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ABSTRACT

LEPERS, R. Analysis of Hawaii Ironman Performances in Elite Triathletes from 1981 to 2007. *Med. Sci. Sports Exerc.*, Vol. 40, No. 10, pp. 1828–1834, 2008. **Purpose:** To examine the improvement in swimming (3.8 km), cycling (180 km), running (42.2 km), and overall performances at the Hawaii Ironman Triathlon of elite males and females between 1981 and 2007. **Methods:** Trends across years, gender differences in performance times in the three disciplines, and overall winning times of the top 10 males and females were analyzed. **Results:** Overall performance time in the ironman decreased rapidly from 1981 but has remained stable since the late 1980s. From 1988 to 2007, linear regression analysis showed that change in swimming, cycling, running, and total performance for both males and females was less than 1.4% per decade, except for females' running time, which decreased by 3.8% per decade. Since 1988, the mean (SD) gender differences in time for swimming, cycling, running, and total event were 9.8% (2.9), 12.7% (2.0), 13.3% (3.1), and 12.6% (1.3), respectively. **Conclusions:** After an initial phase of rapid improvement of performances during the 1980s, there was a relative plateau, but at least in running and cycling, there were small improvements. Over the last two decades, gender difference in swimming remained stable while it slightly increased in cycling and decreased in running. The gender difference in ironman total performance is unlikely to change in the future. **Key Words:** GENDER, SEX DIFFERENCE, SWIMMING, CYCLING, RUNNING, TRIATHLON

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The Ironman triathlon (3.8-km swim, 180-km cycle, and 42-km run) is often considered one of the world's most challenging endurance events. Because the Ironman triathlon is a young sport compared with more traditional endurance events such as cycling or marathon running, the profile and professional status of the Ironman triathlon has increased and become more established in the last 10 yr (5). Indeed, the very first Ironman was performed in 1978 in Honolulu, Hawaii, and involved 12 males who finished the race with the winning time of 11 h 46 min. There were no female competitors in 1978. Only one female competed in 1979, with a finishing time of 12 h 55 min. In 1981, the course moved to Kailua-Kona, Hawaii, where it is still currently staged. In 2007, more than 1700 triathletes (≈27% females) competed in the Hawaii Ironman Triathlon. In the present paper, we focus our attention on this Ironman, which has become the Ironman World Championship, that is, the premier race in the field of long-distance triathlon.

Since the first Ironman, triathletes have continuously modified training methods, equipment, and nutrition strategies to improve performance (5,6,14,15,17). Consequently, total time has dramatically decreased. Over the last two decades, the winning time has been generally less than 8 h 30 min for males and 9 h 30 min for females. Course records are 8 h 4 min for male (in 1996) and 8 h 55 min for female (in 1992). Since Ironman was first performed, however, there has been no detailed analysis of overall performance times and each discipline (i.e., swimming, cycling, and running). It is not known whether performances in the last decades at the Ironman continue to show improvement for elite male and female triathletes.

The gender difference in endurance performance has received considerably more attention in recent decades, but most of studies have focused on running. Using linear regression lines, some scientists have predicted that the gender difference in endurance performance will eventually disappear (38). In contrast, recent studies using historical data for running have shown that the gender difference is no longer diminishing (7,29). Sparling et al. (29) showed that the gender difference in marathon running performance plateaued between 1980 and 1996, representing a difference of approximately 10% (8). In addition, the performance difference between males and females in both swimming and running sprint events has ceased to narrow and has actually widened since the 1990s (28).

Compared with females, males are stronger and have greater aerobic capacity. Even when maximal oxygen uptake is expressed relative to lean body mass, men still retain an aerobic performance advantage (10). Physiological and morphological gender differences such as percentage of body fat, oxygen carrying capacity, and running economy

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may be responsible for gender difference in running performance (22). Less information is available on gender differences in swimming and cycling on level terrain when the body does not act against gravity. Some data exist but for distances considerably shorter than those of the Ironman triathlon. For example, Tanaka and Seals (32) showed that the percent gender difference in swimming performance became progressively smaller with increasing distance from 50 m (~19%) to 1500 m (~11%). In track cycling, where females are weaker than males in terms of power/weight ratios, the performance gap between male and female cyclists appeared constant (~11%) and independent of the race distance from 200 to 1000 m (27).

