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DOI: https://doi.org/10.1123/ijspp.2013-0375



Originally published at:
Knechtle, Beat; Rosemann, Thomas; Lepers, Romuald; Rüst, Christoph Alexander (2014). Women Outperform Men in Ultra-Distance Swimming - The 'Manhattan Island Marathon Swim' From 1983 to 2013. International Journal of Sports Physiology and Performance, 9(6):913-924.
DOI: https://doi.org/10.1123/ijspp.2013-0375

# Women outperform men in ultra-distance swimming - The 'Manhattan Island Marathon Swim' from 1983 to 2013

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Original Investigation

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|---|---|
| Abstract word count | 190 |
| Text word count | 2,922 |
| Number of figures | 5 |
| Number of tables | 5 |

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# Abstract

***Purpose:*** Recent studies suggested that women and men's ultra-swim performances may be similar for distances of ~35 km. The present study investigated both the gender difference and the age of peak ultra-swim performance between 1983 and 2013 at the 46-km 'Manhattan Island Marathon Swim' with water temperatures <20°C. ***Methods:*** Changes in race times and gender difference in 551 male and 237 female finishers were investigated using linear, non-linear, and hierarchical multi-level regression analyses. ***Results:*** The top ten race times ever were significantly ($P$<0.0001) lower for women (371±11 min) than for men (424±9 min). Race times of the annual fastest and annual three fastest women and men did not differ between genders and remained stable across years. The age of the annual three fastest swimmer increased from 28±4 years (1983) to 38±6 years (2013) ($r^2$=0.06, $P$=0.03) in women and from 23±4 years (1984) to 42±8 years (2013) ($r^2$=0.19, $P$<0.0001) in men. ***Conclusions:*** The best women were ~12-14% faster than the best men in a 46-km open-water ultra-distance race with temperatures <20°C. The maturity of ultra-distance swimmers has changed during the last decades with the fastest swimmers becoming older across the years.


**Key words:** swimming, gender difference, extreme, record

## Introduction

Open-water ultra-distance swimming is increasing in popularity. Participation in the 34-km 'English Channel Swim' increased exponentially in the last ten years for both women and men.[1] The number of swimmers at the 'English Channel Swim' increased between 1991-2000 and 2001-2010 by 171% for men and by 135% for women, respectively.[2] Similarly, an increase in the rate of participation has been observed over the past years at the 26-km open-water lake swimming in both the 'Marathon Swim Lake Zurich' [3] and the '12-hour indoor swim' held in Zürich [4].

Gender differences in ultra-distance swim performance have been investigated in both indoor pool swimmers [4] and open-water ultra-endurance swimmers [1,2,5,6] and were leading to disparate findings. It has been shown that the performance of the annual fastest women and men did not differ in 12-hour indoor ultra-endurance swimmers [4] or in open-water ultra-endurance swimmers competing in the 34-km 'English Channel Swim' [2]. In contrast, at the 26-km 'Marathon Swim Lake Zurich', the annual fastest men were on average 11.5% faster than the annual fastest women.[3] In the 32-km 'Traversée Internationale du Lac St-Jean', the gender difference decreased from ~14% in 1973 to ~4% in 2012.[5] And in the FINA (Féderation Internationale de Natation) 10-km open-water race races, the gender difference remained unchanged at ~7% between 2008 and 2012.[6] Women seemed to narrow the gap with increasing race distance. The higher body fat in female ultra-endurance swimmers [7] may be of advantage for ultra-swims especially in cold water because thicker skinfolds could allow them to endure longer in cold water [8].

These disparate findings of gender difference in ultra-distance swimming performance might be due to the length of the swims, the water temperature and the level of the athletes. In the 34-km ‘English Channel Swim’ where the water temperature varied between 15°C and 18°C, the annual fastest swimming speed (men 0.84±0.18 m/s; women 0.89±0.20 m/s) did not differ between genders.[2] Similarly, in a 12-hour indoor pool swim where water temperature was kept constant at ~28°C, the annual fastest swimming speed did not differ between women and men (men 0.88±0.06 m/s; women 0.79±0.19 m/s).[4] In contrast, in the 26-km ‘Marathon Swim in Lake Zurich’ where water temperature varied between 16.2 °C and 25.9 °C across years, the annual male winner’s swimming speed was greater compared to the female swimming speed (men 1.09±0.10 m/s; women 0.97±0.07 m/s).[3] In other terms, the difference between the annual fastest women (636.7 min) and men (674.6 min) in the 34-km ‘English Channel Swim’ was 37.9 min where women were 5.6% faster than men.[2] However, in the ’12-hour indoor swim’, the difference between the annual fastest women (34.4 km) and men (38.3 km) was 3.9 km where men were 10.2% faster than women.[4] And in the 26-km ‘Marathon Swim Lake Zurich’, the difference between the annual fastest women (452 min) and men (403 min) was 49 min where men were 12.1% faster than women.[3] It is therefore very likely that women might outperform men in open-water ultra-distance swimming in a distance longer than then 34 km in the ‘English Channel Swim’ and at temperatures <20 °C.

