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Sex Difference in Draft-Legal Ultra-Distance Events – A Comparison between Ultra-Swimming and Ultra-Cycling

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Abstract

Recent studies reported that the sex difference in performance in ultra-endurance sports such as swimming and cycling changed over the years. However, the aspect of drafting in draft-legal ultra-endurance races has not yet been investigated. This study investigates the sex difference in ultra-swimming and ultra-cycling draft-legal races where drafting – swimming or cycling behind other participants to save energy and have more power at the end of the race to overtake them, is allowed. The change in performance of the annual best and the annual three best in an ultra-endurance swimming race (16-km 'Faros Swim Marathon') over 38 years and in a 24-h ultra-cycling race ('World Cycling Race') over 13 years were compared and analysed with respect to sex difference. Furthermore, performances of the fastest female and male finishers ever were compared. In the swimming event, the sex difference of the annual best male and female decreased non-significantly ($P = 0.262$) from 5.3% (1976) to 1.0% (2013). The sex gap of speed in the annual three fastest swimmers decreased significantly ($P = 0.043$) from 5.9 ± 1.6% (1979) to 4.7 ± 3.1% (2013). In the cycling event, the difference in cycling speed between the annual best male and female decreased significantly ($P = 0.026$) from 33.31% (1999) to 10.89% (2011). The sex gap of speed in the annual three fastest decreased significantly ($P = 0.001$) from 32.9 ± 0.6% (1999) to 16.4 ± 5.9% (2011). The fastest male swimmer ever (swimming speed 5.3 km/h, race time: 03:01:55 h:min:s) was 1.5% faster than the fastest female swimmer (swimming speed 5.2 km/h, race time: 03:04:09 h:min:s). The three fastest male swimmers ever (mean 5.27 ± 0.13 km/h) were 4.4% faster than the three fastest female swimmers (mean 5.05 ± 0.20 km/h) ($P < 0.05$). In the cycling event, the best male ever (cycling speed 45.8 km/h) was 26.4% faster than the best female (cycling speed 36.1 km/h). The three fastest male cyclists ever (45.9 km/h) (mean 45.85 ± 0.05 km/h) were 32.1% faster ($P < 0.05$) than the three fastest female cyclists ever (34.7 km/h) (mean 34.70 ± 1.87 km/h). In summary, in draft-legal ultra-distance events such as swimming and cycling, the sex difference in the annual top and annual top three swimmers and cyclists decreased (*i.e.* non-linearly in swimmers and linearly in cyclists) over the years. The sex difference of the fastest athletes ever was smaller in swimming (1.5%) than in cycling (26.4%). This finding is different from reports about races where drafting was not possible or even prohibited and where the sex difference remained stable over years.

Key Words: athlete, performance, sex difference, swimming

Introduction

Competing in ultra-endurance contests is enjoying an upsurge of popularity. Ultra-endurance sports such ultra-running (13, 22, 40), ultra-swimming (7-10), ultra-cycling (19, 21, 33), and ultra-triathlons from the Ironman (*i.e.* 3.8 km swimming, 180 km cycling, 42 km running) to the Deca Iron ultra-triathlon (*i.e.* 38 km swimming, 1,800 km cycling, 422 km running) (12, 14, 17, 18, 21, 24, 34) have been attracting

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an increasing number of participants and followers.

Ultra-swimming (7, 8, 10, 20) and ultra-cycling (33, 45) are among the most popular ultra-distance disciplines. A few studies investigating participation trends of ultra-distance swimming events showed an exponential increase in the number of participants across a period of time from 14 (7) to 136 (10) years in the 'English Channel Swim'. During the last two decades, the participation in the 'English Channel Swim' increased exponentially for both male and female swimmers (8). Regarding ultra-cycling races such as the 'Race Across America (RAAM)', it is conspicuous that the participation of male athletes (89%) is much higher than that of female athletes (11%) (33).

Another point is the change in performance across years of male and female competitors and their sex difference (27, 30, 35-37). Recent studies showed that the sex difference in ultra-endurance sports like ultra-swimming (10) and ultra-cycling (33) did not change over years. In these studies, races were investigated where drafting was not possible (10) or forbidden (33). However, the sex difference in performance might be different in draft-legal races. To understand these results and compare them with other studies we need to introduce the effect of drafting. Drafting is a strategy where athletes swim, cycle or run behind other participants to save energy and have more power at the end of the race to overtake them. In some of the races drafting is allowed in others not. Female athletes with less strength might profit from drafting behind male athletes to achieve better performances in draft-legal races compared to races where drafting is forbidden.

Considering the sex difference in ultra-cycling performance at the 'RAAM' where drafting is not allowed, the results showed an unchanged sex difference of 19.4 ± 7.3% over 31 years (33). The annual three fastest male cyclists achieved a cycling speed of 21.8 ± 0.9 km/h with no change over the years (33). For the annual three fastest female cyclists there was an unchanged speed of 16.6 ± 1.0 km/h (33). A similar trend was found for the 'English Channel Swim', where the swimming time of the annual three fastest male (564.3 ± 63.8 min) and female swimmers (602.1 ± 58.7 min) did not change over 36 years (10). Similarly to the 'RAAM', each athlete has to cross the 'English Channel' in a solo swim.

Swimming and cycling are ideal sport disciplines where roughly equal athletes can compete one behind the other. Female athletes may draft for a considerably long time behind male athletes to save energy and may even be able to overtake male athletes in the final phase of the race. In the present study, we compare a cycling race and a swimming race where drafting is allowed. Therefore, we analyzed the 16-km open-water swimming race 'Faros Maratón Swim' held in the Mediterranean Sea in Croatia over 38 years considering the annual fastest and the annual three fastest female and male swimmers from 1979 to 2012 and the 24-h cycling race 'World Cycling Race' held in Schötz, Switzerland, from 1999 to 2011 over 13 years. The aim was to investigate whether the sex difference would disappear across years or whether female athletes would be able to overtake male athletes when drafting is allowed. Rüst *et al.* showed that the sex difference decreased in open-water ultra-distance swimming (36). We also focused on the question whether there would be a difference between the swimming event and the cycling event due to the sex gap in top athletes ever. In both sports female athletes can conveniently draft behind male athletes if they can hold the pace. We hypothesized that the sex difference in performance in competitive athletes would decrease in draft-legal events compared to non-draft events across years.

Materials and Methods

Ethics

All procedures used in the study were approved by the Institutional Review Board of Kanton 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.

Race Details

The 'Faros Maratón Swim' (www.farosmarathon.com) - also known as the 'Croatian International Long Swimming Championship' - started as a small provincial marathon swim in 1976 in Stari Grad, which is the third largest city in the north of the island of Hvar in Croatia. The race distance is 16 km in the Adriatic Sea, starting from Stari Grad. The participants have to swim along the coast of Stari Grad for 8 km and then turn back. In 2013, almost 40 years later, the small race has turned into a world-class event with participants from 42 countries. The participants in 'Faros Maratón Swim' need to be invited by the organizing committee after sending an application. The annual field of starters is limited to 35 participants. The three best male and female performers receive compensation of travel costs. The annual female and male winner get a prize money of 1,020 € each. The day of the race is last Saturday in August. All 35 participants start at 8:00 a.m. Two hours after the fastest swimmer reaches Stari Grad, the race is closed, and swimmers who exceed this time limit are disqualified. Each participant has to be followed by a boat. During the race refreshments are provided and are given from the official staff at request. The participants are not allowed to wear a wetsuit.