Triathlon represents an interesting model to examine gender differences in performance because gender differences can be analyzed for three endurance disciplines (i.e., swimming, cycling, and running) separately and also collectively. The gender difference in triathlon, however, has received little attention and is poorly understood (37).

Accordingly, the aim of the present study was to investigate gender-related differences in swimming, cycling, running, and overall performance at the Ironman for the top 10 male and female finishers from each year between 1981 and 2007. Analysis of the top 10 male and female performance was preferred to analysis of winning performance so as to reduce variance between individuals across years.

METHODS

Approval for the project was obtained from the Burgundy University Committee on Human Research. Average swimming, cycling, running, and overall time performances of the top 10 males and females at the Ironman were analyzed from 1981 to 2007. Although the very first Ironman took place in 1978, data were analyzed from 1981 because it was the first year that the Ironman took place in Kailua-Kona, Hawaii, and that there were at least 10 males and 10 females finishing the race. Furthermore, two Ironman races occurred in 1982: one in February (1982a) and one in October (1982b). Since 1982, Ironman has been held each year in October only. The data set from this study was obtained from World Triathlon Corporation Web site, http://vnews.ironmanlive.com/mediacenter, and from a book compiled by the World Triathlon Corporation (3). Until 1998, bike times included both swim–cycle and cycle–run transition times. Bike splits from 1998 onward reflect the actual bike time only. Swimming, cycling, running, and total performance times from the Ironman were converted to minutes.

We focused our attention on the last 20 yr (from 1988 to 2007) and used linear regression lines ($y = ax + b$) to fit to each time series, treating each time as a single independent observation. We tested if the residuals (i.e., the difference between the observed value and the value predicted by the linear regression) of each linear regression were independent using the autocorrelation Durbin–Watson test. The magnitude of the gender difference was examined by calculating the percent difference for the average swimming, cycling, running, and total times of the top 10 males versus females and for the average power in swimming, cycling, and running of the top 10 males versus females. The time difference between the winner and the 10th placer was also analyzed and expressed as a percentage of the winner performance for both males and females over the 1988–2007 period.

Conversion of difference in time to difference in power. Percent differences in time do not equate to percent differences in power output due to nonlinear relationships between speed and power output from air or water resistance (13). We therefore estimated the percent difference in power output between the males and the females for each discipline according to Stefani (30). Briefly, for swimming, the mechanical power (P) depends on the third power of velocity (V) (34):

$$P = KV^3,$$

where K is a constant depending on water density, drag area, and swimming efficiency.

Assuming that the drag coefficient ratio between male (m) and female (f) is about 0.84 (34) and the mass ratio between male and female triathletes is about 0.79 (25), we found, according to the model proposed by Stefani (30), that the power ratio between male and female was

$$\text{Swimming}: P_f/P_m = 0.91(V_f/V_m)^3. \quad [1]$$

Similarly for cycling, the mechanical power depends also on the third power of velocity (12). Assuming level terrain, no wind, and that contribution of rolling resistance to total power demand is negligible and using the drag parameters estimated by Heil (12) in competitive cyclists, we found that the power ratio between male and female was

$$\text{Cycling}: P_f/P_m = 0.93(V_f/V_m)^3. \quad [2]$$

For running, the mechanical power depends on the velocity and on the body mass (M) (30). The power ratio between males and females for running is

$$\text{Running}: P_f/P_m = (M_f/M_m)(V_f/V_m) \quad [3]$$
$$P_f/P_m = 0.79(V_f/V_m).$$

Finally, in the three disciplines, the percent difference in power between female and male (%DP) was calculated as follows:

$$\%\ \text{DP} = 100(1 - P_f/P_m).$$

RESULTS

Figure 1 shows the historical performance trends of the top 10 males and females between 1981 and 2007. The values of the Durbin–Watson statistic did not reach thresholds that are considered indicative of concern about substantial