Interestingly, the water temperature was significantly and negatively associated with swimming speed for the annual top three swimmers in the 26-km ‘Marathon Swim Lake Zurich’, suggesting that the colder the water, the longer the race time. For swimmers not placed in the top three, race time was not associated with water temperature.[3] Considering the fitness level of the athletes, recreational athletes were investigated in the 12-hour indoor pool swim [4] and in the ‘English Channel Swim’ [2]. The ‘English Channel Swim’ is in fact not a race where swimmers have to cross the Channel as solo swimmers. In contrast, elite swimmers were investigated in the 'Traversée Internationale du Lac St-Jean' [5] and in the FINA 10-km competitions [6].

Age could also be an important factor in ultra-distance swim performance. In a 12-hour indoor swim, the best performances were achieved by women and men between 30 and 50 years of age.[4] At the 26-km'Marathon Swim in Lake Zurich', the mean age of both female and male winners did not differ between women (27.7±8.2 years, mean±SD) and men (26.8±9.5 years, mean±SD).[3] The age of the annual winners in the 26-km'Marathon Swim in Lake Zurich' increased across the years with a mean of 30.9±6.5 years (mean±SD) for women and 32.0±6.5 years (mean±SD) for men.[3] Interestingly, increasing age was associated with an increased risk for not finishing the 26-km'Marathon Swim in Lake Zurich'.[3] However, it has been recently shown that for other ultra-endurance events such as the 'Ironman Hawaii', the age of the fastest athletes tended to increase over recent decades.[9]

The purposes of the present study were to investigate (*i*) the gender difference in performance in open-water ultra-distance swimmers and (*ii*) the age of peak ultra-swimming performance in elite athletes competing at the 'Manhattan Island Marathon Swim' during the period of 1983-2012 where participants have to cover the distance of ~46 km at water temperatures varying between 16.5°C and 20°C. Based upon existing reports for recreational and elite open-water ultra-distance swimmers, we hypothesized (*i*) that elite female swimmers competing in an open-water ultra-distance swimming race longer than ~35 km with a water temperature < 20°C would achieve a similar performance to male swimmers or possibly outperform men; and (*ii*) the age of peak ultra-swimming performance would increase across the years.

## Methods

### *Ethics*

All procedures used in the study met the ethical standards of the Swiss Academy of Medical Sciences and were approved by the Institutional Review Board of Kanton St. Gallen, Kantonsspital St. Gallen, Switzerland with a waiver of the requirement for informed consent of the participants given the fact that the study involved the analysis of publicly available data.

### *The race*

The ‘Manhattan Island Marathon Swim‘ is an open-water ultra-endurance swimming event covering a full counter-clockwise circumnavigation of the island of Manhattan, New York, USA, with a total distance of 28.5 miles (45.87 km) (www.nycswim.org). It generally starts at the beginning of June at 7:40 a.m. at Battery Park City - South Cove. The field is generally limited to 40 solo swimmers. The participants have a time limit of 9:30 h:min, must be 19 years or older and are not allowed to wear a wetsuit. To participate in this race, participants must fulfill the qualification criteria. First, all applicants must document their competency to participate in ‘Manhattan Island Marathon Swim‘. This can be done either by completing a similar event or race, or a non-event qualifying swim logged by an observer in a prescribed water temperature of 61°F (16.1°C) or colder and four hours or longer in duration. Secondly, solo swimmers must have at least one and no more than two individuals to serve as support crew aboard their assigned escort boat for this event. Water temperature in this event is generally < 20 °C. In June, the water temperature in New York is between 16 °C and 19 °C (http://www.currentresults.com/Oceans/Temperature/new-york-average-water-temperature.php).

### *Methodology*

All athletes who had ever participated in the 'Manhattan Island Marathon Swim' between 1983 and 2013 were analyzed regarding participation, performance and age. The data set for this study was obtained from the race website www.nycswim.org. Data before 1983 were not complete and deemed not reliable for analysis. All male and female solo swimmers were considered for data analysis. The race times and the ages of the annual top (*e.g.* fastest annual race time) and of the annual top three overall (*e.g.* fastest annual three race times) women and men were determined and analyzed to identify both the peak performance in swimming and the peak age in swimming performance. Due to the low number of annual successful finishers it was not possible to analyze a higher amount of annual data. Gender difference was calculated using the equation ([race time in women] – [race time in men]) / [race time in men] × 100 where gender difference was calculated for every pair of equally placed athletes (*e.g.* the winner between men and women, the 2$^{nd}$ place between men and women, etc.). Performance of the overall fastest, the three fastest and the ten fastest women and men ever were determined and compared for the 31-year period.