In 1993, the 'World Cycling Race' in Lucerne, Switzerland, took place for the first time. This race was one of the first 24-h ultra-cycling races in Europe and many future winners in the RAAM competed in this race. There is no invitation or qualification needed, so that everyone can take part if the start fee is paid. Exceptionally cyclists suspended by Swiss Olympic may not participate during the period of debarment. Single athletes are admitted as well as teams of two or more participants. The race starts on Saturday at 02:00 p.m. and lasts 24 h. The participants do not need to spend all this time cycling. They are allowed to take breaks as often and as long as they want. One lap measures ~5 km and has an altitude difference of ~70 m. The athletes are obliged to wear a helmet during the race. There are also exactly defined criteria that need to be fulfilled where only bikes with UCI regulated wheel size of 29 inches are allowed. Cross-wheels and off road wheels are not allowed. Furthermore, the bikes need to be in perfect condition otherwise the organizer entitled to disqualify the athletes or the teams. In case of small participant rate it is possible to assemble categories.

Data Sampling

For swimming, the data set for this study was obtained from the race website www.farosmarathon.com. The swimming times of all athletes who ever participated in the 'Faros Maratón Swim' between 1979 and 2013 were analysed regarding participation and performance. Data before 1979 (*i.e.* 1976-1978) were excluded from analysis of the annual top three due to the low number (*i.e.* less than three finishers per year in female participants) of finishers, but were used for analysis of sex difference and annual top one results. For cycling, the data for the 'World Cycling Race' was taken from the website www.24stundenrennen.ch. We analyzed the data from 1999 to 2011. The road race was put to a stop in 2011 and turned then into a 24-h mountain bike race.

Methods

All athletes who ever finished the 'Faros Maratón Swim' between 1976 and 2013 and the 'World Cycling Race' between 1999 and 2011 were analysed regarding performance and sex difference in performance. To determine the sex gap in swimming and cycling peak performance, race times of the annual fastest and of the annual three fastest female and male athletes were extracted and analysed. To ensure the comparability between different kinds and distances of events, race times were converted to speed using the equation [speed] = [race distance] / [race time]. The sex difference in speed was calculated using the equation ([speed of female athletes] – [speed of male athletes]) / [speed of male athletes] × 100, where the sex difference was calculated for every pair of equally placed athletes (*e.g.* between male and female 1st place, between male and female 2nd place, *etc.*) before calculating mean and standard deviation (SD) of all pairs. All sex difference times were transformed to absolute values before analysing. When less than the needed amount of athletes was available in a certain year for a certain race, the respective year and race was excluded from analysis. To find absolute peak performance and sex difference in absolute peak performance, speed of the overall top and overall top three male and female ever were analysed. The sex difference between the top and top three ever male and female were determined as described above.

Statistical Analysis

Each set of data was tested for normal distribution (D'Agostino and Pearson omnibus normality test) and for homogeneity of variances (Levene's test) before statistical analysis. Trends in participation were analyzed using regression analysis with linear and exponential growth equation models. For each set of data (*e.g.* sex), both models were compared using Akaike's Information Criteria (AIC) to determine the model that had the highest probability of correctness. Single and multi-level regression analyses investigated changes in performance and sex difference of the finishers. A hierarchical regression model for the analysis of the annual top or top three athletes avoided cluster-effect on results where a particular athlete finished more than once with a top result. We calculated the non-linear regression model that fits the data best since the change of the race results difference between male and female in endurance is assumed to be non-linear (31). Since the best-fit model was in all cases a polynomial regression, we compared the best-fit models to the linear models using AIC as well as F-test in order to show which model would be the most appropriate to explain the trend of the data. Statistical analyses were performed using IBM SPSS Statistics (Version 22, IBM SPSS, Chicago, IL, USA), CurveExpert Professional (Version 2.0.3, Hyams D.G.) and GraphPad Prism (Version 6.01, GraphPad Software, La Jolla, CA, USA). Significance was accepted at $P < 0.05$ (two-sided for *t*-tests). Data in the text and figures are given as mean ± standard deviation (SD).

Results

Participation Trends

Between 1976 and 2013, a total of 1,018 swim-

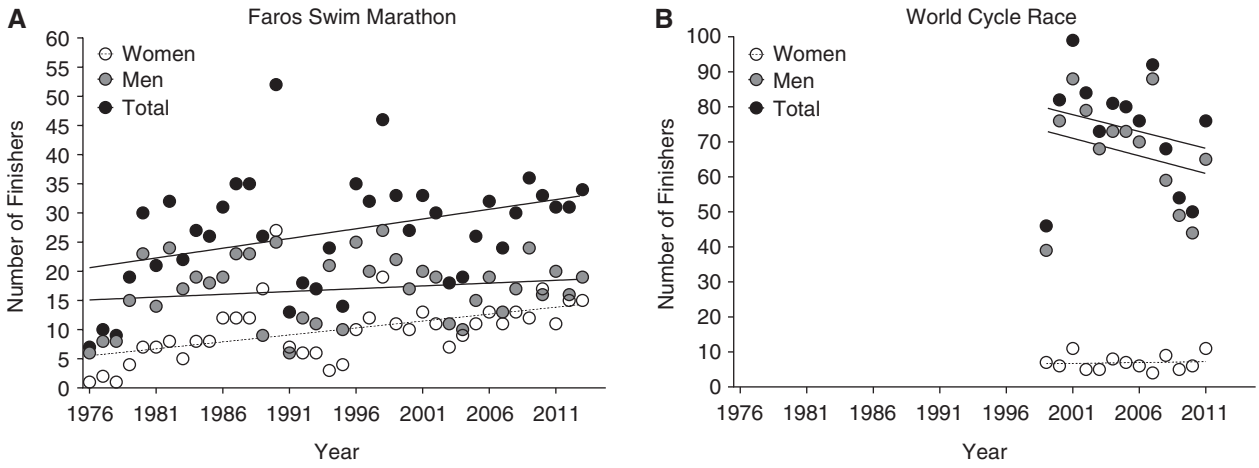

Fig. 1. Number of female and male finishers in the 'Faros Maratón Swim' (Panel A) and 'World Cycling Race' (Panel B).

