Changes in Contributions of Swimming, Cycling, and Running Performances on Overall Triathlon Performance Over a 26-Year Period

Pedro Figueiredo,[1,2] **Elisa A. Marques,**[3,4] **and Romuald Lepers**[5]

[1]School of Physical Education, Federal University of Rio Grande do Sul, Porto Alegre, Brazil; [2]Department of Kinesiology, University of Maryland, College Park, Maryland, USA; [3]Laboratory of Epidemiology and Population Sciences, National Institute on Aging, National Institutes of Health, Bethesda, Maryland, USA; [4]Research Center in Sports Sciences, Health and Human Development (CIDESD), University Institute of Maia (ISMAI), Maia, Portugal; and [5]INSERM U1093, Faculty of Sport Sciences, University of Burgundy, Dijon, France

Abstract

Figueiredo, P, Marques, EA, and Lepers, R. Changes in contributions of swimming, cycling, and running performances on overall triathlon performance over a 26-year period. *J Strength Cond Res* 30(9): 2406–2415, 2016—This study examined the changes in the individual contribution of each discipline to the overall performance of Olympic and Ironman distance triathlons among men and women. Between 1989 and 2014, overall performances and their component disciplines (swimming, cycling and running) were analyzed from the top 50 overall male and female finishers. Regression analyses determined that for the Olympic distance, the split times in swimming and running decreased over the years ($r^2 = 0.25–0.43$, $p \leq 0.05$), whereas the cycling split and total time remained unchanged ($p > 0.05$), for both sexes. For the Ironman distance, the cycling and running splits and the total time decreased ($r^2 = 0.19–0.88$, $p \leq 0.05$), whereas swimming time remained stable, for both men and women. The average contribution of the swimming stage (~18%) was smaller than the cycling and running stages ($p \leq 0.05$), for both distances and both sexes. Running (~47%) and then cycling (~36%) had the greatest contribution to overall performance for the Olympic distance (~47%), whereas for the Ironman distance, cycling and running presented similar contributions (~40%, $p > 0.05$). Across the years, in the Olympic distance, swimming contribution significantly decreased for women and men ($r^2 = 0.51$ and 0.68, $p < 0.001$, respectively), whereas running increased for men ($r^2 = 0.33$, $p = 0.014$). In the Ironman distance, swimming and cycling contributions changed in an undulating fashion, being inverse between the two segments, for both sexes ($p < 0.01$), whereas running contribution decreased for men only ($r^2 = 0.61$, $p = 0.001$). These findings highlight that strategies to improve running performance should be the main focus on the preparation to compete in the Olympic distance; whereas, in the Ironman, both cycling and running are decisive and should be well developed.

Key Words Olympic triathlon, ironman triathlon, endurance

Introduction

Triathlon is a unique endurance sport that comprises a sequential swimming, swimming-to-cycling transition, cycling, cycling-to-running transition, and running over a variety of distances (4). Official triathlon competitions vary from shorter distance races such as "Olympic triathlons" (1.5-km swimming, 40-km cycling, and 10-km running) to longer distance "Ironman triathlons" (3.8-km swimming, 180-km cycling, and 42.2-km running) (4,21). The relative proportion of time spent in the swimming, cycling, and running sections varies with the distance of the event. Also, the distance profile, geographic and climatic factors, and specific tactical and technical elements impact this proportion. In the Olympic distance triathlon, elite triathletes spend approximately 15% of the total time in swimming, 55% in cycling, and 30% in running (16,18); whereas, in the Ironman distance, elite triathletes spend approximately 10% of the total time swimming, 55% cycling and 35% running (22).

Since the first triathlon competitions, triathletes have continuously modified training methods, equipment, and nutrition strategies to improve performance (2,4). Recent studies have shown that overall triathlon performances have improved over the past several years in both Olympic (10,32) and Ironman (21,31) distances. Etter et al. (10) showed that for Olympic distance triathlons between 2000 and 2010, the top five female total race times improved by ~0.8 minutes per year while the total race times remained stable for men. During the same period, for both sexes, swimming and running performance times remained stable, whereas cycling performance time decreased. Rust et al. (32) investigated changes in short distance triathlon performance

Address correspondence to Dr. Pedro Figueiredo, pedfig@me.com.

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of the world's best elite triathletes from 2009 to 2012, showing swimming and running split times remained unchanged, but cycling split times and overall race times increased significantly for both men and women.

For the Ironman distance, total performance improvement has also been observed at the Hawaiian Ironman triathlon from 1983 to 2012 for the top 10 male and female finishers (31). More precisely, split times decreased in swimming for men (−5%) but remained stable for women. Women improved their cycling and running performances by 16% and 17% and men by 14% and 11%, respectively (12).

In the Olympic distance triathlon, a positive association has been reported between the overall race time and the duration of the cycling or running section (11,33). A less pronounced or nonsignificant association has been shown for the swimming section in non-drafting triathlon (7,34). However, for the draft legal Olympic distance, swimming and running performances might be more important for overall performance than cycling (36,37). For the Ironman distance, cycling and running splits showed the greatest influence on overall race performance (17).

Nevertheless, the historical tendencies of the relation between segment contributions and overall triathlon performance have not been previously examined. These data could help to establish an empirical basis for developing individual race strategies for athletes competing in Olympic or Ironman distance triathlons.

Therefore, in the present study, we aimed to examine the changes in the individual contribution of each discipline to the Olympic (draft legal) and Ironman (nondraft legal) distance to overall performance from 1989 to 2014, for both men and women. The results of this study may impact race tactics of triathletes, as well as provide a framework for future changes in the potential development of each discipline such as a well-developed strength and conditioning training program.

Methods

Experimental Approach to the Problem

To assess the relative contribution of the 3 disciplines (swimming, cycling, and running) with overall performance in Olympic and Ironman distance triathlons at an elite level, individual discipline times (predictors) and overall time (outcome) were analyzed from 1989 to 2014. Results were obtained from (a) the International Triathlon Union (ITU) Olympic triathlon World Championships (after 2009, we considered only the "Grand Final" race due to the introduction of the World Triathlon Series) and (b) the Ironman triathlon World Championships in Hawaii. Data analysis was based on the list of results published by the ITU (www.triathlon.org) and the Ironman Hawaii triathlon (www.ironmanworldchampionship.com).