### *Statistical analysis*

In order to increase the reliability of the data analyses, each set of data was tested for normal distribution as well as for homogeneity between variances prior to 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.[10] To find significant changes in a variable (*e.g.* race time, age) across years, regression analysis was used. A hierarchical multi-level regression model was used to avoid the influence of a cluster-effect (*i.e.* when athletes finished more than one event) on the results for the annual top or annual top three competitors. Regression analyses of performance were corrected for age to prevent a misinterpretation of 'age-effect' with 'time-effect'. Since the change in gender difference in endurance is assumed to be non-linear [11], we additionally calculated to the linear also the non-linear regression model. We compared the linear to the best-fit non-linear model using Akaike's Information Criteria (AIC) and F-test in order to show which model would be the most appropriate to explain the trend of the data. The results of the regression analyses (*i.e.* whether the trend was varying over time or not) were confirmed using ANOVA (analysis of variance). The differences between age and performance of the annual top and the annual top three men and women, and between the top three and top ten women and men ever where investigated using a Student's *t*-test with Welch's correction in case of unequal variances for normally distributed and a Mann-Whitney test for non-normally distributed data. Statistical analyses were performed using SPSS Statistics (Version 21, IBM SPSS, Chicago, IL, USA) and GraphPad Prism (Version 6.01, GraphPad Software, La Jolla, CA, USA). $P<0.05$ was used to imply statistical significance (two-tailed for *t*-tests). Data in the text are reported as mean ± standard deviation (SD).

# Results

### *Participation and finisher trends*

Between 1983 and 2013, a total of 909 swimmers (640 men and 269 women) started while 551 men and 237 women finished. On average, 8±4 women and 18±9 men finished the race annually (Figure 1A). The annual number of female and male participants remained unchanged across years. The overall rate of finishers was 86.4±18.0% (*i.e.* women 87.6±20.3% and men 85.8±18.6%) (Figure 1B). Among the total male finishers, 85 swimmers finished the race at least twice. The lowest number of finishers was in 2005 where only two men finished. The largest number of male finishes ($n$=17) belongs to one athlete, Kristian Rutford from the United States of America. Among the female finishers, 44 swimmers finished more than once and Shelley Taylor-Smith from Australia obtained the highest record with eight successful finishes.

### *The best performances*

The race record for women was achieved in 1995 by Shelley Taylor-Smith in 345 min. This time is 14.1% lower than the race record for men set in 1985 by Drury Gallagher in 402 min (Table 1). The three fastest performances ever did not differ statistically between women (357±11 min) and men (413±11 min) (Table 1). However, when the ten fastest race times were considered, women were significantly faster than men ($P$<0.0001) with a gender difference in performance of 12.4±1.0% (Table 1).

### *Performance trends and gender difference in performance*

The annual fastest women completed the race in 440.0±44.8 min, the differences in swimming time across years did not change ($r^2$=0.06, *P*=0.3757) (Figure 2), also when controlled for athletes with multiple finishes (Table 2). The annual fastest race time for men was 458.5±29.4 min and did not change across years ($r^2$=0.04, *P*=0.131) (Figure 2), also when controlled for multiple finishes (Table 2). The annual three fastest race times remained stable across the years for both women (Figure 3A) (461.3±31.7 min, $r^2$=0.02, *P*=0.1117) and men (Figure 3B) (468.8±27.2 min, $r^2$=0.002, *P*=0.0985) also when controlled for multiple finishes (Table 2). ANOVA confirmed the linear trend in performance for the annual three fastest men ($r^2$=0.018, *P*=0.03) but not for the annual three fastest women ($r^2$=0.00017, *P*=0.74) where the change was non-linear (*i.e.* polynomial regression 3$^{rd}$ degree) (Table 3). The corresponding gender difference in performance remained unchanged across years at 6.9±10.7% ($r^2$=0.02, *P*>0.05) for the annual fastest (Figure 4A) and at 4.5±3.9% ($r^2$=0.04, *P*=0.3475) for the annual three fastest swimmers (Figure 4B). ANOVA confirmed the linear trend for the change in gender difference in the annual three fastest ($r^2$=0.04, *P*=0.027) (Table 4).

### *Age trends over time*

The annual fastest men (Figure 5A) became older across years from 27 years (1984) to 34 years (2013) ($r^2$=0.22, *P*=0.008) also when controlled for athletes with multiple finishes (Table 5). The age of the annual fastest women (Figure 5A) remained unchanged at 28.1±6.9 years ($r^2$=0.01, *P*>0.05) also when controlled for athletes with multiple finishes (Table 5). However, the annual three fastest women and men became older across years (Figure 5B) also when controlled for athletes with multiple finishes (Table 5). In women, the age of the annual three fastest increased from 28±4 years (1983) to 38±6 years (2013) ($r^2$=0.06, *P*=0.03). In men, the age of the annual three fastest increased from 23±4 years (1984) to 42±8 years

(2013) ($r^2$=0.19, $P$<0.0001). ANOVA confirmed the linear trend in the change of age for the annual three fastest men ($r^2$=0.13, $P$=0.0002) and women ($r^2$=0.07, $P$=0.012).

## Discussion

The first aim of this study was to investigate the gender difference in performances at the 46-km open-water 'Manhattan Island Marathon Swim' between 1983 and 2013. Interestingly, the results showed that the best women outperformed the best men by ~12-14%. This finding contradicts results from other ultra-endurance events such as ultra-running [12], ultra-cycling [13]and ultra-triathlon [14] where men usually were faster than women.

