

SEX DIFFERENCES IN ULTRA-TRIATHLON PERFORMANCE AT INCREASING RACE DISTANCE^{1, 2}

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Summary.—It has been argued that women should be able to outrun men in ultra-endurance distances. The present study investigated the sex difference in overall race times and split times between elite female and male Ironman triathletes competing in Ironman Hawaii (3.8 km swimming, 180 km cycling, and 42.195 km running) and Double Iron ultra-triathletes (7.6 km swimming, 360 km cycling, and 84.4 km running). Data from 20,638 athletes, including 5,163 women and 15,475 men competing in Ironman Hawaii and from 143 women and 1,252 men competing in Double Iron ultra-triathlon races held worldwide between 1999 and 2011 were analyzed. In Ironman Hawaii, the sex difference in performance of the top three athletes remained unchanged during the period studied for overall race time. For Double Iron ultra-triathletes, the sex difference for the top three athletes remained unchanged for overall race time. Sex differences increased as endurance race distances increased and showed no changes over time. It appears that women are unlikely to close the gap in ultra-endurance performance with men in ultra-triathlons in the near future. Physiological (e.g., maximum oxygen uptake) and anthropometric characteristics (e.g., skeletal muscle mass) may set biological limits for women.

The sex difference in endurance performance has been investigated by a variety of researchers for different race distances (Sparling, O'Donnell, & Snow, 1998; Coast, Blevins, & Wilson, 2004; Thibault, Guillaume, Berthelot, El Helou, Schaal, Quinquis, *et al.*, 2010). Independent of the discipline and the distance, the sex difference in performance was stable at 11–12% (Sparling, *et al.*, 1998; Coast, *et al.*, 2004; Thibault, *et al.*, 2010). Thibault, *et al.* (2010) reported a dominance of men when investigating the sex differences in different sports disciplines such as swimming, athletics, track cycling, weightlifting, and speed skating. They determined sex as a major variable of athletic performance by comparing the best perfor-

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mances of women and men in different sports. In every discipline, male performance was better than female performance with a mean sex difference of 10.0% ($SD = 2.9$).

A sex difference in athletic performance of 10–12% seems to be of biological origin. Success in distance running is undergirded by aerobic capacity and muscular strength. Because male athletes possess a larger aerobic capacity (Murphy, Patton, & Frederick, 1986; Knechtle, Müller, Willmann, Kotteck, Eser, & Knecht, 2004) and greater muscular strength (Ford, Dettlerline, Ho, & Cao, 2000; Chevront, Carter, Deruisseau, & Moffatt, 2005) compared to female athletes, the gap in performance between women and men is unlikely to narrow naturally (Chevront, *et al.*, 2005). The sex difference in endurance performance might be explained by physiological differences such as maximum oxygen uptake (VO_{2max} ; Knechtle, *et al.*, 2004) and anthropometric differences such as skeletal muscle mass and body fat (Knechtle, Senn, Imoberdorf, Joleska, Wirth, Knechtle, *et al.*, 2010; Knechtle, Baumann, Wirth, Knechtle, & Rosemann, 2010; Knechtle, Wirth, Baumann, Knechtle, Kohler, Rosemann, *et al.*, 2010; Knechtle, Wirth, Baumann, Knechtle, Rosemann, & Senn, 2010). Endurance-trained male triathletes have a VO_{2max} of $\sim 61 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ compared to female triathletes with a VO_{2max} of $\sim 53 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ (Knechtle, *et al.*, 2004) with a corresponding sex difference of $\sim 8 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ ($\sim 14\%$). Male Ironman triathletes with 41 kg skeletal muscle mass had a 32% higher skeletal muscle mass compared to female Ironman triathletes with 28 kg of skeletal muscle mass (Knechtle, Wirth, Baumann, Knechtle, Kohler, Rosemann, *et al.*, 2010). For ultra-runners, men with 38 kg skeletal muscle mass (Knechtle, Senn, Imoberdorf, Joleska, Wirth, Knechtle, *et al.*, 2011) had a 28% higher muscle mass compared to women with 27.4 kg (Knechtle, Senn, Imoberdorf, Joleska, Wirth, Knechtle, *et al.*, 2010). Male triathletes with 19.1% body fat have 29% lower body fat compared to female triathletes with 26.9% body fat (Knechtle, *et al.*, 2004).