Subjects

We examined the top 50 men and women from Olympic and Ironman races taking place between 1989 and 2014 ($n = 26$

Table 1. Mean ± *SD* values of time, relative duration, and contribution to overall performance of swimming, cycling and running segments from 1989 to 2014, for both male and female top 50 finishers in Olympic and Ironman distances.

	Men			Women		
	Swimming	Cycling	Running	Swimming	Cycling	Running
Olympic						
Time (min)	19.19 ± 2.64	59.43 ± 4.75*	33.64 ± 1.52*†	21.09 ± 2.61	66.29 ± 5.45*	37.97 ± 2.71*†
Duration (%)	16.94 ± 1.81	52.47 ± 2.38*	29.76 ± 1.21*†	16.65 ± 1.68	52.33 ± 2.70*	30.01 ± 1.85*†
Contribution	0.15 ± 0.092	0.36 ± 0.107*	0.48 ± 0.103*†	0.18 ± 0.051	0.36 ± 0.087*	0.45 ± 0.079*†
Ironman						
Time (min)	55.90 ± 1.18	292.52 ± 9.34*	185.34 ± 4.36*†	62.66 ± 1.52	333.43 ± 15.14*	214.98 ± 9.69*†
Duration (%)	10.43 ± 0.30	54.53 ± 0.77*	34.56 ± 0.61*†	10.21 ± 0.43	54.26 ± 0.84*	35.99 ± 0.88*†
Contribution	0.18 ± 0.038	0.41 ± 0.041*	0.40 ± 0.049*	0.18 ± 0.030	0.40 ± 0.032*	0.42 ± 0.049*

*Different from swimming stage.
†Different from cycling stage; $p \leq 0.05$.

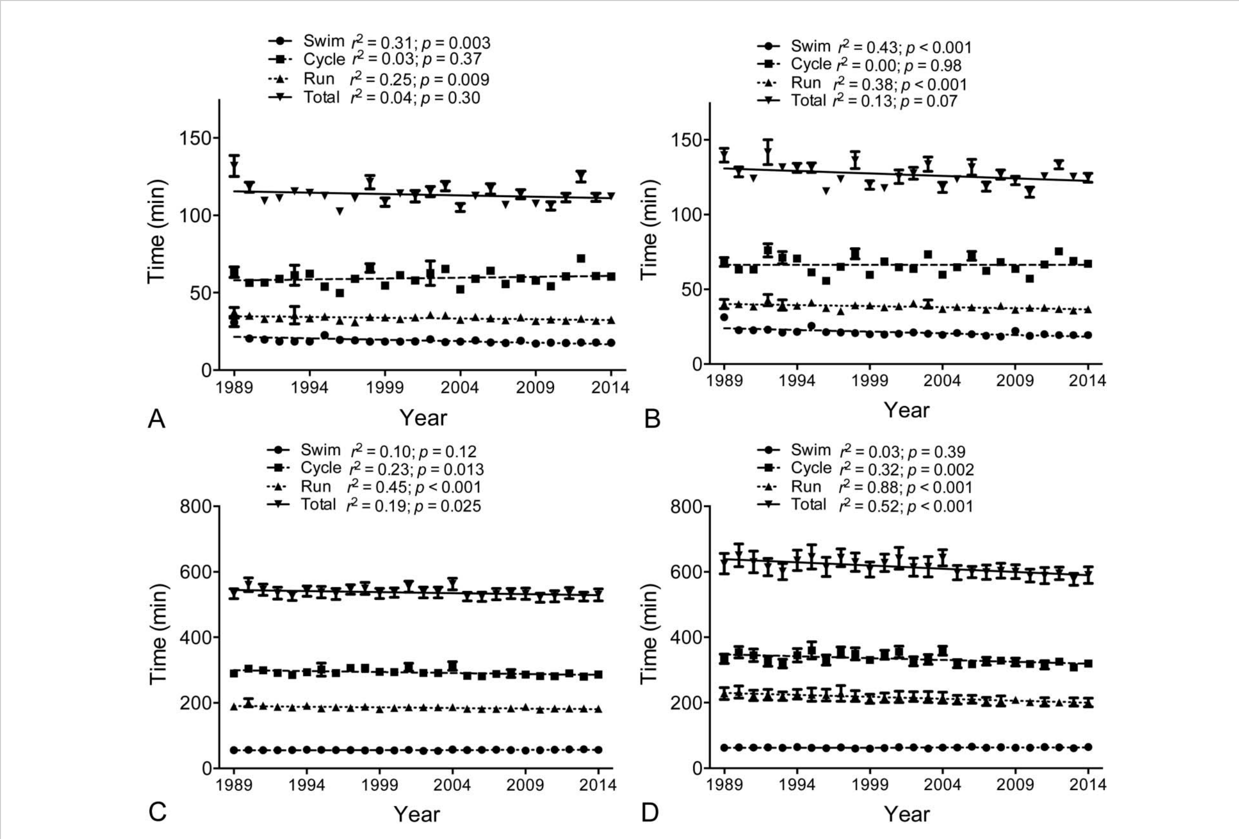

Figure 1. Change in splits and overall performance for top 50 finishers at the Olympic distance World Championships for both men (A) and women (B), and at the Ironman distance World Championships, for both men (C) and women (D), from 1989 to 2014.

years × 2 sexes × 50 triathletes = 2,600 for each distance). Owing to dropouts, disqualifications, and missing data, the sample size was reduced to the data of 2,440 triathletes (1,341 males and 1,099 females) in the Olympic distance. The study was approved by the institutional review board with a waiver of the requirement for informed consent given that the study involved the analysis of publicly available data.