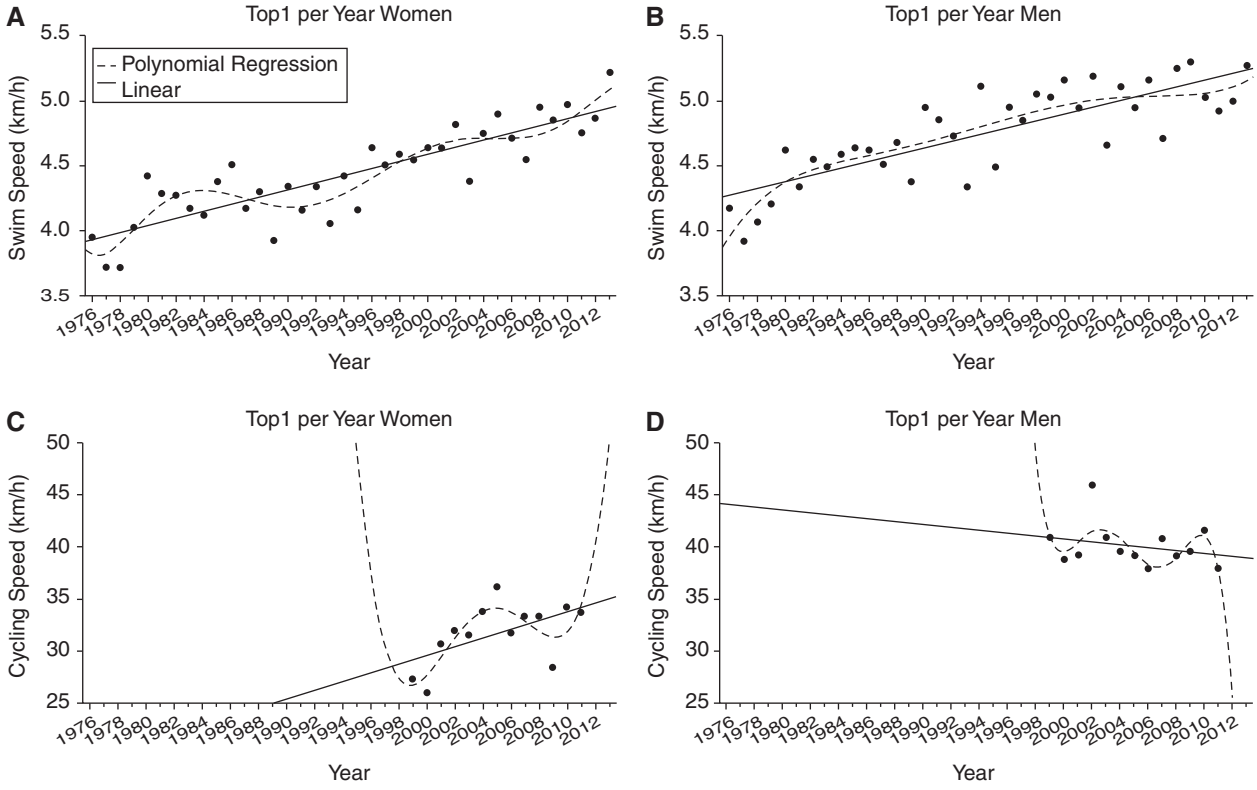

Fig. 2. Swimming speed of annual fastest female (Panel A) and male swimmers (Panel B) in the 'Faros Maratón Swim' and cycling speed of the annual fastest female (Panel C) and male cyclists (Panel D) in the 'World Cycling Race'.

mers, 641 (63.0%) male and 377 (37.0%) female, from 42 different nations participated in the 'Faros Maratón Swim'. Over the years, the annual number of participants increased linearly (Fig. 1A). In 1976, there were six male swimmers (85.7%) and only one female swimmer (14.2%). The last analysed race (37 years later) showed a similar participation rate of female (44.1%) and male (55.8%) athletes (19 male, 15 female). The percentage of female athletes increased from 14% (1976) to 44% (2013) significantly ($P < 0.01$) (Fig. 1A). The 24-h 'World Cycling Race' was held from 1999 to 2011 in Switzerland. A total of 961 athletes 871 (90.6%) male, 90 (9.4%) female took part in this race over the years. After an initial increase, the number of participants decreased over the years (Fig. 1B). The percentage of female athletes was 15.2% in 1999 and showed no significant change until 2011 (14.5%) (Fig. 1B).

Table 1. Multi-level regression analyses for change in swimming speed across years for female and male swimmers after correction for multiple finishes

	β	SE (β)	Stand. β	T	*P*
Annual fastest male	0.026	0.003	0.816	8.460	< 0.001
Annual fastest three male	0.028	0.002	0.784	13.377	< 0.001
Annual fastest female	0.027	0.003	0.858	10.010	< 0.001
Annual fastest three female	0.025	0.002	0.729	10.800	< 0.001

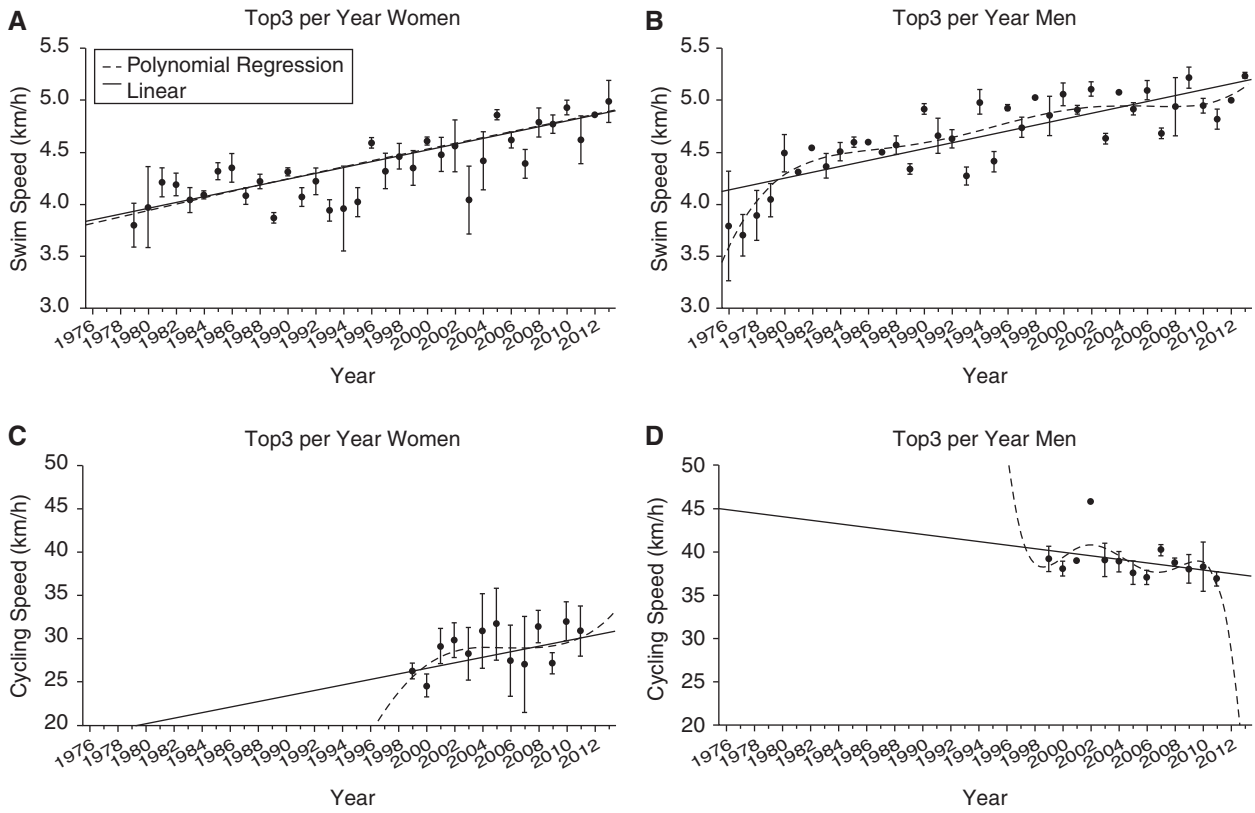

Fig. 3. Swimming speed of the annual three fastest female in the 'Faros Maratón Swim' (Panel A) and male swimmers (Panel B) and cycling speed of the annual three fastest female (Panel C) and male cyclists (Panel D) in the 'World Cycling Race'.