While some studies have suggested that women might be able to reach men's endurance performance levels (Whipp, & Ward, 1992; Speechly, Taylor, & Rogers, 1996; Bam, Noakes, Juritz, & Dennis, 1997; Hoffman, 2008), others indicated that the sex difference in performance arises from inherently different biological capacities and women would not be able to reach men's levels of performance (Murphy, *et al.*, 1986; Ford, *et al.*, 2000; Chevront, *et al.*, 2005). For longer ultra-distances, the sex difference in performance even seemed to increase. When the world best times for ultra-triathlon distances for both women and men were compared, men were $\sim 19\%$ faster than women in both a Double Iron and Triple Iron ultra-triathlon (11.6 km swimming, 540 km cycling, and 126.6 km running), and $\sim 30\%$ faster in a Deca Iron ultra-triathlon (38 km swimming, 1,800 km

TABLE 1
FASTEST RACE TIMES IN IRONMAN HAWAII AND WORLD BEST TIMES IN DOUBLE IRON ULTRA-TRIATHLON

	Swim Split Time (min.)	Bike Split Time (min.)	Run Split Time (min.)	Overall Race Time (min.)
Ironman Hawaii				
Men (2011)	50	258	162	484
Women (2009)	54	292	173	535
Sex difference	8.0%	13.2%	6.8%	10.5%
Double Iron Ultra-triathlon				
Men (2011)	128	631	430	1,190
Women (1992)	165	761	499	1,425
Sex difference	28.9%	20.6%	16.0%	19.8%

Note. — The official world record in Double Iron ultra-triathlon for women was set in 1994 by Tina Bischoff (USA) in 22 hours 07 minutes in Huntsville (USA). The swimming was held downriver; therefore the swim time was not comparable to the course in the men's record race in Austria. To compare the fastest race times in Double Iron for women and men, the second fastest time for women was inserted in order to have comparable data.

cycling, and 422 km running; Knechtle, Knechtle, & Lepers, 2011). Knechtle, Knechtle, and Lepers (2012) argued that the increase in sex difference with increasing length of an ultra-endurance performance such as an ultra-triathlon was most probably due to the lower skeletal muscle mass in women.

Long-distance triathlons such as the Ironman distance (3.8 km swimming, 180 km cycling, and 42.195 km running) and the Double Iron ultra-triathlon (7.6 km swimming, 360 km cycling, and 84.4 km running) are examples of ultra-endurance events, defined as an event lasting more than six hours (Zaryski, & Smith, 2005). The Ironman triathlon, which started in 1978 (Lepers, 2008), and the Double Iron ultra-triathlon with the first race in 1985 (Lenherr, Knechtle, Rüst, Rosemann, & Lepers, 2012), are relatively young ultra-endurance disciplines. The world fastest Double Iron ultra-triathlon times were achieved in 2011 by Adrian Brennwald (Switzerland) in 19 hours 50 minutes and for women in 1994 by Tina Bischoff (USA) in 22 hours 07 minutes. However, the latter race was held downriver and the swim split is not comparable to other races. The second fastest race time for women was achieved in 1991 by Astrid Benöhr (23 hours 45 minutes); the corresponding sex difference in overall performance was 19.8% (Table 1). The fastest Ironman race times in the Ironman Hawaii were more recently achieved, as the current Ironman Hawaii course record for men was set in 2011 by Craig Alexander (Australia) at 8 hours 3 minutes 56 seconds. Chrissie Wellington (Great Britain) set the women's course record in 2009 at 8 hours 54 minutes 2 seconds. The corresponding sex difference was 10.5%.

The higher skeletal muscle mass in men might be an important variable of performance for ultra-endurance athletes and may explain the higher sex difference in the Double Iron ultra-triathlon performance compared to the Ironman distance. During an ultra-endurance performance, skeletal muscle mass decreased in men (Knechtle, Duff, Amtmann, & Kohler, 2008; Knechtle, Duff, Schulze, & Kohler, 2008; Knechtle, Baumann, Wirth, Knechtle, & Rosemann, 2010) but not in women (Knechtle, Wirth, Baumann, Knechtle, Kohler, Rosemann, *et al.*, 2010). The higher muscle mass may help men to maintain a faster speed during a longer time compared to women. When women and men were compared regarding their performance in cycling, the main factor accounting for sex differences in peak and mean power output during cycling was the muscle mass of the lower extremities (Perez-Gomez, Rodriguez, Ara, Olmedillas, Chavarren, González-Henriquez, *et al.*, 2008). Women with a lower lean leg volume developed a lower peak power compared to men (Martin, Dore, Twisk, van Praagh, Hautier, & Bedu, 2004). The lower body fat in men might enhance endurance performance. Body fat has been shown as an important predictor variable for male Ironman triathletes (Knechtle, Wirth, Baumann, Knechtle, & Rosemann, 2010). However, high body fat might enhance female ultra-endurance swim performance due to an increase in buoyancy.

