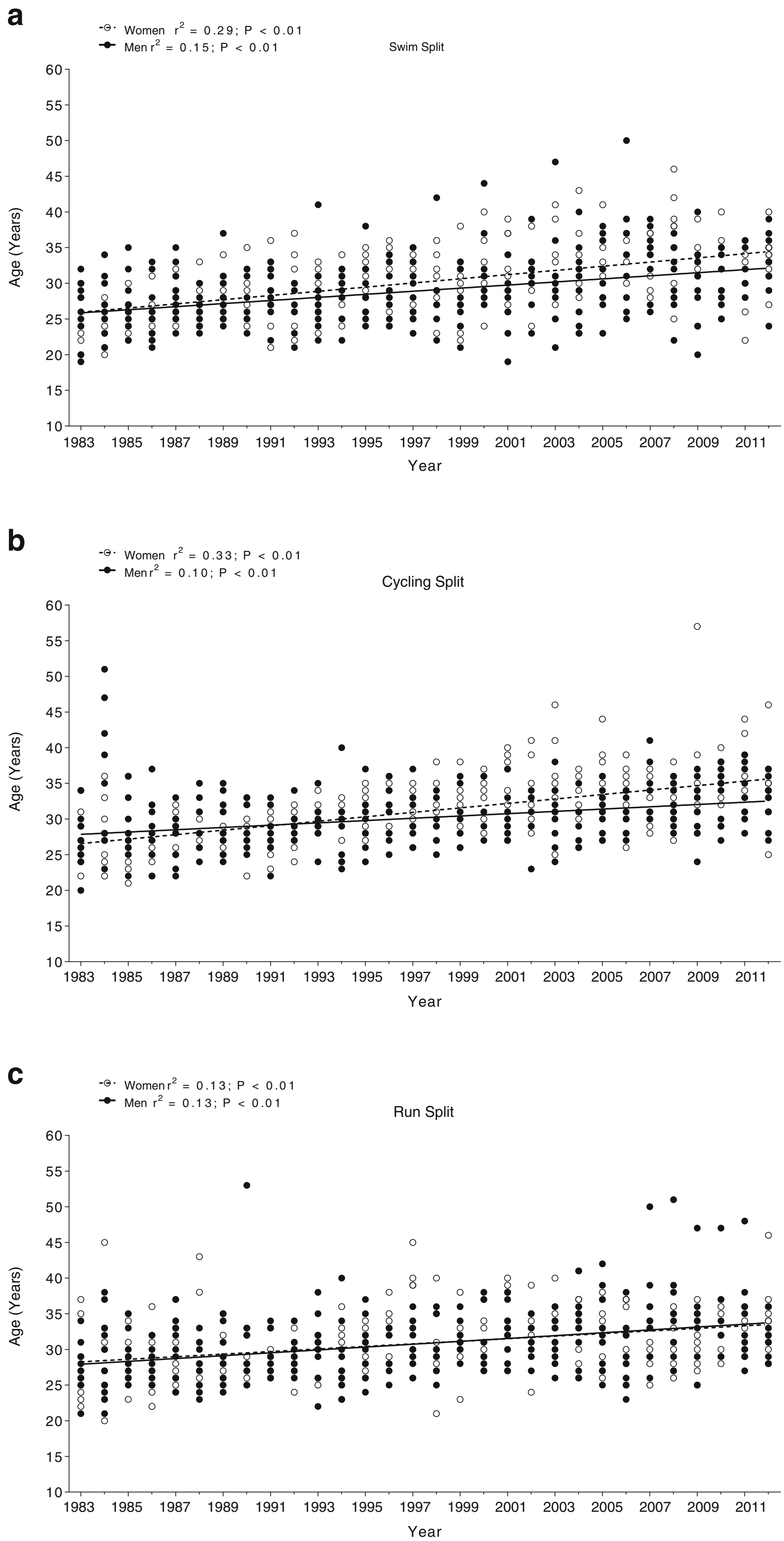


Fig. 4 Changes in the age of the annual top ten women and men in swimming (**a**), cycling (**b**) and running (**c**) over time. Values are presented as individual data with linear regression

One reason for the increase in the age of peak performance could be the increasing importance of experience in training and competition strategies (Knechtle et al. 2010) as the number of competitors was growing in endurance sports events (Hoffman and Wegelin 2009; Lepers et al. 2012). Another reason for the increasing age of peak performance might be the popularity of Ironman triathlon, which attracted more athletes and especially more masters athletes in recent years (Lepers et al. 2012; Stiefel et al. 2012). There was also a growth in participation of older athletes in ultra-marathon (Hoffman and Wegelin 2009) and marathon running (www.runningusa.org). The increased life expectancy and number of healthy life years (OECD 2011) might also account for the increasing age of peak performance in 'Ironman Hawaii'.