Performance Trends

In the 'Faros Maratón Swim', a significant ($P < 0.001$) and linear improvement in swimming speed in the annual fastest male swimmers was found (Fig. 2B, Table 1). The annual fastest (Fig. 2A) and the annual three fastest female (Fig. 3A) showed a significant ($P < 0.001$) and linear improvement in swimming speed as well (Table 1). The annual fastest three male (Fig. 3B) showed a non-linear (*i.e.* polynomial regression 5th degree) and significant ($P < 0.001$) improvement of swimming speed across calendar years (Table 1). In the 'World Cycling Race' there was no significant improvement in cycling speed in the annual fastest (Fig. 2D) and the annual three fastest male (Fig. 3D), whereas the annual three fastest female cyclists (Fig. 3C) increased cycling speed significantly and linearly ($P < 0.05$) across the years (Table 2). The annual fastest female cyclists (Fig. 2C) showed a non-linearly (*i.e.* polynomial regression 4th degree) significantly ($P < 0.05$) accelerated speed.

Change in Sex Difference

Regarding the sex difference of the annual three fastest swimmers there is a significant ($P < 0.05$) approximation observed (Fig. 4B, Table 3). In contrast, the sex difference of the annual best swimmer showed no significant change over the years (Fig. 4A, Table 3). The sex difference changed non-linearly in the annual fastest (*i.e.* polynomial regression 5th degree) and annual three fastest swimmers (*i.e.* polynomial

Table 2. Multi-level regression analyses for change in cycling speed across years for female and male cyclists after correction for multiple finishes

	β	SE (β)	Stand. β	T	*P*
Annual fastest male	-0.138	0.156	-0.258	-0.886	0.394
Annual fastest three male	-0.204	0.101	-0.316	-2.023	0.050
Annual fastest female	0.420	0.189	0.557	2.222	0.048
Annual fastest three female	0.306	0.139	0.340	2.200	0.034

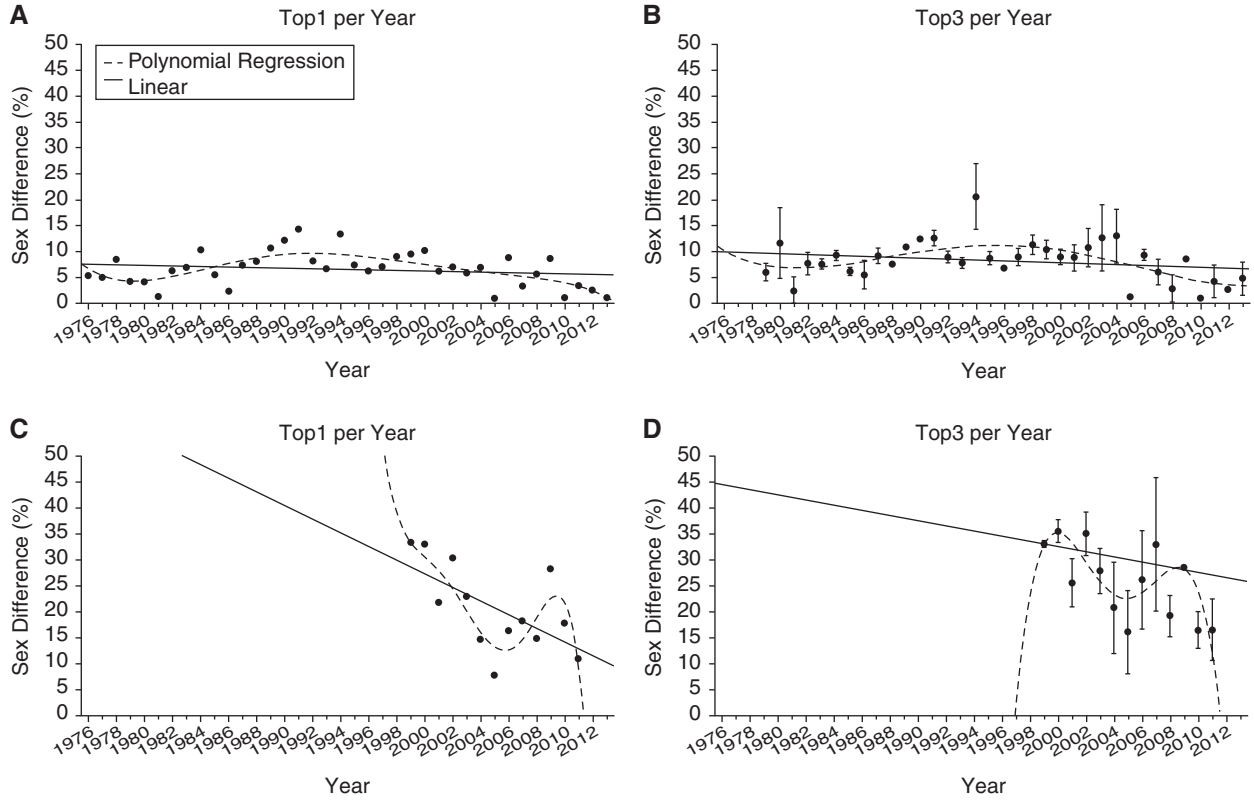

Fig. 4. Sex difference (%) in swimming of the annual (Panel A) and the annual three fastest (Panel B) in the 'Faros Maratón Swim' and in cycling of the annual fastest (Panel C) and the annual three fastest (Panel D) in the 'World Cycling Race'.

Table 3. Multi-level regression analyses for change in sex difference across years for female and male athletes after correction for multiple finishes

	β	SE (β)	Stand. β	T	*P*
Annual fastest in swimming	-0.056	0.049	-0.187	-1.139	0.262
Annual three fastest in swimming	-0.087	0.043	-0.198	-2.052	0.043
Annual fastest in cycling	-1.316	0.510	-0.614	-2.581	0.026
Annual three fastest in cycling	-1.174	0.329	-0.506	-3.565	0.001

regression 4th degree). The sex difference in the annual fastest male and female cyclists (Fig. 4C) decreased significantly ($P < 0.05$) and linearly over the years (Table 3). The same tendency showed the annual top three male and female cyclists ($P = 0.001$) (Fig. 4D, Table 3).

The Fastest Athletes ever in the Events

Comparing the fastest female swimmer ever in 'Faros Maratón Swim' (swimming speed 5.2 km/h, race time: 03:04:09 h:min:s) to the fastest male swimmer ever (swimming speed 5.3 km/h, race time: 03:01:55

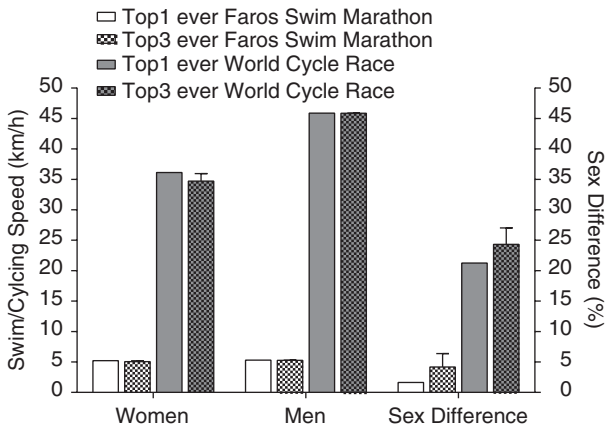

Fig. 5. Scale left: Swim and cycling speed of top one and top three ever in the 'Faros Maratón Swim' and the 'World Cycling Race'. Scale right: Sex difference in top one and top three ever in the 'Faros Maratón Swim' and the 'World Cycling Race'.

h:min:s), the fastest male swimmer was 1.5% faster than the fastest female swimmer (Fig. 5). The sex difference between the top three female and top three male swimmer showed a significant difference ($P < 0.05$) (Fig. 5). Male swimmers were 4.4% (mean 5.27 ± 0.0013 km/h) faster than female swimmers (mean 5.05 ± 0.204 km/h). Comparing the result of the best female cyclist ever to the results of the top three female cyclists ever, there is a significant difference observed. Comparing the number one female cyclist (cycling speed: 36.1 km/h) to the number one male cyclist (cycling speed: 45.8 km/h) at the 'World Cycling Race' the best male cyclist was 26.4% faster than the best female finisher. The top three male cyclists (45.9 km/h) (mean speed 45.85 ± 0.04 km/h, mean distance 1,100.6 ± 0.8 km) were 32.1% faster than the top three female cyclists ever (34.7 km/h) (mean speed 34.70 ± 1.87 km/h, mean distance 832.3 ± 42.34 km).