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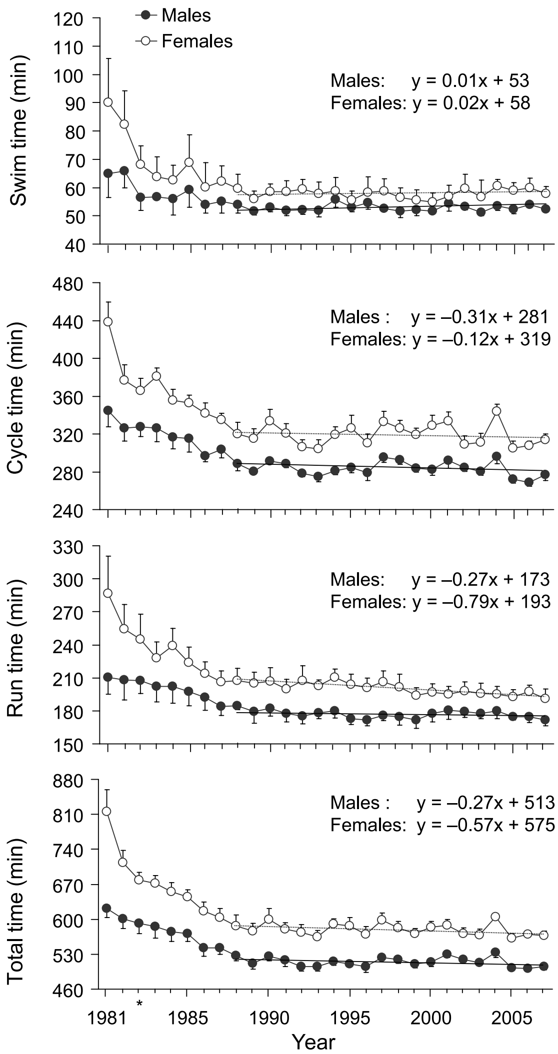

FIGURE 1—Swimming, cycling, running, and total performance times at the Hawaii Ironman Triathlon for the top 10 males and females from 1981 to 2007. Values are mean ± SD. *Two races took place in 1982 (February and October). Regression lines are presented from 1988 to 2007 in bold line for male and in dotted line for females. The equations are for the year 2008 as 0, so the intercept is the time in the year 2008. The slope of each equation indicates the change in time (min) performance per year since 1988.

autocorrelation, suggesting that the residuals were independent. For the three disciplines and for both sexes, time performances decreased during the 1980s and tended to stabilize over the last two decades. Time performances in cycling were apparently more variable compared with swimming and running performances. Regression lines are presented from 1988 to 2007 for the three disciplines and total times for both sexes. The slopes of the regression lines demonstrate that swimming, cycling, and total performances did not really change during the last two decades for both males and females. The changes in swimming, cycling, and total performances ranged from −1.1% to 0.02% per decade. For running, change in performance was −1.4% per decade for males. Interestingly, females improved their running time by 7.9 min per decade (i.e., 3.8% per decade) since 1988. The difference between the observed values and the predicted values in running time for females was between −3.1% and 4.0% over the last 20 yr. In 2007, for example, this difference was 2.9 min, that is, 1.5% (real time = 190.9 min; predicted time = 193.8 min). The 2008 predicted time values for three disciplines and total event correspond to the intercepts of each equation shown in Figure 1.

Figure 2 shows the change in gender difference in time for swimming, cycling, running, and total event between 1988 and 2007. Over this period, the mean (SD) gender difference in time for swimming, cycling, running, and total event were 9.8% (2.9), 12.7% (2.0), 13.3% (3.1), and 12.6% (1.3), respectively. The mean (SD) gender difference