A few studies investigated changes in sex difference in multi sports ultra-endurance events over time (Lepers, 2008; Knechtle, Knechtle, & Lepers, 2011; Rüst, Knechtle, Knechtle, Pfeifer, Rosemann, Lepers, *et al.*, 2012). For long-distance triathlons, such as the Ironman triathlon, Lepers (2008) reported the sex difference in the top ten overall triathletes competing in Ironman Hawaii between 1988 and 2007. Over this period, the mean sex differences in times for swimming, cycling, running, and total event were 9.8% ($SD = 2.9$), 12.7% ($SD = 2.0$), 13.3% ($SD = 3.1$), and 12.6% ($SD = 1.3$), respectively. Between 1988 and 2007, the sex difference remained identical for swimming (+0.1% per decade), increased for cycling (+0.8% per decade), and decreased for running (-2.8% per decade). The sex difference in overall race time also remained stable in the last two decades (-0.5% per decade). Regarding swimming as a separate discipline in triathlon, an actual study found no sex difference in ultra-swimming performance (Eichenberger, Knechtle, Knechtle, Rüst, Rosemann, & Lepers, 2012b). That women store more fat in the hips/buttocks than men has been used to suggest that women produce less drag in the water, thereby saving energy, which translates into potentially superior swimming performance during ultra-endurance swimming. Women also preferentially burn fat due to a sex-hormone advantage, perhaps making it possible for women to outperform men in ultra-endurance exercise (Dasilva, Guidetti, Buzzachera, Elsangedy, Krinski, De Campos, *et al.*, 2011).

In this context, the aim of the present study was to compare the sex differences in swimming, cycling, and running performance and in overall race times between elite Ironman triathletes finishing Ironman Hawaii and Double Iron ultra-triathletes. To achieve this aim, the split and overall race times of the fastest female and male Ironman triathletes in Ironman Hawaii and Double-Iron ultra-triathletes during the period from 1999 to 2011 were analyzed. It was hypothesized that the sex difference in performance would be higher in the overall performance for Double Iron ultra-triathlon distance but lower for the swimming split compared to the Ironman triathlon.

METHOD

The split and the overall race times of female and male winners and top three overall finishers in Ironman Hawaii and Double Iron ultra-triathlons held worldwide between 1999 and 2011 were analyzed. The 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. For Double Iron ultra-triathlons, the race results were provided by the race directors. The corresponding author collected all race results personally over the last 20 years. The data set with the race results from Ironman Hawaii was downloaded from the race website.³

In total, data were available from 20,638 athletes, including 5,163 women and 15,475 men in Ironman Hawaii and from 143 women and 1,252 men in Double Iron ultra-triathlon races held worldwide. For Ironman Hawaii and the Double Iron ultra-triathlons, data from professional and amateur athletes were combined in one group. Table 2 presents the races held in Double Iron ultra-triathlons between 1999 and 2011. Due to the low number of women participating in a Double Iron ultra-triathlon (Knechtle, Knechtle, & Lepers, 2012), races held before 1999 had to be excluded from analysis. From all other races, held between 1999 and 2011, overall race times and split times in swimming, cycling, and running of the winner (e.g., the fastest total race time) and the top three (e.g., the three fastest total race times) triathletes overall per sex and year were defined by Ironman Hawaii and in any participants in a Double Iron ultra-triathlon held worldwide. Split times and overall race times were converted to minutes. Afterwards, race results were analyzed regarding development of performance per split discipline and differences in performances between women and men. The sex difference was calculated as $([\text{performance in men}] - [\text{performance in women}]) / [\text{performance in men}] \times 100$. To facilitate reading, sex differences were converted to absolute values. The change in sex difference over time was also evaluated.

³<http://ironman.com/events/ironman/worldchampionship/>.