Discussion

This study intended to compare the sex difference in draft-legal events held in ultra-swimming and ultra-cycling. It was hypothesized that the sex difference in competitive athletes would decrease in draft-legal events compared to non-draft events. The most important findings were: (1) The annual fastest female athletes improved swimming and cycling speed over the years, (2) the sex difference of the annual fastest and annual three fastest cyclists decreased significantly, and (3) the top athletes ever showed a very small sex difference in the swimming event compared to the cycling event.

The Annual Fastest Female Athletes Improved Swimming and Cycling Speed over the Years

Regarding the annual best female and male swimmers there was a significant and linear improvement of swimming performance. Similar developments were reported for the 'English Channel Swim' where the swimming speeds of the annual fastest increased for both sexes (8). Comparing the results of the annual three fastest athletes in our study to those of the 'English Channel Swim' there is an obvious difference. While both the annual three fastest male and female swimmers did not improve swimming performance at the 'English Channel Swim' there was a significant improvement of swimming speed of the annual three fastest female swimmers at the 'Faros Maratón Swim'. Possible explanations for this different finding are the shorter swim distance and warmer water temperatures in the 'Faros Maratón Swim' compared to the 'English Channel Swim'. In colder water temperatures the swimmers spend a higher part of their energy to keep their body core temperature. Another explanation for these findings is probably the effect of drafting. The swimming distance in the 'Faros Maratón Swim' is shorter than in the 'English Channel Swim'. The participants compete in a field of racers and with many participants consistently the space between the swimmers is smaller, so that drafting is rather possible and allowed compared to the 'English Channel Swim'. While the faster competitors spin out their energy, the slower competitors use the effect of drafting to save energy and use it for the last parts of the race. And thus reduce swimming time.

Comparing the swimming event results of top one and top three of both sexes to the cycling event results there is one other important difference. While both sexes improved their performance in the swimming event, male athletes achieved no improvements across years in the cycling event. In the cycling event, only the annual fastest and the annual three fastest female cyclists increased cycling speed significantly. The male competitors showed no improvement of cycling speed over the observed time period. Similar results were presented by Zingg *et al*. (45) where the sex difference in cycling and the age of peak performance at the 720-km 'Swiss Cycling Marathon' were investigated over 12 years. Female cyclists improved cycling speed from 20.3 ± 3.1 km/h (2003) to 24.8 ± 2.4 km/h (2012) ($P < 0.01$). The cycling speed of male athletes remained unchanged over the observed period at 30.2 ± 0.6 km/h ($P > 0.05$) (45).

A potential explanation could be that this phenomenon is sustained through drafting. In sports like cycling and swimming where drafting is possible and allowed the slower competitors – in this case female cyclists and swimmers – can increase their speed with

less energy expenditure than the faster cyclists or swimmers. Therefore, the slower competitors benefit from the faster ones, while there is no benefit from drafting for the faster male cyclists. Female cyclists benefit more from drafting and reduce the sex difference over the years. Following this explanation the annual second and third placed male cyclists should have improved their performance as well. This finding may be due to lacking willingness of male athletes to draft behind their faster competitors for a long distance. Or *vice versa*, when drafting is allowed, everyone wants to use the advantage of drafting. Nobody is interested in swimming or cycling ahead of somebody for the best part of the race. However, the 'RAAM' is considerably longer where the best male cyclist needs about 8-9 days to finish. Once reached a high level of performance it gets difficult to improve this and drafting has small effect. This is confirmed by findings in the 'RAAM' where the annual three fastest male (21.8 ± 0.9 km/h) and female cyclist (16.6 ± 1.0 km/h) did not increase cycling speed over the years (33). The sex difference remained unchanged at 24.6 ± 3.0% (33).

The Sex Difference of the Annual Fastest and Annual Three Fastest Cyclists Decreased

The sex difference between the annual fastest male and female cyclist decreased over the years similarly to the difference in annual three fastest. These findings contrast with the findings for the 'RAAM'(33). In the 'RAAM', neither the annual fastest nor the annual three fastest reduced their sex difference (33). The possibility of drafting in the 'World Cycling Race' explains the inconsistent results. Female cyclists may catch up to their male competitors. And maybe they will outrun them in the future.

Interestingly, in our study, the best annual female and male swimmers showed no significant reduction in sex difference over the years. Similar observations were made in other studies. Rüst *et al.* reported no alteration in sex difference in performance for swimming and cycling in the ITU World Triathlon Series (*i.e.* 1.5 km swimming, 40 km cycling, 10 km running) from 2009 to 2012 (37).

One of the possible reasons for this observation is that drafting is not always possible even if allowed. Conceivably, the fastest male swimmer is a lot faster than the female swimmer, and drafting is not possible in this case. Another possible explanation for the unchanged sex difference in the annual winners could be that both male and female athletes improve their performance over the years to a very high level. Thus, only physiological and anthropometric differences between male and female swimmers determine the swim performance difference (39).

The influence of physiology and anthropometry in swimming performances was described by various investigators (1, 16, 17, 23, 27, 29, 39, 42-44). One of the most crucial findings was that body fat was ~11.9% higher in female (30.7 ± 3.7%) than in male swimmers (18.8 ± 4.5%) (17, 39, 43). Therefore, the body density of female swimmers was lower compared to the body density of male swimmers (39, 43). Because of lower body density, female swimmers had a higher buoyancy, and moreover the point of buoyancy was located more caudal than in the male competitors (27). This resulted in a more horizontal and streamlined swimming position (39) with less under water torque (*i.e.* tendency of the feet to sink) for female compared to male swimmers (29). Additionally, female swimmers were found to have shorter lower limbs (17, 39) and a smaller body size (17, 39) resulting in less body drag (29, 39). Although male swimmers had larger upper limbs, the propelling efficiency of the arm stroke was nearly the same in both sexes of the same age group and swimming ability (44). All these anthropometric differences provide a higher economy of swimming for female athletes and were postulated to be advantageous particularly in long distance swims (39). Another study showed that body height of male ultra-distance swimmers was an indicator for swim performance in athletes (17). The average body height of male athletes was 1.81 ± 0.07 m and of female athletes 1.68 ± 0.04 m. Therefore, female swimmers had a ~7.2% smaller body height than male swimmers (17).