Regarding the participation in the 'Manhattan Island Marathon Swim', the number of male and female swimmers showed no change across the years and the percentage of finishers remained stable. The unchanged number of participants is due to the fact that the field is limited to 40 solo swimmers (www.nycswim.org). In contrast, in the 'English Channel Swim' was an exponential increase in the number of participants in the last decades.[1] However, the 'English Channel Swim' is not a race since each swimmer has to cross the Channel alone followed by his support boat. A potential reason for the limited field in ultra-distance swimming in an official race is logistical. The security of the swimmers and the limited number of available support boats might be the most important reasons.

Between 1983 and 2013, both women and men showed no improvement in performance. This is in line with 12-hour ultra-swimmers in a pool during the 1996-2010 period [4] and open-water ultra-swimmers in the 'English Channel Swim' between 1975 and 2011 [1]. These time frames of ~30 years seemed to be too short to find an improvement in performance in contrast to the 1955-2012 period in 'La Traversee Internationale du Lac St-Jean' where the fastest women and men improved over time.[5] An improvement in performance across years in open-water ultra-swimmers might be due to changes over time in anthropometric characteristics such as body height. It has been shown that the world's fastest 100 m swimmers became taller and heavier between 1912 and 2008.[15] For open-water ultra-swimmers, anthropometric characteristics such as body height and body mass index were predictive for race time.[16]

A potential physiological explanation for the faster race times in women could be the higher body fat in female ultra-distance swimmers. Recent studies reported a body fat percentage of 30.7±3.7% [7] to 31.3±3.6% [16] for female open water ultra-swimmers compared to 18.8±4.5% [7] to 20.2±5.6% [16] for male open water ultra-distance swimmers. Competitive female swimmers have proportionately more fatty tissue at the lower body than male swimmers.[17] The higher percentage of body fat may improve both buoyancy and swimming performance in women. The higher body fat may also improve women's swimming performance in cold water swimming by acting as insulation against the cold. A case report describing two male swimmers in water at 4°C showed that the swimmer with more body fat (23.4%) was able to complete 2.2 km within 42 min whereas the swimmer with lower body fat (21.0%) stopped after 1.3 km.[18] Keatinge et al. also reported that swimmers with less subcutaneous fat terminated a swim in water at temperatures of 9.4 °C to 11.0 °C after significantly less time in the water than those with thicker skinfold thickness.[8] Swimmers with less thick subcutaneous fat made significantly shorter swims than those with thicker fat layers. The thinnest subject swam for only 23 min, whereas the four with the thickest fatty layers swam for over 60 min.[8] Branningan et al. investigated 70 male and 39 female swimmers in a 19.2-km open water swimming race in Perth, Western Australia.[19] In the study by Branningan et al., hypothermia defined as body core temperature of <35 °C, was the most common race-related illness.[19] Longer race duration was also associated with an increased risk of hypothermia, and higher body mass index was associated with a decreased risk of hypothermia.[19] Taken together, their data suggest that women with higher body fat may stay longer in cold water compared to men with lower body fat.

Apart from gender differences in body fat, swimming efficiency is also different between women and men. Buoyancy is higher in women through a lower 'underwater torque', which can be defined loosely as the tendency for the feet to sink.[20] In addition, and in contrast to running where the energy cost appeared similar between women and men, the energy cost of freestyle swimming has been shown to be significantly higher (*i.e.* lower economy) in men compared to women.[20,21] The energy cost of swimming is a valuable parameter to quantify swimming economy. At a swim speed of 1 m/s, differences in drag force and coefficient of drag have been reported between women and men.[22] The energy cost of swimming depends primarily on the propelling efficiency of the arm stroke and the hydrodynamic resistance. However, it has been suggested that gender differences in energy costs of swimming were mainly attributed to differences in hydrodynamic resistance.[23] Regarding the influence of anthropometry on swimming efficiency, women also have a smaller body size resulting in smaller body drag, a smaller body density with a greater body fat percent and shorter lower limbs, resulting overall in a more horizontal and streamlined position and therefore a smaller underwater torque.[20,24]

Apart of anthropometric characteristics, swimming economy should also be considered as an explanation for the gender difference. Swimming economy is considered as one of the most important predictors in swimming performance.[25-27] There are three swimming economy related parameters known such as the net energy cost corresponding to v $VO_2$max (Cv $VO_2$max), the slope of the regression line obtained from the energy expenditure (E) and corresponding velocities during an incremental test ($C_{slope}$) and the ratio between the mean E value and the velocity mean value of the incremental test ($C_{inc}$).[28] The investigation of the relationship between the time limit at the minimum velocity that elicits the individual's maximal oxygen consumption (TLim-v $VO_2max$) and the above mentioned swimming economy related parameters showed that TLim-v $VO_2max$ seemed to depend in women more on swimming economy than in men.[28]

Another explanation for the performance in women might be drafting during open-water swimming. In triathlon [29] and in open-water ultra-distance swimming [5], athletes draft one behind the other. During the 'Manhattan Island Marathon Swim', women may draft behind men and reduce drag.[30] Drafting may save energy since swimming behind another swimmers reduced oxygen uptake, heart rate, blood lactate and stroke rate. For the last part of the race, the best women may have enough energy to pass and leave the leading men.