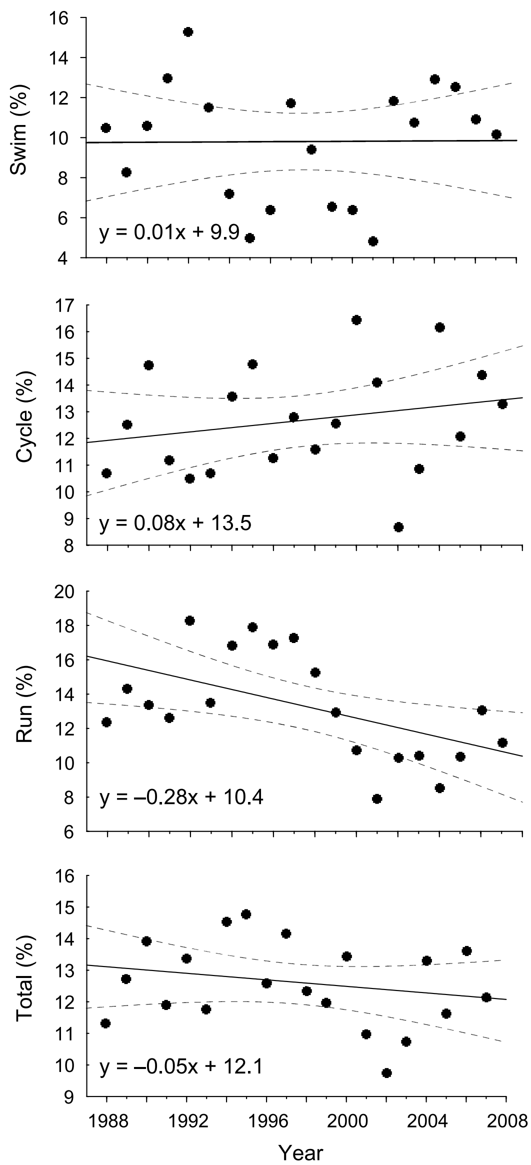

FIGURE 2—Gender differences in time for swimming, cycling, running, and total times from 1988 to 2007. The lenticular curves represent the 95% CI for the predicted mean value. The equations are for the year 2008 as 0, so the intercept is the time in the year 2008. The slope of each equation indicates the change in gender difference (%) per year since 1988.

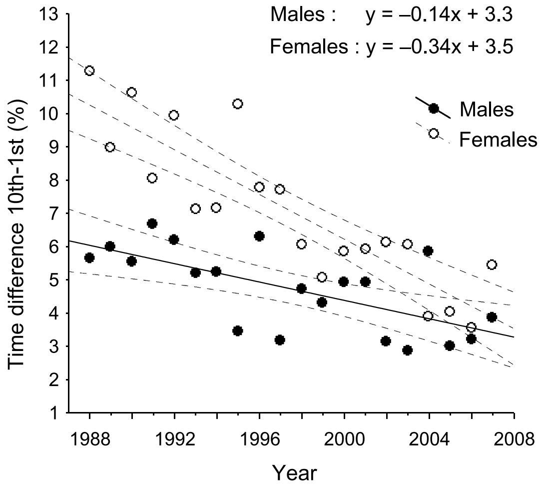

FIGURE 3—Time difference between the winner and the 10th placer expressed as a percentage of the winner time for both females and males over the 1988–2007 period. The lenticular curves represent the 95% CI for the predicted mean value. The equations are for the year 2008 as 0, so the intercept is the time in the year 2008. The slope of each equation indicates the change in time difference (%) between the winner and the 10th placer per year since 1988.

in power output for swimming, cycling, and running were 33.0% (6.5), 38.0% (4.3), and 31.5% (2.4), respectively. For running, when the gender difference in power output was expressed relatively to the body mass, the gender difference was reduced to 13.4 ± 3.0%.

Between 1988 and 2007, the gender difference remained stable and practically identical for swimming (+0.1% per decade), increased a little for cycling (+0.8% per decade), and decreased somewhat more for running (−2.8% per decade). The gender difference in time for total event also remained stable in the last two decades (−0.5% per decade). Gender differences in time for swimming, cycling, running, and total event predicted for 2008 are 9.9% (95% CI ±1.4%), 13.5% (±1.0%), 10.4% (±1.5%), and 12.1% (±0.6%), respectively. Gender difference in power output for swimming, cycling, and running predicted for 2008 are 33.4% (95% CI 3.1%), 39.8% (±2.1%), and 29.2% (±1.2%), respectively.

Figure 3 shows the difference in time between the 1st and the 10th placer for both males and females between 1988 and 2007. Overall, the difference between the winner and the 10th placer was 4.8 ± 1.3% (25 ± 7 min) for males and 7.1 ± 2.3% (42 ± 14 min) for females. During this period, the time difference between the 1st and the 10th placer decreased by −1.4% per decade for males and by −3.4% per decade for females, respectively. The time difference between the 1st and the 10th placer predicted for 2008 is 3.3% for males and 3.5% for female, respectively.

DISCUSSION

The objective of this study was to conduct a year-by-year analysis of performance during the Hawaii Ironman Triathlon over a 27-yr period between 1981 and 2007. The average of the top 10 performances provided a more accurate detection of performance change than winner time alone and formed a better index for comparing male and female performances. Overall performance time of elite male and female triathletes decreased rapidly between 1981 and the late 1980s and then plateaued thereafter for both males and females. During these last two decades, whereas swimming times for males and females and running times in males tended to stagnate, running times in females marginally improved. In contrast, cycling performance over time was more stochastic due presumably to the substantial impact of wind conditions. Between 1988 and 2007, the average gender difference in times was less for swimming than for cycling and running. However, predicted values for 2008 suggest that gender difference for swimming and running will be very similar in the future.