The fastest Ironman triathletes appeared older than the fastest elite marathon runners. Indeed, Hunter et al. (2011) investigated the age of peak marathon performance in elite marathoners and reported that the fastest marathoners were about 30 years of age where women with 29.8±4.2 years were older than men with 28.9±3.8 years. A reason for the higher age of peak performance in elite Ironman triathletes compared to elite marathoners could be the increasing importance of experience in training and competition strategies (Knechtle et al. 2010), where experience could be more important in multi-sports disciplines than in single-sport disciplines. The age of master athletes is generally higher than the age range in which world records typically are achieved (Ransdell et al. 2009). Therefore, the definition that masters athletes are typically older than 35 years of age and systematically train for and compete in organized forms of sport specifically designed for older adults (Reaburn and Dascombe 2008) needs re-evaluation for ultra-endurance athletes such as Ironman triathletes.

Similar age ranges for peak endurance performance had been observed in investigations about several sports disciplines such as pool swimming (Donato et al. 2003; Tanaka and Seals 1997), marathon running (Hunter et al. 2011), ultra-marathon running (Eichenberger et al. 2012; Hoffman and Wegelin 2009), long-distance duathlon (Rüst et al. 2013), half-Ironman triathlon (Knechtle et al. 2012b) and both Triple Iron and Deca Iron ultra-triathlon (Knechtle et al. 2012a). Peak performance was achieved at the age of 25–40 years in men in 1,500-m freestyle swimming and 30–35 years in women, respectively (Donato et al. 2003; Tanaka and Seals 1997), at 25–34 years in marathoners (Hunter et al. 2011) and in the upper thirties in ultra-marathoners (Hoffman and Wegelin 2009). Long-distance duathlon performance (i.e. 10-km run, 150-km cycle and 30-km run) peaked between 25 and 39 years for women and men (Rüst et al. 2013), and in both Triple Iron and Deca Iron ultra-triathlon, male athletes peaked between 25 and 44 years (Knechtle et al. 2012a). In half-Ironman triathlon, women peaked at 25–39 years and men at 18–39 years, respectively (Knechtle et al. 2012b). In mountain ultra-marathon running in the 78-km 'Swiss Alpine Marathon', the peak age for the top ten men increased from 34±5 years in 1998 to 38±5 years in 2011 and from 32±5 to 39±6 years for women, respectively (Eichenberger et al. 2012). As the age of peak performance seems comparable between all these disciplines, the age range of 25–40 years seems to be the best age for peak performance in endurance disciplines (Schulz and Curnow 1988).

There are several reasons to explain this finding. Athletic tasks requiring strength, speed and explosive power peaked in the early twenties, whereas tasks requiring endurance, acquired skill and knowledge peaked in the late twenties and early thirties (Schulz and Curnow 1988). A larger range of the age of peak performance suggests that non-biological factors such as experience (Knechtle et al. 2010) and learning (Schulz and Curnow 1988) seem to be important. Probably, a lot of mental strength and motivation is required to complete an Ironman triathlon (Parry et al. 2011). Possibly, mental strength in some individuals increases with age. This might be a reason for peak performance resting generally until ~40 years, and if the trend of the last three decades continues, it might still increase. However, there are some top ten triathletes being much older than this. For example, Natascha Badmann, six times female winner in 'Ironman Hawaii' was 46 years old in 2012 and is still one of the best female Ironman triathletes in the world with second place in 'Ironman Lanzarote' in 2011, first place in 'Ironman South Africa' in 2012, sixth place in 'Ironman Hawaii' in 2012, and fourth place in 'Ironman Melbourne' in 2013 (www.ironman.com/triathlon-news/articles/2012/04/ironmanlife-ageless-wonder.aspx#axzz2FoaTjfhk).

These world best Ironman triathletes were older than elite marathon runners (Hunter et al. 2011). A reason for the increasing age of peak performance across years in Ironman triathletes could be the increasing importance of experience in training and competition strategies

(Knechtle et al. 2010); experience could be more important in multi-sports disciplines than in single-sport disciplines. The comparison of the age of peak performance for different running distances from marathon to ultra-marathon and different triathlon distances from Olympic distance to ultra-triathlon distances might reveal that the age of peak endurance performance increases with increasing length of the race distance.

A further important finding was that the mean age of the fastest triathletes was not different between men and women for overall race, and both swimming and cycling split times. However, the fastest male runners were older than the fastest female runners. This is in contrast to elite marathoners, where women (29.8±4.2 years) were slightly older than men (28.9±3.8 years; Hunter et al. 2011). For women, the fastest swimmers were younger than the fastest cyclists. An explanation for this could be the 'history' of the athlete. It has been reported that triathletes have previously been competitive swimmers (O'Toole and Douglas 1995). For recreational Ironman triathletes competing in 'Ironman Lanzarote', however, 28 % of the athletes had a background as a runner, 14 % as a swimmer and 13 % as a cyclist (Gulbin and Gaffney 1999).

Conclusion

Over the last three decades, the age of the annual top ten female and male triathletes at the 'Ironman Hawaii' increased while their performances improved. These findings suggest that the maturity of long-distance elite triathletes has changed during this period and raises the question of the upper limits of the age of peak performance in ultra-endurance. Future studies need to compare the age of peak endurance performance for different distances in both running and triathlon. The 'history' of Ironman triathletes needs further investigations.

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