Statistical Analyses

The data analyzed consisted of the athletes' overall time and times for each one of the 3 disciplines. All times were tested for normal distribution as well as for homogeneity of variances before statistical analyses.

Linear regressions were used to analyze changes in performance, and multiple linear regressions were used to identify the independent contribution of each discipline to the total performance. These analyses were carried out separately for each year (1989–2014), distance, and sex. To better express the relative importance of each predictor, the weights of the regression were converted to standardized regression coefficients (beta weights) and afterward transformed to proportions. One-way repeated measures ANOVA was used to compare the time, relative duration, and contributions of the different race segments. Bonferroni's post hoc analyses were used to test differences within the ANOVAs when appropriate. The effect sizes (ESs; Cohen's *d* (5)) and the 95% confidence intervals (CIs) for ES of significant differences detected by ANOVA were calculated among the groups. The trends of the contribution of the disciplines to the overall performance were computed using linear, polynomial (second and third degree), exponential, and power regression models. The mathematical model that presented the best adjustment and lowest standard error of the estimation was adopted. The level of statistical significance was set at $p \leq 0.05$.

Results

Table 1 shows the time performances, relative durations, and contributions of each split for the top 50 male and female finishers at the Olympic and Ironman distance during the 1989–2014 period. For both Olympic and Ironman distances, and both men and women, swimming presents a significantly ($p \leq 0.05$) very large to extremely large difference compared with the other disciplines, being the lowest contribution to the overall performance (ES [95% CI] = −2.15

[−2.18 to −2.11], −3.45 [−3.48 to −3.41], −2.57 [−2.59 to −2.54], −4.14 [−4.16 to −4.11], −5.93 [−5.95 to −5.92], −5.12 [−5.13 to −5.10], −7.23 [−7.25 to −7.22], and −6.02 [−6.04 to −6.01] compared with cycling and running, for men and women, in the Olympic and Ironman distances, respectively). For Olympic triathlon, the difference between running and swimming contributions was very large to extremely large (ES [95% CI] = 3.45 [3.41–3.48] and 4.14 [4.11–4.16] for men and women, respectively) and moderate to large between running and cycling (ES [95% CI] = 1.17 [1.13–1.21] and 1.10 [1.07–1.14], for men and women, respectively) to overall performance. For Ironman triathlon, similar contributions were observed for cycling and running, presenting small magnitudes of differences between them (ES [95% CI] = 0.23 [0.21 to 0.24] and −0.50 [−0.51 to −0.47] for men and women, respectively).

The changes in total race and split times from 1989 to 2014 are presented in Figure 1. For the Olympic distance, the split times in swimming (−0.19 and −0.22 minutes per year for men and women, respectively) and running (−0.10 and −0.14 minutes per year for men and women, respectively) decreased across the years ($p \le 0.05$), whereas the cycling split and total time remained unchanged for both sexes. For the Ironman distance, the cycling (−0.59 and −1.13 minutes per year for men and women, respectively) and running (−0.38 and −1.19 minutes per year for men and women, respectively) splits, and total time (−0.63 and −1.97 minutes per year for men and women, respectively) decreased along the years ($p \le 0.05$), whereas swimming time remained stable, for both sexes.

The changes in contribution of each segment to the overall performance for the Olympic distance triathlon are shown in Figure 2. Significant changes in contribution were observed for men in