In the present study, the ten best women ever were ~12-14% faster than the ten best men ever when the fastest race times ever were analyzed and the mean gender difference in performance across years was ~5-7%. When the three best women and men ever were compared, the performances did not differ between women and men. Any difference might not have been identified because of the small sample size. When taken as the whole cohort, the gender difference in ultra-endurance performance appears higher and men were faster than women. For example, in ultra-endurance cyclists competing in the 'Race Across America' between 1982-2012, the fastest men were 14-15% faster than the fastest women and the gender difference was ~25% for the annual three fastest women and men in the last 30 years.[13] In running, the gender difference is at ~11-12% when considering running distances from 100m to 200km.[31,32] In 161-km trail running, the gender difference was even at ~20%.[12] According to Cheuvront et al., the gender difference in running performance appears biological in origin.[33] Success in distance running and sprinting is determined largely by aerobic capacity and muscular strength with men having a larger aerobic capacity and greater muscular strength, respectively.[33] Therefore, the gap in running performance between women and men is unlikely to narrow naturally. This might be true for running and ultra-running but our results suggest not for ultra-swimming in cold water.

The second aim of this study was to investigate the change in the age of peak ultra-swimming performance across years. Based upon recent findings for long-distance triathletes it was hypothesized that the age of the fastest swimmers would increase across years. Indeed, the age of the annual fastest men increased over time whereas the age of the annual fastest women remained unchanged. For both the annual three fastest women and men the age of the fastest race times increased across years also when controlled for athletes with multiple finishes. In 2012, the annual three fastest women and men were older than 35 years. By definition, these were master athletes defined as athletes older than 35 years and systematically training for and involved in organized forms of sport specifically designed for athletes older than 35 years.[34] However, previous studies suggested that athletes in ultra-endurance races became older across years without an impairment of performance. For example, in the Ironman World Championship ‘Ironman Hawaii’ the annual top ten finishers became older and faster across years.[9] The annual ten fastest Ironman triathletes in ‘Ironman Hawaii’ were at the age of ~35 years for both women and men.[9] In ultra-marathon runners competing in ‘Spartathlon’ and ‘Badwater’ as two of the toughest ultra-marathons held worldwide, the fastest runners were 40-45 years old.[35] It seems that age, as a performance limiting factor, in ultra-endurance moved to higher ages in recent years.

## Practical Applications

The results of the present study suggest that women may outperform men in ultra-distance swimming, especially in cold water. These last three decades at the 46-km ‘Manhattan Island Marathon Swim’, the best women outperformed the best men by ~12-14% while the annual best performance remained stable for both women and men across years. The age of the annual fastest male swimmers became older over time. The maturity of these ultra-distance swimmers changed during the last decades where the fastest swimmers became older over time. Future studies need to compare anthropometric, training and physiological variables of the fastest open-water ultra-distance swimmers. Specifically, body core temperature should be recorded in the fastest open-water ultra-distance swimmers and correlated to their body fat and body mass index.

## Conclusions

The best women were ~12-14% faster than the best men in the 46-km open-water ultra-distance swimming ‘Manhattan Island Marathon Swim’ held at temperatures <20°C. The annual fastest women were faster than the annual fastest men and it seems unlikely that men would be able to overtake women in this specific race since the changes were linear, but not non-linear, across years. The maturity of ultra-distance swimmers has changed during the last years with the fastest swimmers becoming older across the years.

# References


1 Fischer G, Knechtle B, Rüst CA, Rosemann T. Male swimmers cross the English Channel faster than female swimmers. *Scand J Med Sci Sports.* 2013;23:e48-e55.

2 Eichenberger E, Knechtle B, Knechtle P, Rüst CA, Rosemann T, Lepers R. Best performances by men and women open-water swimmers during the 'English Channel Swim' from 1900 to 2010. *J Sports Sci.* 2012;30:1295-1301.

3 Eichenberger E, Knechtle B, Knechtle P, Rüst CA, Rosemann T, Lepers R, Senn O. Sex difference in open-water ultra-swim performance in the longest freshwater lake swim in Europe. *J Strength Cond Res.* 2013;27:1362-1369.

4 Eichenberger E, Knechtle B, Christoph AR, Knechtle P, Lepers R, Rosemann T. No gender difference in peak performance in ultra-endurance swimming performance - analysis of the 'Zurich 12-h Swim' from 1996 to 2010. *Chin J Physiol.* 2012;55:346-351.

5 Rüst CA, Knechtle B, Rosemann T, Lepers R. Women reduced the sex difference in open-water ultra-distance swimming – 'La Traversée Internationale du Lac St-Jean' 1955-2012. *Appl Physiol Nutr Metab*, 2014;39:270-273.

6 Vogt P, Rüst C, Rosemann T, Lepers R, Knechtle B. Analysis of 10 km swimming performance of elite male and female open-water swimmers. *SpringerPlus* 2013; 2:603

7 Weitkunat T, Knechtle B, Knechtle P, Rüst CA, Rosemann T. Body composition and hydration status changes in male and female open-water swimmers during an ultra-endurance event. *J Sports Sci.* 2012;30:1003-1013.