TABLE 2
RACES IN DOUBLE IRON ULTRA-TRIATHLON

Races	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Virginia (USA)	x	x	x	x	x	x	x	x	x	x	x	x	x
Yahuarcocha (ECU)	x	x	x	x	x	x	x	x					
Panevezys (LTU)	x	x		x	x	x	x						
Den Haag (NED)	x												
Monterrey (MEX)	x		x										
Levis (CAN)		x	x	x	x	x	x	x	x	x			
Le Fontanil (FRA)			x										
Neulengbach (AUT)				x	x	x	x	x	x		x		x
Ottobrunn (GER)				x		x							
Moosburg (AUT)							x	x	x				
Ras-al-Khaimar (UAE)									x				
Lichfield (GBR)										x	x	x	
Bonyhad (HUN)										x	x	x	
Murska Sobota (SLO)												x	x
Lanzarote (ESP)													x
New Forrest (GBR)													x
Leon (MEX)													x
Neftenbach (SUI)													x
Florida (USA)													x

Note.—Lower case x's indicate which years the races have occurred. USA = United States of America, ECU = Ecuador, LTU = Lithuania, NED = Netherlands, MEX = Mexico, CAN = Canada, FRA = France, AUT = Austria, GER = Germany, UAE = United Arab Emirates, GBR = Great Britain, HUN = Hungary, SLO = Slovenia, ESP = Spain, SUI = Switzerland.

Statistical Analysis

To increase the reliability of data analyses, each set of data was tested for normal distribution as well as for homogeneity of variances before any other statistical analysis. The test for a normal distribution was performed using a D'Agostino-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 statistically significant changes in performances and sex differences over time, linear regressions were used. To find differences between two groups, a Student's *t* test was used when the data was normally distributed and a Mann-Whitney test was used otherwise. To find interactions between years and distance in sex differences, a two-way analysis of variance (ANOVA; time \times distance) with subsequent Bonferroni *post hoc* analysis was performed. Some of the competitors participated for several years and were able to finish several times within the top three. To account for potential clustering for repeated athletes, we performed multi-level hierarchical regression analyses accounting for repeated measurements in athletes. Statistical analyses were performed using SPSS Version 19 (IBM SPSS, Chicago, IL, USA) and GraphPad Prism (Version 5, GraphPad Software, La Jolla, CA, USA). Significance was accepted at $p < .05$ (two-sided for *t* tests).

RESULTS

Changes in Overall Race Time and Split Times Across Years

In Ironman Hawaii, men improved overall race times from 502 min. ($SD = 5$) to 488 min. ($SD = 4$), 1.9% ($r = .39$, $p = .02$) and women improved from 560 min. ($SD = 5$) to 539 min. ($SD = 4$), 3.8% ($r = .31$, $p < .05$). In swimming, neither women (58 min., $SD = 3$) nor men (50 min., $SD = 1$) showed changes over time ($p > .05$). In cycling, men decreased split times from 279 min. ($SD = 1$) to 262 min. ($SD = 3$), 6.1% ($r = .45$, $p < .01$). For women, the cycling split times remained unchanged at 306 min. ($SD = 5$, $r = .23$, $p > .05$). In running, men improved split times from 164 min. ($SD = 3$) to 160 min. ($SD = 2$) by 1.1% ($r = .14$, $p < .01$) and women from 182 min. ($SD = 8$) to 173 min. ($SD = 1$, $r = .37$, $p < .01$).

In the Double Iron ultra-triathlons, overall race times remained unchanged in men ($r = .18$) at 1,296 min. ($SD = 32$) and in women ($r = .08$) at 1,666 min. ($SD = 90$, $p > .05$). In swimming, the split times remained unchanged for men ($r = .17$) at 104 min. ($SD = 5$) and at 137 min. ($SD = 15$) for women ($r = .28$, $p > .05$). For cycling, split times remained unchanged for men ($r = .12$) at 658 min. ($SD = 19$) and at 841 min. ($SD = 77$) for women ($r = .01$, $p > .05$). In running, the split times remained unchanged for men ($r = .23$) at 463 min. ($SD = 29$) and for women ($r = .05$) at 636 min. ($SD = 48$, $p > .05$).