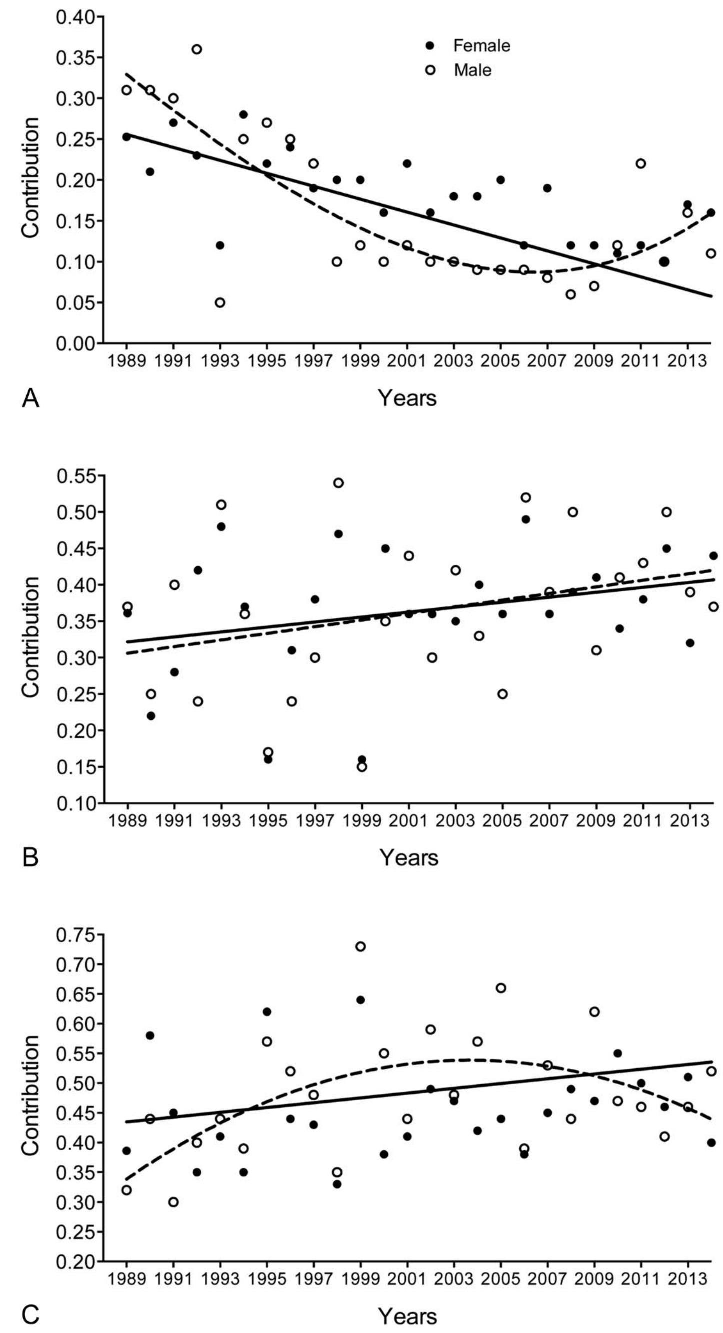

Figure 2. Change in contribution of each segment to the overall performance between 1989 and 2014 for the Olympic distance triathlon World Championships. The dotted (men) and full (women) lines represent the regressions that best fit the data, for the swimming segment (A), for men ($r^2 = 0.68$, $p < 0.001$, $y = -0.029x^2 + 0.001x + 0.367$) and women ($r^2 = 0.51$, $p < 0.001$, $y = -0.005x + 0.254$); for the cycling segment (B), for men ($r^2 = 0.11$, $p = 0.11$, $y = 0.005x + 0.302$) and women ($r^2 = 0.09$, $p = 0.13$, $y = 0.003x + 0.318$); and for the running segment (C), for men ($r^2 = 0.33$, $p = 0.014$, $y = 0.031x^2 - 0.001x + 0.29$) and women ($r^2 = 0.017$, $p = 0.53$, $y = 0.001x + 0.436$).

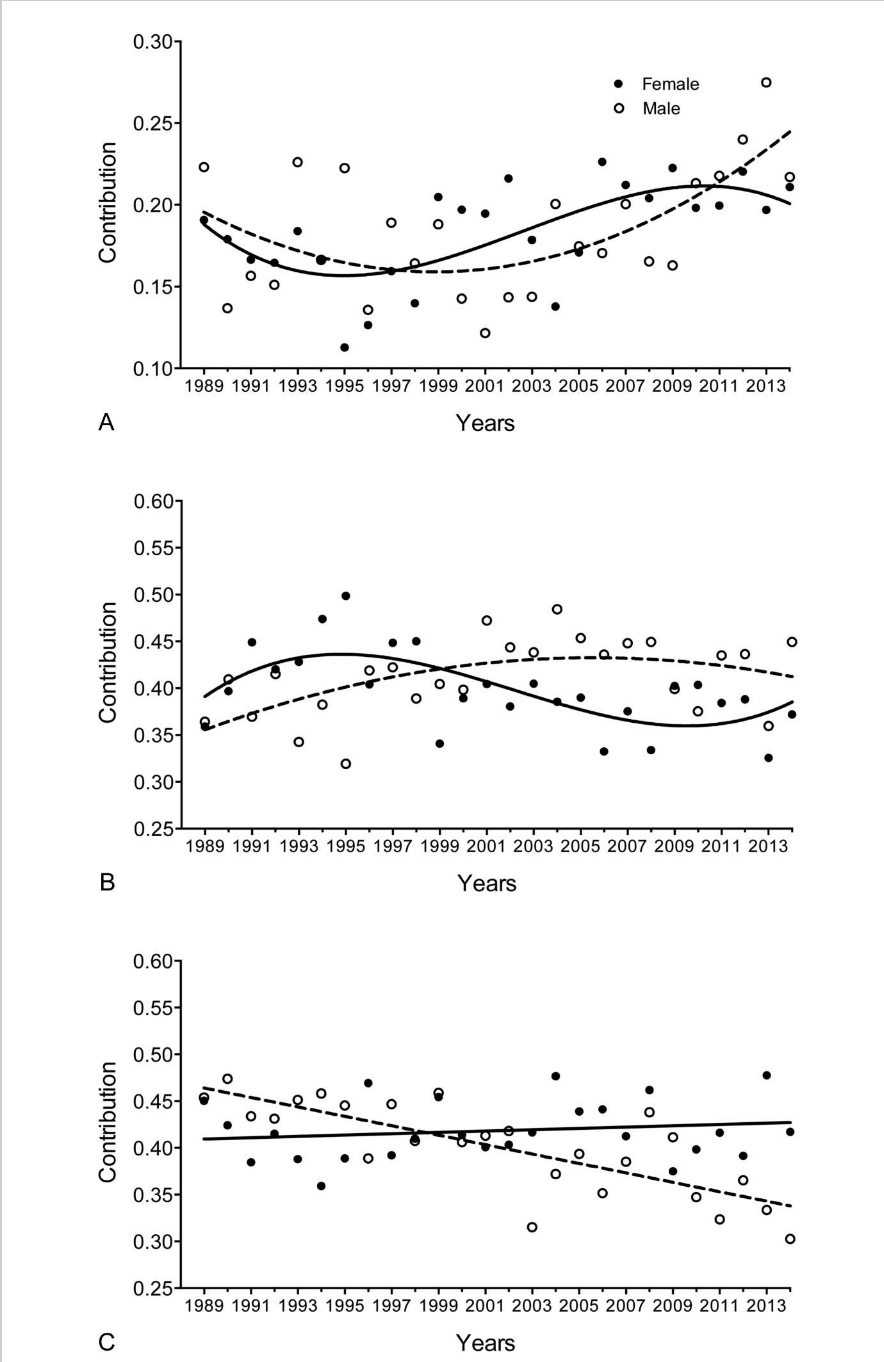

Figure 3. Change in contribution of each segment to the overall performance between 1989 and 2014 for the Ironman distance triathlon World Championships. The dotted (men) and full (women) lines represent the regressions that best fit the data, for the swimming segment (A), for men ($r^2 = 0.40$, $p = 0.003$, $y = -0.008x^2 + 0.203$) and women ($r^2 = 0.44$, $p = 0.004$, $y = -0.014x^3 + 0.001x^2 + 0.201$); for the cycling segment (B), for men ($r^2 = 0.31$, $p = 0.015$, $y = 0.010x^2 + 0.346$) and women ($r^2 = 0.42$, $p = 0.007$, $y = 0.021x^3 - 0.002x^2 + 0.372$); and for the running segment (C), for men ($r^2 = 0.61$, $p < 0.001$, $y = -0.005x + 0.469$) and women ($r^2 = 0.03$, $p = 0.41$, $y = 0.001x + 0.409$).

swimming and running, both with a quadratic fit, giving a U-shape to the development of those contributions ($p \leq 0.05$). For women, only the contribution of swimming significantly changed ($p < 0.001$) across the years with a linear fit.