Methodological considerations. During the 1981–2007 period, the Ironman course underwent only a few modifications. The second transition area (bike to run) moved three times over this period, but the cycle and run courses changed very slightly and the main course remained consistent. Ironman performances, however, are influenced by weather conditions. Indeed, tide and chop in the water, water temperature, and wind direction and velocity, as well as air temperature and humidity, are all factors that could influence performance in the three individual disciplines and overall performance. Hawaii's climate is tropical in October (~30°C, ~70% humidity), albeit the triathletes liking hot and humid conditions are favored (19). Changes in weather conditions may limit the comparison of performances across the years, especially the cycling time. However, this factor would not especially influence the gender difference.

The present data should be interpreted with caution due to the potential confounding role of drug use on performance. According to the race director, Ironman has been conducting drug tests every year since 1990, and since 2004, the top three males and females were tested, along with a random selection of triathletes placing 4th to 10th. However, use of performance-enhancing drugs may still occur. For example, the 2004 female winner was disqualified for testing positive for the banned performance-enhancing drug erythropoietin. By analyzing the top 10 performances in Ironman instead of the winner time, the impact of any isolated cases of undetected illegal drug use is reduced.

Changes in performance from 1981 to 2007. A long-duration, moderate-intensity exercise in the heat, such as Ironman, creates unique physiological challenges, including energy balance and fluid and electrolyte homeostasis (16). Triathletes perform the cycle and run phases of an Ironman triathlon at an exercise intensity near their ventilatory threshold (17,18), and the total energy expenditure is between 8500 and 10,000 kcal (16), whereas sweat rates can reach up to 2 $L \cdot h^{-1}$ in the heat (19). Time performance in the three disciplines depends on the triathlete's ability to replace fluid and energy to control body temperature and to sustain endurance.

The average swimming time of the best triathletes decreased rapidly and then plateaued for both males and females. No technological advances took place in swimming because wetsuits have been forbidden at the Ironman due to warm water temperatures. In 2006, the elite male and female triathletes completed the swim stage of the Ironman, on average, ≈9–10% slower than the elite swimmer specialists for the same distance at the Waikiki Roughwater Swim race that took place in Honolulu, Hawaii (source: http://www.wrswim.com/; see Table 1). This difference could be explained by better technical efficiency and coordination in elite swimmers compared with elite triathletes (9,35). However, it should be noted that the top 10 triathlete finishers do not correspond generally to the top 10 after the swim, and the triathletes may not swim at maximal speeds because they have yet to cycle and run.

Through the 1980s, cycling performance improved in both males and females but remained stable thereafter. This finding appears surprising at first glance because in contrast to swimming and running, cycling technology has consistently improved since 1981 (11). Modifications of cycle equipment (e.g., light and aerodynamic bicycle and wheels) and body position (elbows on time trail handle bars) have helped to decrease time performance in cycling (14). Because the Ironman bike course is relatively flat, aerodynamic improvements were more important for cycling performance than bike weight reduction. However, the most important aerodynamic improvements in bicycles were already made by the end of the 1980s. The absence of significant improvements in cycling performance in Ironman over the last two decades can therefore be explained in part by the lack of significant recent aerodynamics improvements (2). For example, in 2004, the weather was very windy, explaining the greater cycling time for females compared with the preceding 20 yr. In contrast, optimal weather conditions in 2005 and 2006 likely explain the faster cycling performances in those years. Comparing cycling performance at the Ironman with other single bike event performance is not possible because there is no official cycling time trial greater than 60 km.

After a consistent decrease from 1981 to the late 1980s, running time for the Ironman has remained stable over the last 20 yr for men. The running marathon in the Ironman is performed, on average, 33% slower than the time elite running specialists complete the New York Marathon (see Table 1). This difference in running performance is much greater than that observed when comparing swim specialists and triathletes (9–10%). The much slower running velocity in marathon for triathletes compared with running specialists may be explained in part by the fact that the Ironman marathon is completed after a 3.8-km swim and a 180-km cycle, that is, after 5–6 h of exercise. Accumulated metabolic and neuromuscular fatigue following a 3.8-km swim and a 180-km cycle inevitably limits the performance on the subsequent marathon (1,21).