Sex Difference in Overall Race Times and Split Times

For overall race times, the sex difference remained unchanged in Ironman Hawaii ($r = .01, p > .05$) and in Double Iron ultra-triathlons ($r = .25, p > .05$). The sex difference for overall race times was 17.4% higher in Double Iron ultra-triathlons with 28.4% ($SD = 4.0$) for ultra-triathletes compared to 11.0% ($SD = 0.7$) for Ironman Hawaii triathletes ($p < .05$). For swimming, the sex difference remained unchanged in Ironman Hawaii ($r = .05, p > .05$) and in Double Iron ultra-triathlons ($r = .08, p > .05$). The sex difference was 25.7% higher in Double Iron ultra-triathletes with 31.2% ($SD = 11.4$) compared to 5.5% ($SD = 1.8$) for Ironman Hawaii triathletes ($p < .05$). For cycling, the sex difference remained unchanged in Ironman Hawaii ($r = .01, p > .05$) and in Double Iron ultra-triathlons ($r = .11, p > .05$). The sex difference was 15.3% higher in Double Iron ultra-triathlons with 27.8% ($SD = 11.4$) for ultra-triathletes compared to 12.5% ($SD = 1.4$) for Ironman Hawaii triathletes ($p < .05$). For running, the sex difference remained unchanged in Ironman Hawaii ($r = .14, p > .05$) and in the Double Iron ultra-triathlons ($r = .18, p > .05$). The sex difference was 24.6% higher in Double Iron ultra-triathletes with 44.5% ($SD = 16.2$) compared to 19.9% ($SD = 7.5$) for Ironman Hawaii triathletes ($p < .05$).

For the top three athletes, there was a significant distance \times years interaction term for the sex difference in overall race time ($F_{12,51} = 12.09, p < .0001$), swimming ($F_{1,52} = 3.2, p = .002$), and running ($F_{12,51} = 5.8, p < .0001$), but not for cycling ($F_{12,51} = 1.6, p > .05$). For overall race times, distance accounted for 57% of the total variance ($F_{1,51} = 431.0, p < .0001$) and years for 17% ($F_{12,51} = 10.7, p < .0001$). For swimming, distance accounted for 45.2% of the total variance ($F_{1,52} = 104.7, p < .0001$) and years for 15.6% ($F_{12,52} = 3.0, p = .0029$). For running, distance accounted for 23.4% of the total variance ($F_{1,51} = 57.5, p < .0001$) and years for 27.7% ($F_{12,51} = 5.7, p < .0001$).

For overall race times, the sex difference for the annual winners remained unchanged over time ($p > .05$) in Ironman Hawaii ($r = .09$) and Double Iron ultra-triathlons ($r = .28$). The sex difference for overall race time (Panel A) was 14.4% higher in Double Iron ultra-triathlons with 25.2% ($SD = 10.4$) for ultra-triathletes compared to 10.8% ($SD = 2.3$) for Ironman Hawaii triathletes ($p < .05$). For swimming, the sex difference for the annual winners remained unchanged in Ironman Hawaii ($r = .13$) and Double Iron ultra-triathlons ($r = .15$) over time ($p > .05$). The sex difference was 17.3% higher in Double Iron ultra-triathletes with 22.5% ($SD = 10.0$) compared to 5.2% ($SD = 4.6$) for Ironman Hawaii triathletes ($p < .05$). For cycling, the sex difference for the annual winners remained unchanged in Ironman Hawaii ($r = .29$) and Double Iron ultra-triathlon ($r = .01$) over time ($p > .05$). The sex difference was 11.7% higher in Double Iron

TABLE 3
MEAN ABSOLUTE TIMES AND SEX DIFFERENCE FOR TOP THREE ATHLETES FROM 1999–2011 ($N = 36$)

	Swim Split Time (min.)		Bike Split Time (min.)		Run Split Time (min.)		Overall Race Time (min.)	
	M	SD	M	SD	M	SD	M	SD
Ironman Hawaii								
Women	58.2*	1.9	309.8*	11.3	186.8*	4.8	559.0*	14.5
Men	52.1	1.0	277.1	8.4	170.7	3.7	503.4	10.3
Sex difference (%)	12.0 [†]	2.9	11.9 [†]	2.6	9.7 [†]	1.9	11.0 [†]	1.8
Double Iron Ultra-triathlon								
Women	147.9*	13.8	855.3*	62.2	661.3*	76.3	1,670*	114.4
Men	123.5	11.9	674.5	26.9	495.7	43.44	1,297	56.9
Sex difference (%)	26.2	14.2	27.0	7.6	35.9	13.4	28.9	9.3