A further deciding physiological fact is that male athletes have a higher skeletal muscle mass due to a higher level of androgen compared to female athletes (26, 27). Weitkunat *et al.* investigated body mass changes during ultra-endurance open-water swimming race of 20 male and 11 female athletes and demonstrated that male athletes had ~6.3% more skeletal muscle mass compared to female athletes (43). Further, male athletes have a higher heart stroke volume inducing a higher cardiac output (32). These physiological conditions and the higher blood volume of male athletes lead to a better muscle vascularization and finally a higher oxygen capacity (VO_2 max) in male swimmers compared to female swimmers (25, 28). Summarizing, the physiological and anthropometric differences with the most important effects were higher body fat in female and higher skeletal muscle mass in male swimmers. The higher body fat in female swimmers results in a higher buoyancy. The higher skeletal muscle mass in male swimmers results in a higher swimming speed. It seems like the muscle mass has a higher impact on swimming performance than body fat.

As expected there was a significant reduction in sex difference at the 'Faros Maratón Swim' over the

years. In contrast to our findings, the 'English Channel Swim' did not indicate any change in sex difference over the years (8). This difference between the two races is explained by the drafting, when female swimmer could save energy swimming behind their faster competitors, whereas the female swimmers in the 'English Channel Swim' did not have this opportunity (10).

Our finding is consistent with other recent findings. Rüst *et al.* investigated the sex difference at the 36-km 'Maratona del Golfo Capri-Napoli' of 662 male and 228 female ultra-distance swimmers and showed a linear decrease in sex difference in swimming performance for the annual fastest from 39.2% to 4.7% and for the annual three fastest from 38.2% to 6.0% over 59 years (38). Previous investigations of sex difference in swimming performance showed that performance difference between male and female swimmers is higher in shorter swimming distances, but becomes smaller in longer distances (39). Based on that, we expected an approximation of sex difference in performance over the years; possibly even that female swimmers would overtake the male. This observation was made by Knechtle *et al.* in the 'Manhattan Island Marathon Swim', a 46-km open-water ultra-distance race, where the best female swimmers were ~12-14% faster than the best male competitors (20).

Sex Difference in Cycling Decreases More than Sex Difference in Swimming

The comparison between the cycling and the swimming event with respect to sex difference reveals that there has been a higher approximation of performance from female and male athletes in the cycling event than in the swimming event over the years. Cycling races can be performed for hours to one day, as we see in the 'World Cycling Race', or even several days (33) while swimming races are limited to some hours (7-10, 15-17, 20). For this reason ultra-cycling races usually last longer than ultra-swimming races. This is one explanation for our observation. In the examined cycling race drafting has a major effect because of the longer duration (24 h) compared to 3-4 h for the 16-km swimming race. Therefore, the equation could be: the longer the drafting the smaller the sex difference.

Another explanation for the decrease in speed difference among male and female cyclists is to assume that drafting is easier in cycling than in swimming. Considering the fact that athletes generally draft in packages or small fields cycling has an advantage over swimming. While the cycling race is hold in laps, the swimming race is a point-to-point race. Female cyclists can join a faster or slower field depending on whether they want to go faster or slow down for a break, without losing the possibility to draft, while female swimmers need to be able to hold the pace of the leaders in the field to benefit from drafting. If they are not able to hold the pace, they lose the contact to the leaders and similarly lose the benefit from drafting.

Comparison between Sports with Drafting and Sports without Drafting

In many sports disciplines such as athletics (*i.e.* high jump, broad jump and weightlifting) drafting is not possible. Thibault *et al.* investigated the performance trends of male and female athletes in various Olympic disciplines such as swimming, athletics, track cycling, weightlifting and speed skating (41). Since 1983, the sex difference in world records (for all events), remained stable at 10 ± 2.9% (41). The smallest sex difference in performance was reported for 800 m freestyle swimming with ~5.5%, the highest sex difference in performance in long jump with ~18.8% (41). The mean difference over all investigated swimming races was ~8.9% (41). It supports our hypothesis that long jump as a discipline with no possibility of drafting showed the highest sex difference, whereas swimming as a discipline with possibility of drafting showed the smallest sex difference.

Drafting seems to have physiological as well as non-physiological effects on the performance of athletes (46). Zouhal *et al.* investigated ten elite distance runners in a 3000-m running track, while the athletes completed the track three times. On the first session they wore a lightweight ambulatory respiratory gas-exchange system to determine maximal oxygen uptake and maximal aerobic speed, on the second session the runners were not allowed to draft. On the last session they were allowed to draft for the first 2000 m. The results demonstrated significantly better results in the session with drafting, while there were no significant cardiorespiratory responses. The authors concluded that drafting improves performance in running in physiological and non-physiological manners, such as psychological (46).

In the cycling event, the sex difference between the fastest woman and man in the 'World Cycling Race' was 26.4%. In contrast to our results, the 'RAAM' showed a smaller difference in race time of 14.2% (33). However, the absolute speed of the fastest cyclist was considerably lower in the 'RAAM' with 24.8 km/h for the male and 21.3 km/h for the female athlete. The fastest male athlete ever at the 'World Cycling Race' had a cycling speed of 45.9 km/h and the fastest female 36.1 km/h. These results depend on the constitution and kind of the race track. Zingg *et al.* analysed the 720-km 'Swiss Cycling Marathon' and showed a sex difference between the best and the three best

Table 4. Summary of cited cycling races

	'World Cycling Race'	'RAAM' (33)	'Swiss Cycling Marathon' (45)
Male Top 1 ever	45.8 km/h	24.77 km/h	
Female Top 1 ever	36.1 km/h	21.27 km/h	
Sex Difference Top 1 ever	26.40%	14.2%	13.6%
Male Top 3 ever	45.85 ± 0.05 km/h		
Female Top 3 ever	34.70 ± 1.87 km/h		
Sex Difference Top 3 ever	32.1%		13.9 ± 0.5%
Male Top 1 per Year		22.7 ± 1.1 km/h	
Female Top 1 per Year		18.4 ± 1.6 km/h	
Sex Difference Top 1 per Year		19.4 ± 7.3% ($P > 0.05$)	
Male Top 3 per Year		21.8 ± 0.9 km/h	
Female Top 3 per Year		16.6 ± 1.0 km/h	
Sex Difference Top 3 per Year		24.6 ± 3.0% ($P > 0.05$)	
Male Mean Speed 2003			30.2 ± 0.6 km/h
Male Mean Speed 2012			30.2 ± 0.6 km/h
Male Improvement			($P > 0.05$)
Female Mean Speed 2003			20.3 ± 3.1 km/h
Female Mean Speed 2012			24.8 ± 2.4 km/h
Female Improvement			($P < 0.01$)
Male Mean Speed		19.4 ± 2.0 km/h	
Female Mean Speed		17.5 ± 2.0 km/h	
Sex Difference of Mean Speed		1.9 ± 2.0 km/h (10.9%)	

cyclists ever of 13.6% and 13.9 ± 0.5%, respectively (45) (Table 4).

Focusing the results of the best athletes ever, it is remarkable that the sex difference in swimming event is very small (~1.5%) compared to the sex difference of top one ever cycling event (~26.4%). This trend continues to be the same in three fastest athletes ever, where the sex difference in the swimming event was ~4.4% and ~32.1% in cycling event. In the 'English Channel Swim' drafting was not allowed (8). The sex difference of fastest swimmers ever was 6.7% and of three fastest swimmers ever 8.9% (8). These findings compared with our study confirm our thesis that drafting results in smaller sex differences (Table 5).