8 Keatinge WR, Khartchenko M, Lando N, Lioutov V. Hypothermia during sports swimming in water below 11 degrees C. *Br J Sports Med.* 2001;35:352-353.

9 Gallmann D, Knechtle B, Rüst CA, Rosemann T, Lepers R. Elite triathletes in 'Ironman Hawaii' get older but faster. *Age (Dordr),* 2014;36:407-416.

10 D'Agostino RB. 'Tests for Normal Distribution' in Goodness-Of-Fit Techniques, edited by D'Agostino RB and Stepenes MA, Macel Decker, 1986.

11 Reinboud W. Linear models can't keep up with sport gender gap. *Nature.* 2004;432(7014):147

12 Hoffman MD. Performance trends in 161-km ultramarathons. *Int J Sports Med.* 2010;31:31-37.

13 Rüst CA, Knechtle B, Rosemann T, Lepers R. Men cross America faster than women - the 'Race Across America' (RAAM) from 1982 to 2012. *Int J Sports Physiol Perform.* 2013;8:611-617.

14 Rüst CA, Knechtle B, Rosemann T, Lepers R. Sex difference in race performance and age of peak performance in the Ironman Triathlon World Championship from 1983 to 2012. *Extrem Physiol Med.* 2012;1:15.

15 Charles JD, Bejan A. The evolution of speed, size and shape in modern athletics. *J Exp Biol*. 2009;212:2419-2425.

16 Knechtle B, Baumann B, Knechtle P, Rosemann T. Speed during training and anthropometric measures in relation to race performance by male and female open-water ultra-endurance swimmers. *Percept Mot Skills.* 2010;111:463-474.

17 McLean SP, Hinrichs RN. Sex differences in the centre of buoyancy location of competitive swimmers. *J Sports Sci.* 1998;16:373-383.

18 Knechtle B, Christinger N, Kohler G, Knechtle P, Rosemann T. Swimming in ice cold water. *Ir J Med Sci.* 2009;178:507-511.

19 Brannigan D, Rogers IR, Jacobs I, Montgomery A, Williams A, Khangure N. Hypothermia is a significant medical risk of mass participation long-distance open water swimming. *Wilderness Environ Med.* 2009;20:14-18.

20 Pendergast DR, Di Prampero PE, Craig AB, Wilson DR, Rennie DW. Quantitative analysis of the front crawl in men and women. *J Appl Physiol.* 1977;43:475-479.

21 Pate RR, Sparling PB, Wilson GE, Cureton KJ, Miller BJ. Cardiorespiratory and metabolic responses to submaximal and maximal exercise in elite women distance runners. *Int J Sports Med.* 1987;8:91-95.

22 Zamparo P. Effects of age and gender on the propelling efficiency of the arm stroke. *Eur J Appl Physiol.* 2006;97:52-58.

23 Toussaint HM, de Groot G, Savelberg HH, Vervoorn K, Hollander AP, van Ingen Schenau GJ. Active drag related to velocity in male and female swimmers. *J Biomech.* 1988;21:435-438.

24 Lavoie JM, Montpetit RR. Applied physiology of swimming. *Sports Med.* 1986;3:165-189.

25 Fernandes RJ, Vilas-Boas JP. Time to exhaustion at the $VO_2$max velocity in swimming: A review. *J Hum Kinet*. 2012;32:121-134.

26 Chatard JC, Lavoie JM, Lacour JR. Analysis of determinants of swimming economy in front crawl. *Eur J Appl Physiol Occup Physiol*. 1990;61:88-92.

27 Smith DJ, Norris SR, Hogg JM. Performance evaluation of swimmers: scientific tools. *Sports Med*. 2002;32:539-554.

28 Fernandes RJ, Billat VL, Cruz AC, Colaço PJ, Cardoso CS, Vilas-Boas JP. Has gender any effect on the relationship between time limit at $VO_2$max velocity and swimming economy? *J Hum Movement Stud*. 2005;49:127-148

29 Landers GJ, Blanksby BA, Ackland TR, Monson R. Swim positioning and its influence on triathlon outcome. *Int J Exerc Sci.* 2008;1:96-105.

30 Chatard JC, Wilson B. Drafting distance in swimming. *Med Sci Sports Exerc*. 2003;35:1176-1181.

31 Coast JR, Blevins JS, Wilson BA. Do gender differences in running performance disappear with distance? *Can J Appl Physiol.* 2004;29:139-145.

32 Sparling PB, O'Donnell EM, Snow TK. The gender difference in distance running performance has plateaued: an analysis of world rankings from 1980 to 1996. *Med Sci Sports Exerc.* 1998;30:1725-1729.

33 Cheuvront SN, Carter R, Deruisseau KC, Moffatt RJ. Running performance differences between men and women: an update. *Sports Med* 2005;35: 1017-1024.