The changes in contribution of each segment to the overall performance for the Ironman distance triathlon are shown in Figure 3. Significant changes in contribution of each segment were observed for all male stages ($p \leq 0.05$). Both swimming and cycling presented a quadratic fit, whereas the swimming stage was convex and the cycling concave. Running contribution decreased linearly ($p < 0.001$). For females, both swimming and cycling presented changes across the years with a polynomial of third degree ($p < 0.01$) as best fit and the changes between segments occurred inversely.

Discussion

This study aimed to examine the changes in the individual contribution of each segment to the overall performance of Olympic and Ironman triathlon distances over a 26-year period (1989–2014) for both male and female elite triathletes. The results show that the average contribution of the cycling and running stages is of large to very large magnitude compared with that of the swimming stage for both distances and sexes. Running had the greatest contribution to overall performance for the Olympic distance compared with swimming (very large to extremely large magnitude) and cycling (moderate to large magnitude); whereas, for the Ironman distance, cycling and running presented similar contributions. These results highlight the greater importance of running for the overall performance, with cycling being as important as running in the Ironman distance. Over the past 26 years, in the Olympic distance, among women, swimming contribution decreased, whereas cycling and running remained constant. For men, swimming contribution decreased and running contribution increased. For the Ironman distance, swimming and cycling changes were undulating over the period, being inverse between the two segments, for both sexes, with an increase in the last years. Running segment only changed in males, decreasing its contribution. Although the cycling and running segments are very important in the Ironman triathlon, it seems that increasing the swimming contribution can potentially be decisive and should be improved in the training process.

In the Olympic distance, a decrease in swimming and running performance of male and female triathletes during the 1989–2014 period was observed. But, these improvements did not reflect a better overall performance. Rust et al. (32) observed stability in both swimming and running stages and an increase in overall race times and cycling split times between 2009 and 2012 in the ITU World Triathlon Series. However, a smaller range and only recent years were analyzed, which seem to be the reasons for the differences between studies. This phenomenon was previously described in the Ironman Hawaii Triathlon (21), where a fast change in the early years occurs, followed by stagnation. In the cycling stage and overall performances, our results (stability) oppose to the increase found by Rust et al. (32). However, as stated by the authors, owing to several limitations, including different races each year, different environmental conditions, and potential differences in the course lengths, these changes may not be relevant. Also, in that study, only the top ten finishers were used in the analysis.

On a 10-year range (2000–2010 period), Etter et al. (10) analyzed the Olympic distance triathlon performed in Zürich. The results showed that the female elite triathletes improved both their cycling time and their overall race time, whereas the male elite triathletes showed marginal improvement in cycling. These results oppose our findings. However, Etter et al. (10) investigated a nondrafting cycling competition and analyzed only the top 5 triathletes, probably imposing a different pacing strategy compared with draft-legal cycling competitions (15). Also, during this 10-year period, cycling equipment went through several modifications and improvements (4). Altogether, different contributions of each split to the overall time are expected, as well as changes on performance across the years.

The decrease of overall Ironman race times for both sexes was associated with an improvement in cycling and running splits, as also observed by Gallmann et al. (12) and Rust et al. (31) for the top 10 male and female participants in Ironman Hawaii from 1983 to 2012. However, on a separate analysis of the first and last years, using the top 10 performances and competition, Lepers (21) found a rapid decrease between 1981 and the late 1980s on the overall performance time of elite male and female triathletes and afterward a plateau. From 1988 to 2007, swimming, cycling, and overall times for men and women and running times in men tended to stagnate; however, running times in women tended to improve (21). This was observed in the analysis of Gallmann et al. (12) and Rust et al. (31) when excluding the performances from the 1980s. Although our analysis started with the 1989 race results, this stagnation was only found for swimming. Cycling, running, and overall times decreased across the years, for men and women. These differences in the results are likely due to our larger sample size (top 50 performances), whereas the above-referred studies only analyzed the top 10 performances. Considering stagnation on the top 10 (male and female) performances, our results suggest a higher competitive density across the years, where the triathletes from 11th to 50th place approximate their performances to the top 10. The stability in swimming performance might be due to the fact that wetsuits are not allowed in Ironman Hawaii, thus no technological advances have been achieved in swimming (21).

Time performances and the relative durations of each discipline split were similar to previous studies, both for the Olympic distance (4,18) and the Ironman distance triathlons (22). We found that approximately 15% of the total time is spent in swimming, 55% in cycling, and 30% in running in the Olympic distance; whereas, in the Ironman distance approximately 10% of the total time is spent swimming, 55% in cycling, and 35% in running. For the Olympic distance triathlon, the greater contributions of cycling and running compared with swimming to overall performances, for both men and women, support the results of previous correlational studies, which found high associations between cycling and running, and the overall performance (7,33,34). However, analyzing correlations between segment time and overall triathlon time may not reflect performance dynamics of the segments in relation to the race leaders' and overall finishing positions, nor on how the different percentages of the total race time of each segment can impact those associations.

For Olympic distance triathlon, swimming performance dynamics seem to be of greater importance to the overall result in elite triathletes (for review see Ref. (28)). For example, Vleck et al. (37) found that the first 400–500 m of the swimming stage appears to be critical for the development of the race as a whole, where the position of the athletes at the end of this phase of the race seems to reflect the position at the end of the swimming stage. Also, in 90% of elite male and in 70% of elite female racers, the winner of the draft legal Olympic distance triathlons exited water in the first pack of racers (18). Although the contribution of swimming might be low, the strategic positioning in this segment may be critical to overall race performance.