Note.—*Female split times are statistically significantly different from male split times ($p < .05$). [†]Values in Ironman sex differences statistically significantly differ from Double Iron ultra-triathlon sex differences ($p < .05$).

ultra-triathlons with 23.7% ($SD = 9.7$) for ultra-triathletes compared to 12.0% ($SD = 3.9$) for Ironman Hawaii triathletes ($p < .05$). For running, the sex difference for the annual winners decreased in Ironman Hawaii ($r = .46$, $p = .01$) but increased in Double Iron ultra-triathlons ($r = .39$, $p = .02$) over time. In 2011, the sex difference was 5.3% higher in Double Iron ultra-triathletes with 32.8% ($SD = 15.6$) compared to 27.5% ($SD = 13.0$) for Ironman Hawaii triathletes ($p < .05$).

The mean in overall race times and split times of the top three overall finishers and the annual winners with the corresponding sex differences for Ironman Hawaii and Double Iron ultra-triathlons are presented in Tables 3 and 4, respectively. For the top three finishers (Table 3), women were significantly slower than men for all split times and overall race times. For winners in Ironman Hawaii (Table 4), men were faster than women for overall race times and split times. For Double Iron ultra-triathletes, women and men had similar times in swimming.

Results of the multi-level hierarchical regression analyses are presented in Table 5. Women were slower in both Ironman Hawaii and Double Iron ultra-triathlons. Race year showed an influence on race time in Ironman Hawaii, but not in Double Iron ultra-triathlon.

DISCUSSION

This study was intended to compare the sex differences in swimming, cycling, running, and overall race times between elite Ironman Hawaii triathletes in the Ironman World Championship, Ironman Hawaii, and Double Iron ultra-triathletes. It was hypothesized that the sex difference

TABLE 4
MEAN ABSOLUTE TIMES AND SEX DIFFERENCES FOR WINNERS FROM 1999–2011 ($N = 12$)

	Swim Split Time (min.)		Bike Split Time (min.)		Run Split Time (min.)		Overall Race Time (min.)	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Ironman Hawaii								
Women	58.6*	2.9	305.5*	11.1	168.2*	5.1	556.7*	7.4
Men	51.9	1.1	275.7	8.7	184.8	8.1	499.2	8.5
Sex difference (%)	13.0 [†]	6.7	10.9 [†]	4.5	9.9 [†]	3.7	10.8 [†]	2.3
Double Iron Ultra-triathlon								
Women	142.8	22.6	840.4*	71.9	606.1*	71.6	1,594*	115.8
Men	129.2	13.5	659.8	38.5	472.1	49.1	1,264	72.2
Sex difference (%)	20.2	13.6	27.4	8.2	32.4	15.7	26.3	9.0

Note. — *Split times in women were statistically significantly different from split times in men ($p < .05$). [†]Values in Ironman sex differences statistically significantly different from sex differences in Double Iron ultra-triathlon ($p < .05$).

TABLE 5
RESULTS OF THE MULTI-LEVEL HIERARCHICAL REGRESSION ANALYSES SHOWING THE EFFECTS OF SEX AND RACE YEAR ON OVERALL RACE TIME CONTROLLING FOR REPEATED MEASUREMENTS IN ATHLETES

Effect	β	SE	<i>p</i>	95% Confidence Interval	
Ironman Hawaii					
Sex	-56.36	2.46	<.001	-61.19	-51.53
Race year	-1.96	0.32	<.001	-2.60	-1.31
Double Iron Ultra-triathlon					
Sex	-388.01	32.42	<.001	-451.56	-324.46
Race year	1.73	3.62	.63	-5.37	8.84

Note. — β = standardized regression coefficient, SE = Standard Error.

in performance would be higher in the overall performance for Double Iron ultra-triathlon distance but lower for the swim split compared to the Ironman Hawaii triathlon. However, the opposite was found. The sex difference in performance between the annual top three Ironman Hawaii and Double Iron ultra-triathletes was 17.4% higher in Double Iron ultra-triathlon for overall race time and 25.7% higher in Double Iron ultra-triathletes for the swimming split. A lower sex difference between the distances was found for cycling (15.3%), but not for running (24.6%).