34 Reaburn P, Dascombe B. Endurance performance in masters athletes. *Eur Rev Aging Phys Act.* 2008;5:31-42.

35 Zingg MA, Knechtle B, Rüst CA, Rosemann T, Lepers R. Analysis of participation and performance in athletes by age group in ultramarathons of more than 200 km in length. *Int J Gen Med*. 2013;6:209-220.

| | |
|---|---|
| Record time (min) for men in1985 | 402 |
| Record time (min) for women in 1995 | 345 |
| Gender difference in performance (%) | 14.1 |

| | |
|---|---|
| Top three race time (min) for men | 413±11 |
| Top three race time (min) for women | 357±11 |
| Gender difference in performance (%) | 13.6±0.4 |

| | |
|---|---|
| Top ten race time (min) for men | 424±9 |
| Top ten race time (min) for women | 371±11 *** |
| Gender difference in performance (%) | 12.4±1.0 |

**Table 1:** Record and performance of the top three and top ten fastest finishers during the 1983-2012 period with corresponding gender difference in performance. Results are expressed as mean±SD. *** = $P<0.0001$

| **Model** | ***β*** | **SE (*β*)** | **Stand. *β*** | **T** | ***P*** |
|---|---|---|---|---|---|
| | | | **Annual fastest men** | | |
| **1** | 0.638 | 0.619 | 0.191 | 1.031 | 0.311 |
| **2** | 0.638 | 0.619 | 0.191 | 1.031 | 0.311 |
| **3** | 1.190 | 0.681 | 0.357 | 1.749 | 0.092 |
| | | | **Annual three fastest men** | | |
| **1** | 0.154 | 0.367 | 0.046 | 0.421 | 0.675 |
| **2** | 0.154 | 0.367 | 0.046 | 0.421 | 0.675 |
| **3** | -0.033 | 0.407 | -0.010 | -0.081 | 0.936 |
| | | | **Annual fastest women** | | |
| **1** | 1.262 | 0.944 | 0.249 | 1.338 | 0.192 |
| **2** | 1.262 | 0.944 | 0.249 | 1.338 | 0.192 |
| **3** | 1.261 | 0.968 | 0.249 | 1.302 | 0.204 |
| | | | **Annual three fastest women** | | |
| **1** | 0.623 | 0.508 | 0.137 | 1.225 | 0.224 |
| **2** | 0.623 | 0.508 | 0.137 | 1.225 | 0.224 |
| **3** | 0.465 | 0.523 | 0.102 | 0.889 | 0.377 |

**Table 2:** Multi-level regression analyses for change in performance across years for women and men (Model 1) with correction for multiple finishes (Model 2) and age of athletes with multiple finishes (Model 3)

| Swimming speed | Kind of regression | Sum of Squares | DOF | AICC | Best regression AIC-Test | Best regression F-Test | Delta | Probability | Likelihood |
|---|---|---|---|---|---|---|---|---|---|
| Annual fastest men | polynomial | 22394.1 | 26 | 213.59 | linear | linear | 3.90 | 0.12 | 87.57% |
| | linear | 25066.6 | 29 | 209.69 | | | | | |
| Annual fastest women | polynomial | 49449.8 | 26 | 229.14 | linear | linear | 2.87 | 0.19 | 80.81% |
| | linear | 52689.4 | 28 | 226.27 | | | | | |
| Annual three fastest men | polynomial | 19603.8 | 18 | 231.13 | linear | linear | 31.90 | $1.17\ e^{-07}$ | 100% |
| | linear | 21391.5 | 28 | 199.22 | | | | | |
| Annual three fastest women | polynomial | 18282.3 | 24 | 188.48 | polynomial | polynomial | 4.29 | 0.10 | 89.53% |
| | linear | 25339 | 26 | 192.77 | | | | | |

**Table 3:** Comparison of linear and non-linear regression analyses of changes in swimming speed across years for women and men to determine which model is the best

| Gender difference | Kind of regression | Sum of Squares | DOF | AICC | Best regression AIC-Test | Best regression F-Test | Delta | Probability | Likelihood |
|---|---|---|---|---|---|---|---|---|---|
| Annual fastest | polynomial<br>linear | 2871.75<br>3113.91 | 24<br>28 | 149.34<br>141.41 | linear | linear | 7.92 | 0.018 | 98.13% |
| Annual three fastest | polynomial<br>linear | 209.24<br>378.19 | 19<br>26 | 79.89<br>75.04 | linear | linear | 4.85 | 0.081 | 91.87% |

**Table 4:** Comparison of linear and non-linear regression analyses of changes in gender difference across years for women and men to determine which model is the best

| Model | *β* | SE (*β*) | Stand. *β* | T | *P* |
|---|---|---|---|---|---|
| **Annual fastest men** | | | | | |
| **1** | 0.346 | 0.121 | 0.476 | 2.863 | 0.008 |
| **2** | 0.346 | 0.121 | 0.476 | 2.863 | 0.008 |
| **Annual fastest three men** | | | | | |
| **1** | 0.414 | 0.093 | 0.435 | 4.460 | < 0.001 |
| **2** | 0.414 | 0.093 | 0.435 | 4.460 | < 0.001 |
| **Annual fastest women** | | | | | |
| **1** | 0.093 | 0.149 | 0.119 | 0.623 | 0.539 |
| **2** | 0.093 | 0.149 | 0.119 | 0.623 | 0.539 |
| **Annual fastest three women** | | | | | |
| **1** | 0.234 | 0.103 | 0.248 | 2.271 | 0.026 |
| **2** | 0.234 | 0.103 | 0.248 | 2.271 | 0.026 |