Our results are in line with a previous study (11) showing a higher contribution of running (~47%) than cycling (~37%) to the overall performance. Using world championships data from 2003 to 2007, Fröhlich et al. (11) showed that running performance, as a single predictor of overall time, was the best predictor in almost every year. Vleck et al. (37) in a comparison between the top and bottom competitors in an ITU World Cup found that running performance largely reflected overall performance, where performance (rank and velocity) in the running stage was highly correlated with overall race result ($r = 0.86$ and -0.53, respectively). In the first 2 segments (swimming and cycling), no average velocity differences were observed between the top and bottom competitors. This might reflect a strategy of those triathletes who are better runners than their competitors to limit their energy expenditure during the swimming and cycling segments. In fact, the only segment that has to be maximal is running. Supporting this, Wu et al. (40) presented similar values of velocity and power for swimming and cycling, respectively, in sprint, Olympic and half-Ironman, however, with differences in the running segment. Performing the running segment as fast as possible may require a more even pace, as Le Meur et al. (19) observed in the best runners during the 10-km running of an Olympic distance triathlon. Despite changes in gradient, these runners demonstrated superior ability in limiting decrements in running speed during the later stages (19). This lower decrement might be responsible for the higher contribution of the running discipline to overall triathlon performance.

The physiological and biomechanical adaptations to cycle-run transition are well documented (for reviews see (4,24)), showing a negative influence of cycling over the running stage. Nevertheless, in the cycling stage, an inverse association between the speed in the final lap and position after this particular stage was previously demonstrated (37). Hence, as speed increased in the final lap, the finishing position at the end of the cycling stage improved, which can justify the higher and lower contributions compared with the swimming and running stages, respectively.

Also, the drafting in the cycling stage has influenced contribution results, making them lower than the running ones. Drafting was associated with a global reduction in energy expenditure, heart rate, and ventilation values (16). It allows better performance in the cycling stage but more importantly for the Olympic triathlon is the energy saving for the running stage, as triathletes ride in packs. In fact, the velocities during this stage are similar between the top 50% and bottom 50% athletes grouped by overall position at the end of the triathlon (37).

For Ironman, as in the Olympic distance, swimming contribution was lower compared to other disciplines for both sexes, which is in accordance with the data from Knechtle et al. (17) presenting a lower association between time spent on swimming and overall performance, than in cycling and running stages. The lower contribution of swimming should be expected because it is a highly strategic stage rather than a decisive one. Most studies investigating pacing during prolonged exercise in ambient temperatures have observed a fast start, followed by an even pace strategy in the middle of the event (30). A fast start during the beginning of a triathlon (i.e., swimming discipline) is required for several purposes, including to achieve a good drafting position behind the fastest swimmer during the early portions of the swimming discipline, to conserve energy throughout the remainder of the swim, to reduce the delaying effects of previous waves of swimmers, and to be better positioned for the beginning of the cycling stage (20,36,37). Also, swim drafting is allowed, which makes the performance less variable between triathletes in this stage. Cycling and running contributions were similar, which is in accordance with the associations presented previously (17), probably due to the nondrafting cycling, in opposition to the draft-legal Olympic distance. Also, there is evidence indicating that an even pacing, achieved by maintaining a constant velocity despite varying external conditions (i.e., wind and altitude), may be ideal during endurance events such as the triathlon (1). A similar change from the Olympic to the Ironman distance only in the cycling stage was previously observed (38). What may happen in the running change is that the performance is likely influenced by a reduction in muscle glycogen content (13,14), neuromuscular activity (27), and mental fatigue (23). Differences in performance between men and women have been reported (12,31), suggesting the use of distinct strategies coupled with the well-known sex differences in physiology, decision-making, or both. However, during long distance running, women were reported to slow less at the end (8). Taken together the existent evidence for a plausible difference between male and female performance, our results showed a similar running stage contribution for the final result for both sexes.

The observed changes across the years for the Olympic distance in swimming were quadratic for men and linear for women. These may be a reflection of both, the improvement in the swimming performance over the years and the decrease in performance variability, which also contributes to the average performance improvement and might explain the lower contribution of this segment. This trend is probably due to more and better training, improved diet plans (26), and to the continuous development of better wetsuits (25). Also, the introduction of the draft-legal cycling at the 1995 ITU World Championships might have changed the tactics used during swimming. Finishing the first segment with no pack has limited advantage because maintaining that isolated position will be harder without draft, and also the influence of the effort of swimming segment to cycling and overall performance is negative (3,29). Modifying this rule may have had a higher impact in the swimming segment in men than in women, as the cycling segment is a considerably stronger segment in men (36), thus explaining, at least in part, the differences in the best-fit regressions between sexes.

In Ironman, both male and female triathletes presented inverse changes in swimming and cycling stages, thus an increase in the swimming contribution would determine a decrease in cycling contribution, also linked to the transition swim-cycle. In the latter years, swimming stage showed a higher contribution, which might be consistent with an increase of swimming practice hours along the years, as weekly swimming hours were associated with better race time (17), although no mean performance improvement was observed. Also, this provides evidence that although with a low average contribution, swimming can impact the final results when the two most decisive segments (cycling and running) are very similar between competitors.

For both distances, swimming presented a higher variability in the contributions along the years, probably due to the influence of several race dynamics such as swimming in packs, drafting, the impact of the initial positioning in performance and energy saving, and being mass-start events. The use of wetsuits, in the Olympic distance, may also influence the contribution, particularly, the less-skilled swimmers (35). The wetsuits help shorting the draft distances between athletes, and weaker swimmers may exit the water closer to the lead swimmer.