Gender difference. The number of females competing in the Ironman increased progressively from 20 in 1981 (6% of the participants) to more than 450 in 2007 (27% of the participants). By comparison, women represented 32% of the participants at the New York Marathon in 2007. In the last two decades, female triathletes have had the same opportunities to train and compete as males. Between 1981 and 2007, the average time difference between the winner and the 10th placer was smaller for the males than for the females, suggesting that the top 10 density was higher in males than in females. However, the last 4 yr was characterized by quite similar time differences between the winner and the 10th placer for male and female, suggesting that elite female performance density will probably become similar to what is seen among males in the future. Indeed, the time difference between the 1st and the 10th placer predicted for 2008 is 3.3% for males and 3.5% for females.

The magnitude of gender difference in power output associated with the given performance–time difference gives a more correct representation of underlying gender differences in physiological capacity (28). For example, the gender difference in power output is more consistent with the reported difference in lower- and upper-body muscle mass and maximal strength (36).

The average gender difference in swimming performance at the Ironman over the last 20 yr was ~10%, which is close to the gender difference between top 10 male and female swimmers at the Waikiki Roughwater Swim race (see Table 1). The gender difference in Ironman 3.8-km swimming is consistent with values found by Stefani (30) for different swimming events (varying from 50- to 400-m freestyle) but is lower than the gender difference found for 100-m freestyle by Seiler et al. (28). Tanaka and Seals (32) also found that swimming gender difference became progressively less with increasing distance between 50 and 1500 m. Two factors could explain the reduced gender

TABLE 1. Comparison of the top 10 Hawaii Ironman Triathlon times and the top 10 specialist elite race times for swimming and running among males and females in 2006. Comparison for cycling is not possible because there is no 180-km cycling official time trial.

	3.8-km Swimming Time (min)			42.2-km Running Time (min)		
	Hawaii Ironman Triathlon	Waikiki Roughwater Swim (Honolulu)	Difference (%)	Hawaii Ironman Triathlon	New York Marathon	Difference (%)
Male	54.0 ± 0.2	49.6 ± 2.1	8.9	174.4 ± 4.8	131.1 ± 1.1	33.0
Female	59.9 ± 3.4	54.4 ± 1.0	10.1	197.4 ± 6.0	148.9 ± 2.9	32.6
Difference (%)	10.9	9.7		13.2	13.3	

Values are mean ± SD.

difference for longer distances, especially for ocean swimming compared with sprint events in the pool. First, the denser salt water compared with less dense fresh water would differentially raise more of a female's body out of the water due to females having more body fat than males. This would reduce surface area in the water and total drag compared with swimming in fresh water and would give some specific advantage to females. Second, at lower velocity, a woman's drag coefficient drops somewhat compared with men in any similar water condition (34).

Over the last two decades, the swimming gender difference in time was, on average, smaller compared with cycling and running. The difference between swimming and the two other disciplines could be explained in part by the biological gender difference in relative body fatness (7–9% of body mass higher in females) (20,24). Indeed, greater body fat may represent a limit in weight-bearing activities such as running, but in contrast, it increases buoyancy in water. Moreover, it has been shown that the underwater torque, a measure of the tendency of the feet to sink, is lower for females than for males (26). In addition, the mechanical efficiency of swimming corrected to body surface area is greater for females than for males (26). Upper-body strength differences between males and females are actually larger compared with the lower body, so presumably, buoyancy issues may outweigh this difference. Theses differences could explain the reduced difference between males and females in swimming compared with running and cycling.

The gender difference in cycling at Ironman was ~13% in performance time and ~38% in power. Gender difference in absolute power output might be underestimated because total elevation is not accounted for in the cycling power model. Cycling performance comparison between genders in a single cycling event is difficult because cycling does not have an official time trial championship with a distance close to 180 km or shorter at the same distance for males and females. For example, at the 2007 world cycling time trial championships (http://www.uci.ch), the difference between the male champion's pace and the female's pace was 11.5%, but males rode 44.9 km and females 25.1 km. Schumacher et al. (27) reported that in track cycling, the gender gap difference between males and females appeared constant (~11%) for distances between 200 and 1000 m. The present data suggest that the difference in cycling between males and females is of similar magnitude for much longer time trial cycling. Greater muscle mass and aerobic capacity in males, even expressed relative to the lean body mass (10, 22), may represent an advantage during long-distance cycling, especially on a relative flat course such as Ironman cycling, where cycling approximates a non–weight-bearing sport. Indeed, it has been shown that absolute power output (which is greater for males than females) is associated with successful performance because the primary force inhibiting forward motion on a flat course is air resistance (23). In addition, a significant correlation has been also reported between 40-km time trial performance and body mass (31).