**Table 5:** Multi-level regression analyses for change in age across years for women and men (Model 1) and with correction for multiple finishes (Model 2)

## Figure captions

**Figure 1** Number of female, male and overall participants (Panel A) and percent finisher rate for men, women and overall (Panel B) across years

**Figure 2** Race times of the annual fastest women and men across years

**Figure 3** Race times of the annual top three women (Panel A) and men (Panel B) across years. Results are presented as mean ± SD

**Figure 4** Gender difference in performance of the annual fastest (Panel A) and the annual three fastest (Panel B) swimmers across years. Results are presented as mean ± SD for the annual three fastest

**Figure 5** Age of the annual top (Panel A) and the annual top three (Panel B) men and women across years. Results are presented as mean ± SD for the annual top three

**Figure 1**

Swim Time (min)

**Figure 2**

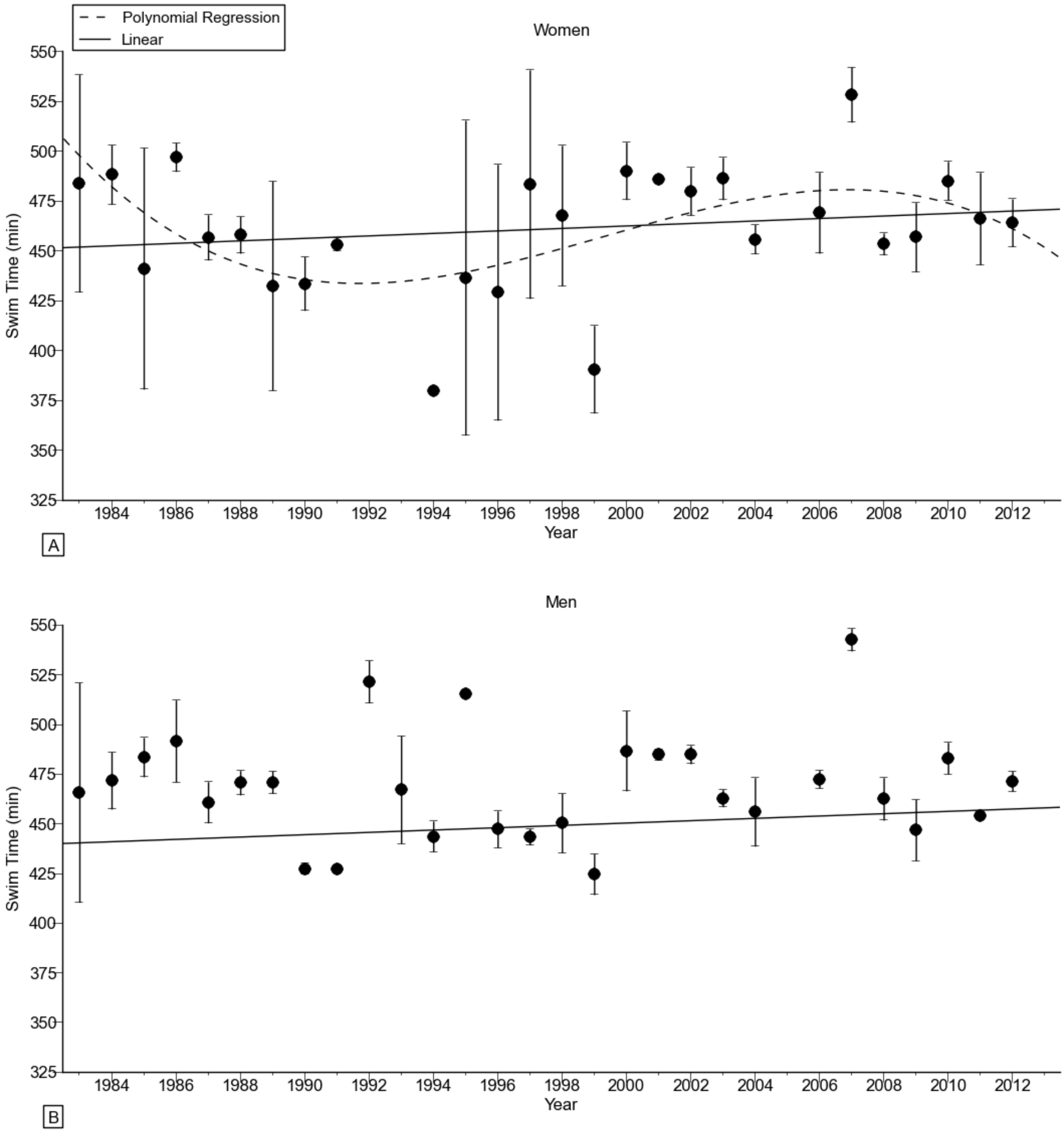
Polynomial Regression
Linear
Women
Swim Time (min)
Year
A
Men
Swim Time (min)
Year
B

**Figure 3**

**Figure 4**

**Figure 5**