In cycling, the contribution was stable across the analyzed years for both sexes, concomitant with the performance plateau observed in this split, despite the above-referred and discussed increases reported by Rust et al. (32). A large variation was observed around the mean contribution (Table 1) and regression line (Figure 2), which may reflect, for example, the course design, that especially during the cycling stage, varies between the ITU World Cup races. According to Vleck et al. (37), within the first Olympic qualification cycling (from 1997 to 2000), the majority of cycling courses, while being multiloop, were flat. However, the opposite trend in course profiles has taken place in the recent Olympic cycles. Although, training, equipment, and pace strategies are continuously improving, the latter might explain the stability of the cycling contribution. Also, the transition swim-cycle plays a crucial role in this stage. As described above, the use of wetsuit decreases the gross energy consumption during triathlon swimming (35) and may aid the less skilled swimmer to produce the power outputs required during the initial cycling phase to reach a good cycling pack position (36). In this study, we only examined the cycling stage time, and considering the distance of the stage, it provides the performance velocity and not the performance power. Power is a better indicator of the physiological demands imposed by the cycling stage (6,39), being also influenced by drafting (9,16). Therefore, performance velocity during the cycling stage may not reflect performance power.

In the Ironman distance, the increase in the contribution of the cycling stage in the early years might be due to some modifications in the aerodynamics of bicycles; however, for males, the contributions stabilized afterward. On the other hand, for females, we observed a decrease of cycling contribution along the years, except during the past 5 years, where this contribution is increasing. This result may be linked with the stable high contribution of the running stage, larger number of participants, and an increased interest for training plans for female triathletes in relation with an increased acceptance and the public interest of female sports participation over recent decades, mainly in cycling where a larger potential for development is observed (20,36). For Ironman races, the cycling stage presented lower contribution variability. This may be linked to the great distance that have to be covered in an Ironman, and with the effort to minimize the adverse effect of fatigue during the running stage, with a concomitant decrease in velocity (38).

Running contribution for the Olympic distance in women remained stable, whereas in men had a quadratic adjustment, reviling an increase in the first years and a decrease in the final years, despite the observed improvement in performance. The running stage of a triathlon is highly influenced by the precedent cycling stage (4,24) and is reasonable to assume that running is the only segment that is performed at maximum, to fight for the best position at the finish line. Before 1995, when cycling draft was illegal, cycling was performed at "maximal" intensities, explaining the subsequent increased contribution of running stage. This may be particularly true for men, as they exhibit best performances in cycling (10,20,32,36). Nevertheless, when no draft is allowed, running times have been decreasing more in women than in men (10), evidencing a larger potential for development in this stage, particularly their cycling skills (20,36). Also, Vleck et al. (36) suggest that the elite women with better swimming and cycling ability than the group may have a greater competitive advantage at the running start compared with elite men. Sex difference in running is higher than in swimming and cycling (10,32), which might be due to drafting during the swimming and cycling splits. Male triathletes might benefit more from cycling drafting than women because they tend to ride in larger packs (18). Plus fast runners seem to benefit even more from drafting during cycling (16). Interestingly, it was previously shown that running speed decreases significantly over the whole distance in males, whereas women slowdown in the up- and down-hill sections (20), influencing the overall performance differently for both sexes.

The observed decrease of the running contribution in the most recent years could be due to the stability showed by Etter et al. (10) between 2009 and 2012. Whenever we approximate a "virtual human limit," the variability between triathletes expectably decreases, as observed in the present study. Also, this stage is less affected by progresses in equipment (e.g., wetsuit, bicycle). Because the proportions of the stages are summed 1, it is understandable that this decrease in running is concomitant with an increase in the swimming stage.

In Ironman distance, men showed a decrease in running contribution, which may be the result of a higher performance density across the years. By contrast, women remained stable, which could be due to their improved running time across the years, shown by Lepers (21) to be about 3.8% per decade since 1988 to 2007.

The contribution of the running, as well as all the other disciplines, in the Olympic distance presented higher variability across the years, mainly due to the differences on distance. It is expected with an increase in distance that fewer changes occur, as paces became uniform.

Some limitations of the study should be recognized. We only included the top 50 athletes in the Ironman distance, which may limit comparability between the distances as well as the overall generalizability of these results, as there is a higher heterogeneity in athletes' performance level at the Olympic distance, whereas in the Ironman, the top 50 represent a more uniform performance level within the group of athletes. Nevertheless, the analysis was able to detect differences in the contributions between distances that seem reasonable and ecologic. Also, different environmental conditions, potential differences in the course lengths and morphology, the use of wetsuit may contribute to differences across the years. Finally, we were unable to analyze the transition times (swim-cycle and cycle-run), because data were not available for the 26-year period.

Practical Applications

The present 26-year descriptive study shows that the time spent swimming is less predictive of the overall triathlon performance compared with the time spent cycling or running in both Olympic and Ironman distances. Running is the stage with highest contribution in the Olympic distance, while in the Ironman, running and cycling contributed similarly to the overall performance. These results present strong evidence that running performance should be the main focus when preparing to compete at the Olympic distance, and all strategies that can promote this improvement should be implemented (e.g., strength training). In the Ironman distance, emphasis should be put on both cycling and running training, independent of the sex. For the triathletes who are not able to have an outstanding running, the Ironman distance could be a good option since cycling has also a decisive role in the overall performance. Not only does this contribution help to define priorities in the training process but also can be useful for talent identification for Olympic distance triathlon or in decision-making to change to the Ironman distance.

Supporting these ideas, for Olympic distance triathlons, the contribution of swimming decreased for both men and women, while the contribution of cycling remained stable for both sexes, and the contribution of running increased for men and remained stable for women. These present the need for a continuous improvement in the decisive segments, mainly running at the elite level. It is also clear that both the performance and the dynamics within each stage are very relevant and should be planned and practiced. For Ironman distance triathlon, despite the lower average swimming contribution, it is clear that this segment has been more important over the years, meaning that a better focus in the swimming training of Ironman triathletes can be beneficial to the overall performance, mainly when both cycling and running are very similar between competitors.