Regarding the performance across time in the single Ironman distance in Ironman Hawaii, both women and men improved overall race time and in the running split and men also improved in the cycling split. In the

Double Iron ultra-triathlon, overall race times and split times remained unchanged in both women and men's races over time. An interesting finding was that the sex difference in performance remained unchanged over time for both Ironman Hawaii triathletes and Double Iron ultra-triathletes. The sex difference in Ironman Hawaii for the top three athletes between 1999 and 2011 was 11.0% ($SD = 0.7$) over time, with a smaller sex difference in swimming at 5.5% ($SD = 1.8$) compared to cycling at 12.5% ($SD = 1.4$) and running at 19.9% ($SD = 7.5$). For the top three Double Iron ultra-triathletes, the sex difference over time in overall performance was 17.4% higher compared to the sex difference in Ironman Hawaii⁴. Also for swimming (+25.7%), cycling (+15.3%), and running (+24.6%), the sex difference was higher in Double Iron ultra-triathletes as compared to Ironman Hawaii triathletes.

The sex differences in performance between Ironman Hawaii and Double Iron ultra-triathlon were similar for overall race time (17.4%) and the cycling split time (15.3%), but higher for swimming (25.7%) and running (24.6%). For the longer triathlon distance, swimming and running seemed to be the crucial disciplines for women. These differences might be explained by the sex differences within the disciplines, the history of the triathlete, and the equipment used. The sex difference in performance between Ironman Hawaii and Double Iron ultra-triathlon distance might be explained by the single disciplines. Recent studies suggested that women were able to achieve similar swimming times for longer distances since similar performances in female and male ultra-swimmers in a 12-hour ultra-swim (Eichenberger, Knechtle, Knechtle, Rüst, Rosemann, & Lepers, 2012a) and in the Channel Crossing (Eichenberger, Knechtle, Knechtle, Rüst, Rosemann, & Lepers, 2012b) have been reported. However, when the annual fastest swimmers in the Channel Crossing were considered, the top three male swimmers in the English Channel were approximately 12% faster than females over the last 36 years (Fischer, Knechtle, Rüst, & Rosemann, 2012). Also in an open-water ultra-swim in a lake, the sex difference remained unchanged at ~11.5% (Eichenberger, Knechtle, Knechtle, Rüst, Rosemann, Lepers, & Senn, 2012c). For cycling, the sex difference in performance was ~11% when different cycling distances were investigated (Schumacher, Mueller, & Keul, 2001). In ultra-running, however, the sex difference in performance was ~20% in 161 km ultra-marathons (Hoffman, 2010).

The increase in sex difference might also be explained with the increasing length of the single disciplines. A recent study investigated the change in sex difference in performance for Triple Iron ultra-triath-

⁴There were no repeat top-three athletes of either sex, so the results are not biased in any way by individuals' performances.

letes between 1988 and 2011 for the annual fastest athletes (Rüst, Knechtle, Knechtle, Rosemann, & Lepers, 2012). For the Triple Iron distance, women were able to narrow the gap in swimming, but not in cycling and running. Men improved their overall race time, whereas women became slower across years. The sex difference in overall race time increased from 10% to 42% ($r = .63, p < .01$). In swimming, neither top men nor top women improved ($p > .05$) but the sex difference decreased from 35% in 1992 to 28% in 2011 ($p < .05$). Top men became faster in cycling, whereas top women became slower across years. The sex difference increased from 12% to 40% ($p < .05$). For running, top men showed no change in performance across years whereas top women became slower. The gender difference increased from 10% in 1992 to 64% in 2011 ($p < .05$). An actual study on sex-related participation and performance trends in ultra-mountain biking showed contrary results (Gloor, Knechtle, Knechtle, Rüst, Haupt, Rosemann, *et al.*, 2013). In the Swiss Bike Masters between 1994 and 2012, the participation in men decreased while the participation in women remained low at ~2.4%. Performances of the annual fastest women improved while performances of the annual fastest men remained unchanged. Top racers at world class level may start in shorter races and avoid these races that debilitate them for Olympic Games and World Championships.