Limitations

One of the limitations of this study is that the percentage of female participants in the 'World Cycling Race'was only 10% compared to the percentage of initial 14% in 1976 and finally 44% in 2010 at the 'Faros Maratón Swim'. It is possible that a higher female participation would change the results. The observed time period of ~38 years for the 'Faros Maratón Swim' is a long time and allows a stable statement about the development of sex difference in swimming event. Since the data investigated only 13 years of the 'World Cycling Race', an analysis of a longer time period might deliver different results. The third very important limitation is the different duration of the two kinds of sports. While cycling can be performed for hours to one day, swimming is limited to only some hours (7-10, 15-17, 20). This fact can impact our results. It is possible that female athletes improved their performance in cycling more than in swimming because they could benefit for a longer time from drafting. We need to underline the fact that, even if drafting is allowed in a race, we are not able to control whether women really drafted or not, what is a further limitation of this study. Taken together, the difference of observation time, the lower participation of female athletes in cycling than in swimming and the different duration of these two kinds of sports makes it apparent that the results of these two races are difficult to compare. Not least in addition to drafting other important factors such as water temperature, swimming distance, and anthropometric and physiological factors determine the sex difference between male and female athletes in cycling and swimming.

Practical Applications

In ultra-endurance races drafting is a good possibility to save energy and achieve better results. An athlete should use the gain by drafting as long as

Table 5. Summary of cited swimming races

	'Faros Maratón Swim'	'English Channel Swim' (8)	'Maratona del Golfo Capri-Napoli' (38)
Male Top 1 ever	5.3 km/h		
Female Top 1 ever	5.2 km/h		
Sex Difference Top 1 ever	1.50%	6.70%	
Male Top 3 ever	5.27 ± 0.13 km/h		
Female Top 3 ever	5.05 ± 0.20 km/h		
Sex Difference Top 3 ever	4.40%	8.90%	
Male Top 1 per Year		0.89 ± 0.20 m/s	
Female Top 1 per Year		0.84 ± 0.18 m/s	
Sex Difference Top 1 per Year		$P > 0.05$	
Male Top 1 per Year 1954			600 min
Male Top 1 per Year 2013			373 min
Male Improvement			227 min
Female Top 1 per Year 1954			731 min
Female Top 1 per Year 2013			391 min
Female Improvement			340 min
Male Top 3 per Year 1963			627.1 ± 34.5 min
Male Top 3 per Year 2013			374.1 ± 0.3 min
Male Improvement			($P < 0.0001$)
Female Top 3 per Year 1963			736.8 ± 78.4 min
Female Top 3 per Year 2013			396.6 ± 4.5 min
Female Improvement			($P < 0.0001$)
Sex Difference Top 1 per Year 1955			39.2%
Sex Difference Top 1 per Year 2013			4.7%
Significance			($P < 0.0001$)
Sex Difference Top 3 per Year 1963			38.2 ± 14.0%
Sex Difference Top 3 per Year 2013			6.0 ± 1.0%
Significance			($P < 0.0001$)

possible when drafting is allowed. We compared the change of sex difference in two kinds of sports. In the cycling event, the effect of drafting was higher than in the swimming event. Whenever drafting is possible it is advisable to seize the opportunity in order to enhance one's performance. However, drafting led to more approximation of the sex difference in cycling event than in swimming event. To summarize, the most important finding was the significant improvement in performance in the swimming event of both sexes when drafting was possible. The annual fastest and the annual three fastest swimmers enhanced swimming speed during the last 38 years significantly. However, there was no reduction in sex difference in the swimming event, for the annual best male and female. Interestingly, in the cycling event, only female athletes improved cycling speed, while their male counterparts showed no improvement. This trend leads to a reduction of the sex difference in cycling. Moreover it is conspicuous that in general the sex difference in the swimming event is very small compared to the sex difference in the cycling event. This comes to a head at the best performances ever, where the sex difference between the two disciplines is particularly large. Whenever drafting is allowed and practicable the participants of sport races should use this opportunity to improve their performance. Drafting seems to be more profitable in swimming event than in cycling. Especially female athletes can benefit from faster competitors to draft behind, and maybe overtake them towards the end of a race. The effect of drafting is only practicable as long as female athletes are able to join and follow the male competitors. When female athletes are not able to follow there is no decrease of sex difference due drafting to be expected. Further studies should continue to observe this finding in longer swim races in the future.

References

1. Brannigan, D., Rogers, I.R., Jacobs, I., Montgomery, A., Williams, A. and Khangure N. Hypothermia is a significant medical risk of