In running, the gender difference in absolute power output was 31.5%. However, if we consider the power relative to the body mass, the relative power ratio corresponds to the velocity ratio (Eq. 3), and therefore, the difference in power equals the performance–time difference (i.e., 13.4%). In swimming and cycling on level terrain (accounted for in our cycling power model), the concept of power relative to the body mass is not useful because the body mass is not working against gravity. Thus, the gender difference in running power is much lower compared with the difference in swimming and cycling.

Overall, in the last 20 yr, top 10 males ran the Ironman marathon, on average, ~13% faster than the top 10 females. Table 1 shows the gender difference in running at the Ironman marathon versus the New York Marathon. Similar gender differences in marathon running alone apart from the Ironman performance suggests that the swim and cycle portions of the triathlon do not exacerbate the gender difference in running. The physiological differences between male and female in running performance that are well identified in the literature (7,8,22) still persist in the marathon running of an Ironman. Morphological (body fatness) and physiological gender differences such as oxygen carrying capacity (hemoglobin concentration) and running economy may partly account for the gender difference in distance running performance (22). Some previous studies suggested that gender differences in running could diminish as distance increases past the marathon (e.g., 4). The rationale has been that females have greater fat stores or preferential fat metabolism and should be more fatigue resistant than males at the ultra distances (33).

Interestingly, linear regression analysis showed that from 1988 to 2007, elite female triathletes have improved their running time by 0.8 $\mathrm{min \cdot yr^{-1}}$ whereas it remained stable for the males. The reasons for such an improvement in females' running performance at the Ironman are not clear because both males and females had the opportunities to use new training methods (e.g., altitude training) and nutrition (15) these last two decades. Gender difference in time for Ironman marathon running predicted for 2008 (~10%) appears very similar to gender difference for 3.8-km swimming. If females continue to improve their running performance at the Ironman in the future, they could reduce the gender difference in the marathon and therefore in overall performance.

CONCLUSION

Since 1981, elite male and female triathletes have improved their performances at the Hawaii Ironman Triathlon. The initial improvements were obviously due to increases in participation and possibly also to improved training, nutrition, and experience-related pacing strategies.

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However, since the late 1980s, there was a relative plateau in performances, but, at least in running and cycling, there were small improvements. Overall, in the last 20 yr, gender difference remained practically identical for swimming, increased a little for cycling, and decreased for running. The smallest gender difference in time for swimming compared with cycling and running may be explained by differences in body fat, leg muscle mass, and aerobic capacity. The gender difference in Ironman total performance is unlikely to change in the future, owing to these gender differences.