Another explanation for the high sex difference in swimming performance between Ironman Hawaii and Double Iron ultra-triathlon could be the fact that wetsuits are prohibited in Ironman Hawaii but allowed in the Double Iron ultra-triathlons. Wearing a wetsuit leads to a significantly lower swimming cadence (-14%), a significantly lower heart rate (-11%), and a significantly lower lactate values (-47%) compared to swimming without a wetsuit (Delextrat, Bernard, Hausswirth, Vercruyssen, & Brisswalter, 2003). Additionally, cycling efficiency was significantly higher (+12.1%) after swimming with a wetsuit compared to swimming without a wetsuit (Delextrat, *et al.*, 2003). In an Ironman triathlon where athletes can wear a wetsuit in the swim, athletes without background as a swimmer may profit from wearing a wetsuit and achieve faster swim times. However, in Ironman Hawaii, athletes with swimming backgrounds may swim fast in open water independently of whether they wear a wetsuit or not. It has been shown that wearing a wet suit improves swim performance more in inefficient swimmers with low buoyancy when swimming at low speeds (Chatard, Senegas, Selles, Drenot, & Geysant, 1995).

A further explanation for the sex difference in swimming and running performance between Ironman Hawaii and Double Iron ultra-triathlon could be the history of the athlete. It has been reported that many triathletes have been competitive swimmers (O'Toole, & Douglas, 1995). For recreational Ironman triathletes competing in Ironman Lanzarote, how-

ever, 28% of the athletes had running backgrounds, 14% had been swimmers, and 13% cyclists (Gulbin & Gaffney, 1999). In ultra-triathlon, the cycling and the running split showed the strongest effect on overall race time. For male Triple Iron ultra-triathletes, a significant correlation ($p < .05$) was observed between total race time and both running time ($r = .87$) and cycling time ($r = .62$). In contrast, no correlation ($p > .05$) was shown between swim split times and overall race times (Knechtle, & Kohler, 2009). Most probably, triathletes competing in longer distances than the Ironman triathlon might prepare more specifically and have backgrounds as cyclists or runners. When training characteristics between Ironman and Triple Iron ultra-triathletes were compared, Triple Iron ultra-triathletes relied more on training volume in cycling and running, whereas speed in cycling training was related to race time in Ironman triathletes (Knechtle, Rüst, & Rosemann, 2011).

The multi-level hierarchical regression analyses showed that the inclusion of athletes finishing repeatedly within the top three had an influence on Double Iron ultra-triathlon race times, but not on Ironman Hawaii race times. The annual field in Ironman Hawaii with approximately 2,000 starters is considerably higher compared to the approximately annual 100 starters in Double Iron ultra-triathlons. The approximately 20 times larger field in Ironman Hawaii lowers the possibility for athletes to finish several times across years within the top three compared to the considerably smaller field in Double Iron ultra-triathletes where finishing within the top three several times across years seems more likely.

Limitations

This study is limited because potential predictor variables for an ultra-endurance performance were not measured. Weather would only potentially affect year-by-year comparisons. The drastically different participation numbers is a limitation. Although the top finisher and top three finishers were compared, smaller numbers of competing women (1/9 to 1/3 of men) suggests a deeper talent pool from which to draw in Double Iron ultra-triathlon competitions in particular. Race times from Double Iron ultra-triathlons were obtained from different races held in different locations. In contrast to Ironman Hawaii, held at the same site each year, the inclusion of different race sites in Double Iron ultra-triathlon might influence race times due to different topography. Split and race times in Ironman Hawaii were achieved using electronic timekeeping, while in the ultra-triathlons race times were measured by hand. While transition times were excluded in Ironman Hawaii, transition times were added to split times in cycling and running in ultra-triathlons as a general rule. In Ironman Hawaii wet suits are prohibited while wet suits are allowed in Double Iron ultra-triathlons. Additionally, disk wheels are prohibited on

bicycles in Ironman Hawaii, but allowed in Double Iron ultra-triathlons. These differences in equipment might also have had an influence on both split times and overall race times.

Conclusions

These findings suggest that the sex difference in performance is greater for Double Iron ultra-triathlon compared to a single Ironman triathlon distance for each split discipline and overall race time. The sex difference in performance for each discipline and overall race time has remained stable during the period between 1999 and 2011. It seems unlikely that women will be able to close the sex gap in ultra-triathlon performance in the near future. Further studies should examine the sex difference for other ultra-endurance events longer than a Double Iron ultra-triathlon such as Quintuple Iron, Deca Iron, and Double Deca Iron ultra-triathlon. The sex difference in swim performance might narrow, and the overall performance might extend, in longer triathlon distances. Future studies need to investigate the background of elite Ironman triathletes and ultra-triathletes whether they had backgrounds in swimming, cycling, or running.

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