mass participation long-distance open water swimming. *Wilderness Environ. Med.* 20: 14-18, 2009.
2. Cheuvront, S.N., Carter, R., Deruisseau, K.C. and Moffatt, R.J. Running performance differences between men and women: an update. *Sports Med*. 35: 1017-1024, 2005.
3. Coast, J.R., Blevins, J.S. and Wilson, B.A. Do gender differences in running performance disappear with distance? *Can. J. Appl. Physiol*. 29: 139-145, 2004.
4. Da Fonseca-Engelhardt, K., Knechtle, B., Rüst, C.A., Knechtle, P., Lepers, R. and Rosemann, T. Participation and performance trends in ultra-endurance running races under extreme conditions - 'Spartathlon' versus 'Badwater'. *Extrem. Physiol. Med.* 2: 15, 2013.
5. Deaner, R.O. Distance running as an ideal domain for showing a sex difference in competitiveness. *Arch. Sex. Behav*. 42: 413-428, 2013.
6. Deaner, R.O. More men run relatively fast in U.S. road races, 1981-2006: a stable sex difference in non-elite runners. *Evol. Psychol.* 9: 600-621, 2011.
7. Eichenberger, E., Knechtle, B., Rüst, C.A., Knechtle, P., Lepers, R. and Rosemann, T. No gender difference in peak performance in ultra-endurance swimming performance - analysis of the 'Zurich 12-h Swim' from 1996 to 2010. *Chinese J. Physiol*. 55: 346-351, 2012.
8. Eichenberger, E., Knechtle, B., Knechtle, P., Rüst, C.A., Rosemann, T. and Lepers, R. Best performances by men and women open-water swimmers during the 'English Channel Swim' from 1900 to 2010. *J. Sports Sci*. 30: 1295-1301, 2012.
9. Eichenberger, E., Knechtle, B., Knechtle, P., Rüst, C.A., Rosemann, T., Lepers, R. and Senn, O. Sex difference in open-water ultra-swim performance in the longest freshwater lake swim in Europe. *J. Strength Cond. Res*. 27: 1362-1369, 2013.
10. Fischer, G., Knechtle, B., Rüst, C.A. and Rosemann, T. Male swimmers cross the English Channel faster than female swimmers. *Scand. J. Med. Sci. Sports*. 23: e48-e55, 2013.
11. Gallmann, D., Knechtle, B., Rüst, C.A., Rosemann, T. and Lepers, R. Elite triathletes in 'Ironman Hawaii' get older but faster. *Age (Dordr.)* 36: 407-416, 2014.
12. Herbst, L., Knechtle, B., Lopez, C.L., Andonie, J.L., Fraire, O.S., Kohler, G., Rüst, C.A. and Rosemann, T. Pacing strategy and change in body composition during a Deca Iron triathlon. *Chinese J. Physiol*. 54:255-263, 2011.
13. Hoffman, M.D. Performance trends in 161-km ultramarathons. *Int. J. Sports Med*. 31: 31-37, 2010.
14. Jürgens, D., Knechtle, B., Rüst, C.A., Knechtle, P., Rosemann, T. and Lepers, R. An analysis of participation and performance by nationality at 'Ironman Switzerland' from 1995 to 2011. *J. Sci. Cycling* 1: 10-20, 2012.
15. Keatinge, W.R., Khartchenko, M., Lando, N. and Lioutov, V. Hypothermia during sports swimming in water below 11 degrees C. *Brit. J. Sports Med.* 35: 352-353, 2001.
16. Knechtle, B., Christinger, N., Kohler, G., Knechtle, P. and Rosemann, T. Swimming in ice cold water. *Ir. J. Med. Sci.* 178: 507-511, 2009.
17. Knechtle, B., Baumann, B., Knechtle, P. and 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* 111: 463-474, 2010.
18. Knechtle, B., Knechtle, P. and Lepers, R. Participation and performance trends in ultra-triathlons from 1985 to 2009. *Scand. J. Med. Sci. Sports.* 21: 82-90, 2011.
19. Knechtle, B., Knechtle, P. and Rosemann, T. No case of exercise-associated hyponatremia in male ultra-endurance mountain bikers in the 'Swiss Bike Masters'. *Chinese J. Physiol.* 54:379-384, 2011.
21. Knechtle, B., Rosemann, T., Lepers, R. and Rüst, C.A. Women outperform men in ultra-distance swimming – The 'Manhattan Island Marathon Swim' from 1983 to 2013. *Int. J. Sports Physiol. Perform.* 9: 913-924, 2014.
21. Knechtle, B., Wirth, A., Knechtle, P., Rüst, C.A., Rosemann, T. and Lepers, R. No improvement in race performance by naps in male ultra-endurance cyclists in a 600-km ultra-cycling race. *Chinese J. Physiol.* 55: 125-133, 2012.
22. Krouse, R.Z., Ransdell, L.B., Lucas, S.M. and Pritchard, M.E. Motivation, goal orientation, coaching, and training habits of women ultrarunners. *J. Strength Cond. Res.* 25: 2835-2842, 2011.
23. Lavoie, J.M. and Montpetit, R.R. Applied physiology of swimming. *Sports Med*. 3: 165-189, 1986.
24. Lepers, R. Analysis of Hawaii ironman performances in elite triathletes from 1981 to 2007. *Med. Sci. Sports Exerc*. 40: 1828-1834, 2008.
25. Lepers, R. and Maffiuletti, N.A. Age and gender interactions in ultraendurance performance: insight from the triathlon. *Med. Sci. Sports Exerc*. 43: 134-139, 2011.
26. Lynch, S.L. and Hoch, A.Z. The female runner: gender specifics. *Clin. Sports Med*. 29: 477-498, 2010.
27. McLean, S.P. and Hinrichs, R.N. Sex differences in the centre of buoyancy location of competitive swimmers. *J. Sports Sci*. 16: 373-383, 1998.
28. Pate, R.R., Sparling, P.B., Wilson, G.E., Cureton, K.J. and Miller, B.J. Cardiorespiratory and metabolic responses to submaximal and maximal exercise in elite women distance runners. *Int. J. Sports Med*. 8: 91-95, 1987.
29. Pendergast, D.R., Di Prampero, P.E., Craig, A.B., Wilson, D.R. and Rennie, D.W. Quantitative analysis of the front crawl in men and women. *J. Appl. Physiol*. 43: 475-479, 1977.
30. Pyne, D.B., Trewin, C.B. and Hopkins, W.G. Progression and variability of competitive performance of Olympic swimmers. *J. Sports Sci.* 22: 613-620, 2004.
31. Reinboud, W. Linear models can't keep up with sport gender gap. *Nature* 432: 147, 2004.
32. Reaburn, P. and Dascombe, B. Endurance performance in masters athletes. *Eur. Rev. Aging Phys. Act.* 5: 31-42, 2008.
33. Rüst, C.A., Knechtle, B., Rosemann, T. and Lepers, R. Men cross America faster than women - the 'Race across America' (RAAM) from 1982 to 2012. *Int. J. Sports Physiol. Perform*. 8: 611-617, 2013
34. Rüst, C.A., Knechtle, B., Knechtle, P. and Rosemann, T. Higher prevalence of exercise-associated hyponatremia in triple iron ultra-triathletes than reported for ironman triathletes. *Chinese J. Physiol.* 55: 147-155, 2012.
35. Rüst, C.A., Knechtle, B., Knechtle. P., Rosemann, T. and Lepers, R. Sex differences in ultra-triathlon performance at increasing race distance. *Percept. Mot. Skills* 116: 1-17, 2013.
36. Rüst, C.A., Knechtle, B., Rosemann, T. and Lepers, R. Women reduced the sex difference in open-water ultra-distance swimming. La Traversée international du Lac St-Jean1955-2012. *Appl. Physiol. Nutr. Metab.* 39: 270-273, 2014.
37. Rüst, C.A., Lepers, R., Stiefel, M., Rosemann, T. and Knechtle, B. Performance in Olympic triathlon: changes in performance of elite female and male triathletes in the ITU World Triathlon Series from 2009 to 2012. S*pringerplus* 2: 685, 2013.
38. Rüst, C.A., Lepers, R., Rosemann, T. and Knechtle, B. Will women soon outperform men in open-water ultra-distance swimming in the 'Maratona del Golfo Capri-Napoli'? *Springerplus* 3: 86, 2014.
39. Tanaka, H. and Seals, D.R. Age and gender interactions in physiological functional capacity: insight from swimming performance. *J. Appl. Physiol*. 82: 846-851, 1997.
40. Teutsch, A., Rüst, C.A., Knechtle, B., Knechtle, P., Rosemann, T. and Lepers, R. Differences in age and performance in 12-h and 24-h ultra-runners. *Adapt. Med.* 5: 138-146, 2013.
41. Thibault, V., Guillaume, M., Berthelot, G., El Helou, N., Schaal, K., Quinquis, L., Nassif, H., Tafflet, M., Escolano, S., Hermine, O. and Toussaint, J.F. Women and men in sport performance: the gender gap has not evolved since 1983. *J. Sports Sci. Med.* 9: 214-223, 2010.
42. Toussaint, H.M., de Groot, G., Savelberg, H.H., Vervoorn, K., Hollander, A.P. and van Ingen Schenau, G.J. Active drag related to velocity in male and female swimmers. *J. Biomech*. 21: 435-

438, 1988.
43. Weitkunat, T., Knechtle, B., Knechtle, P., Rüst, C.A. and Rosemann, T. Body composition and hydration status changes in male and female open-water swimmers during an ultra-endurance event. *J. Sports Sci*. 30: 1003-1013, 2012.
44. Zamparo, P. Effects of age and gender on the propelling efficiency of the arm stroke. *Eur. J. Appl. Physiol*. 97: 52-58, 2006.
45. Zingg, M., Knechtle, B., Rüst, C.A., Rosemann, T. and Lepers, R. Age and gender difference in non-drafting ultra-endurance cycling performance - the 'Swiss Cycling Marathon'. *Extrem. Physiol. Med.* 2: 18, 2013.
46. Zouhal, H., Ben Abderrahman, A., Prioux, J., Knechtle, B, Bounguerra, L., Kebsi, W. and Noakes, T.D. Drafting's improvement of 3000-m running performance in elite athletes: is it a placebo effect? *Int. J. Sports Physiol. Perform.* 10: 147-152, 2015.