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APPLIED SCIENCES

REFERENCES

1. Abbiss CR, Laursen PB. Models to explain fatigue during prolonged endurance cycling. *Sports Med*. 2005;35:865–98.
2. Abbiss CR, Quod MJ, Martin DT, et al. Dynamic pacing strategies during the cycle phase of an Ironman triathlon. *Med Sci Sports Exerc*. 2006;38(4):726–34.
3. Babbitt B. *25 Years of the Ironman Triathlon World Championship*. Oxford: Meyer & Meyer; 2004. p. 190–6.
4. Bam J, Noakes TD, Juritz J, Dennis SC. Could women outrun men in ultramarathon races? *Med Sci Sport Exerc*. 1997;29(2):244–7.
5. Bentley DJ, Millet GP, Vleck VE, MacNaughton LR. Specific aspects of contemporary triathlon. *Sports Med*. 2002;32:1–15.
6. Bentley DJ, Cox G, Green D, Laursen PB. Maximizing performance in triathlon: applied physiological and nutritional aspects of elite and non-elite competitions. *J Sci Med Sport*. 2008;11:407–16.
7. Cheuvront SN, Carter III R, DeRuisseau KC, Moffart RJ. Running performance differences between men and women. An update. *Sports Med*. 2005;35:1017–24.
8. Coast JR, Blevins JS, Wilson BA. Do gender difference in running performance disappear with distance. *Can J Appl Physiol*. 2004;29:139–45.
9. Costill DL, Kovaleski J, Porter D, Kirwan J, Fielding R, King D. Energy expenditure during front crawl swimming: predicting success in middle distance events. *Int J Sports Med*. 1985;6:226–70.
10. Drinkwater BL. Women and exercise: physiological aspects. *Exerc Sport Sci Rev*. 1984;12:21–51.
11. Faria EW, Parker DL, Faria IE. The science of cycling: factors affecting performance—part 2. *Sports Med*. 2005;35:313–37.
12. Heil DP. Body mass scaling of projected frontal area in competitive cyclist. *Eur J Appl Physiol*. 2001;85:358–66.
13. Hopkins WG, Schabort EJ, Hawley JA. Reliability of power in physical performance tests. *Sports Med*. 2001;31:211–34.
14. Jeukendrup AE, Martin J. Improving cycling performance: how should we spend our time and money. *Sports Med*. 2001;31:559–69.
15. Jeukendrup AE, Jentjens RL, Mosely L. Nutritional considerations in triathlon. *Sports Med*. 2005;35:163–81.
16. Laursen PB, Rhodes EC. Factors affecting performance in an ultraendurance triathlon. *Sports Med*. 2001;31:195–209.
17. Laursen PB, Rhodes EC, Langill RH, McKenzie DC, Taunton JE. Relationship of exercise test variables to cycling performance in an Ironman. *Eur J Appl Physiol*. 2002;87:433–40.
18. Laursen PB, Knez WL, Shing CM, Langill RH, Rhodes EC, Jenkins DG. Relationship between laboratory-measured variables and heart rate during an ultra-endurance triathlon. *J Sports Sci*. 2005;23:1111–20.
19. Laursen PB, Suriano R, Quod MJ, et al. Core temperature and hydration status during an Ironman triathlon. *Br J Sports Med*. 2006;40:320–5.
20. Lavoie JM, Montpetit RR. Applied physiology of swimming. *Sports Med*. 1986;3:165–89.
21. Lepers R, Maffiuletti N, Rochette L, Brugniaux J, Millet GY. Neuromuscular fatigue during a long duration cycling exercise. *J Appl Physiol*. 2002;92:1487–93.
22. Levis DA, Kamon E, Hodgson JL. Physiological differences between genders. Implications for sports conditioning. *Sports Med*. 1986;3:357–69.
23. Lucia A, Joyos H, Chicharro JL. Physiological response to professional road cycling: climbers vs time trialists. *Int J Sports Med*. 2000;21:505–12.
24. McLean SP, Hinrichs RN. Sex differences in the centre of buoyancy location of competitive swimmers. *J Sports Sci*. 1998;16:373–83.
25. O'Toole ML, Douglas PS, Hiller WDB. Applied physiology of a triathlon. *Sports Med*. 1989;8:201–25.
26. 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;43:475–79.
27. Schumacher YO, Mueller P, Keul J. Development of peak performance in track cycling. *J Sports Med Phys Fitness*. 2001;41:139–46.
28. Seiler S, D Koning JJ, Foster C. The fall and rise of the gender difference in elite anaerobic performance 1952–2006. *Med Sci Sports Exerc*. 2007;39(3):534–40.
29. Sparkling 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(12):1725–29.
30. Stefani RT. The relative power output and relative lean body mass of World and Olympic male and female champions with implications for gender equity. *J Sports Sci*. 2006;24:1329–39.
31. Swain DP. The influence of body mass in endurance bicycling. *Med Sci Sports Exerc*. 1994;26(1):58–63.
32. Tanaka H, Seals DR. Age and gender interactions in physiological functional capacity: insight from swimming performance. *J Appl Physiol*. 1984;82:846–51.
33. Tarnopolsky MA. Gender differences in substrate metabolism during endurance exercise. *Can J Appl Physiol*. 2000;25:312–27.
34. Toussaint HM, De Groot G, Savelberg HM, Vervoorn K, Hollander AP, Van Ingen Scheanu GJ. Active drag related to velocity in male and female swimmers. *J Biomech*. 1988;21:435–38.
35. Toussaint HM. Differences in propelling efficiency between competitive and triathlon swimmers. *Med Sci Sports Exerc*. 1990;22(3):409–15.
36. Vanderburgh PM, Kasuno M, Sharp M, Nindl B. Gender differences in muscular strength: an allometric model approach. *Biomed Sci Instrum*. 1997;33:100–5.
37. Vleck VE, Bentley DJ, Millet GP, Bürgi A. Pacing during an elite Olympic distance triathlon: comparison between male and female competitors. *J Sci Med Sport*. 2008;11:424–32.
38. Whipp BJ, Ward SA. Will women soon outrun men? [Letter]. *Nature*. 1992;335(6355):25.