References

1. Abbiss, CR and Laursen, PB. Describing and understanding pacing strategies during athletic competition. *Sports Med* 38: 239–252, 2008.
2. Bentley, DJ, Cox, GR, Green, D, and Laursen, PB. Maximising performance in triathlon: Applied physiological and nutritional aspects of elite and non-elite competitions. *J Sci Med Sport* 11: 407–416, 2008.
3. Bentley, DJ, Libicz, S, Jougla, A, Coste, O, Manetta, J, Chamari, K, and Millet, GP. The effects of exercise intensity or drafting during swimming on subsequent cycling performance in triathletes. *J Sci Med Sport* 10: 234–243, 2007.
4. Bentley, DJ, Millet, GP, Vleck, VE, and McNaughton, LR. Specific aspects of contemporary triathlon: Implications for physiological analysis and performance. *Sports Med* 32: 345–359, 2002.
5. Cohen, J. *Statistical Power Analysis for the Behavioral Sciences.* Hillsdale, NJ: Lawrence Erlbaum, 1988.
6. Coyle, EF. Integration of the physiological factors determining endurance performance ability. *Exerc Sport Sci Rev* 23: 25–63, 1995.
7. De Vito, G, Bernardi, M, Sproviero, E, and Figura, F. Decrease of endurance performance during Olympic Triathlon. *Int J Sports Med* 16: 24–28, 1995.
8. Deaner, RO, Carter, RE, Joyner, MJ, and Hunter, SK. Men are more likely than women to slow in the marathon. *Med Sci Sports Exerc* 47: 607–616, 2015.
9. Delextrat, A, Bernard, T, Hausswirth, C, Vercruyssen, F, and Brisswalter, J. Effects of swimming with a wet suit on energy expenditure during subsequent cycling. *Can J Appl Physiol* 28: 356–369, 2003.
10. Etter, F, Knechtle, B, Bukowski, A, Rust, CA, Rosemann, T, and Lepers, R. Age and gender interactions in short distance triathlon performance. *J Sports Sci* 31: 996–1006, 2013.
11. Fröhlich, M, Klein, M, Pieter, A, Emrich, E, and Gießing, J. Consequences of the three disciplines on the overall result in olympic-distance triathlon. *Int J Sports Sci Eng* 2: 204–212, 2008.
12. Gallmann, D, Knechtle, B, Rust, CA, Rosemann, T, and Lepers, R. Elite triathletes in 'Ironman Hawaii' get older but faster. *Age (Dordr)* 36: 407–416, 2014.
13. Guezennec, CY, Vallier, JM, Bigard, AX, and Durey, A. Increase in energy cost of running at the end of a triathlon. *Eur J Appl Physiol Occup Physiol* 73: 440–445, 1996.
14. Hausswirth, C, Bigard, AX, Berthelot, M, Thomaidis, M, and Guezennec, CY. Variability in energy cost of running at the end of a triathlon and a marathon. *Int J Sports Med* 17: 572–579, 1996.
15. Hausswirth, C and Brisswalter, J. Strategies for improving performance in long duration events: Olympic distance triathlon. *Sports Med* 38: 881–891, 2008.
16. Hausswirth, C, Lehenaff, D, Dreano, P, and Savonen, K. Effects of cycling alone or in a sheltered position on subsequent running performance during a triathlon. *Med Sci Sports Exerc* 31: 599–604, 1999.
17. Knechtle, B, Wirth, A, Rüst, CA, and Rosemann, T. The relationship between anthropometry and split performance in recreational male ironman triathletes. *Asian J Sports Med* 2: 23–30, 2011.
18. Landers, GJ, Blanksby, BA, Ackland, TR, and Monson, R. Swim positioning and its influence on triathlon outcome. *Int J Exerc Sci* 1: 96–105, 2008.
19. Le Meur, Y, Bernard, T, Dorel, S, Abbiss, CR, Honnorat, G, Brisswalter, J, and Hausswirth, C. Relationships between triathlon performance and pacing strategy during the run in an international competition. *Int J Sports Physiol Perform* 6: 183–194, 2011.
20. Le Meur, Y, Hausswirth, C, Dorel, S, Bignet, F, Brisswalter, J, and Bernard, T. Influence of gender on pacing adopted by elite triathletes during a competition. *Eur J Appl Physiol* 106: 535–545, 2009.

21. Lepers, R. Analysis of Hawaii ironman performances in elite triathletes from 1981 to 2007. *Med Sci Sports Exerc* 40: 1828–1834, 2008.

22. Lepers, R, Knechtle, B, and Stapley, PJ. Trends in triathlon performance: Effects of sex and age. *Sports Med* 43: 851–863, 2013.

23. Marcora, SM, Staiano, W, and Manning, V. Mental fatigue impairs physical performance in humans. *J Appl Physiol (1985)* 106: 857–864, 2009.

24. Millet, GP and Vleck, VE. Physiological and biomechanical adaptations to the cycle to run transition in olympic triathlon: Review and practical recommendations for training. *Br J Sports Med* 34: 384–390, 2000.

25. Millet, GP and Vleck, VE. Triathlon specificity. In: *World Book of Swimming: From Science to Performance.* L. Seifert, D. Chollet, and I Mujika, eds.: Hauppauge, NY: Nova Science Publishers, Inc., 2010. pp. 481–495.

26. Millet, GP, Vleck, VE, and Bentley, DJ. Physiological requirements in triathlon. *J Hum Sport Exerc* 6: 184–204, 2011.

27. Millet, GY and Lepers, R. Alterations of neuromuscular function after prolonged running, cycling and skiing exercises. *Sports Med* 34: 105–116, 2004.

28. Peeling, P and Landers, G. Swimming intensity during triathlon: A review of current research and strategies to enhance race performance. *J Sports Sci* 27: 1079–1085, 2009.

29. Peeling, PD, Bishop, DJ, and Landers, GJ. Effect of swimming intensity on subsequent cycling and overall triathlon performance. *Br J Sports Med* 39: 960–964, 2005; discussion 964.

30. Roelands, B, de Koning, J, Foster, C, Hettinga, F, and Meeusen, R. Neurophysiological determinants of theoretical concepts and mechanisms involved in pacing. *Sports Med* 43: 301–311, 2013.

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

32. Rust, CA, 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. *Springerplus* 2: 685, 2013.

33. Schabort, EJ, Killian, SC, St Clair Gibson, A, Hawley, JA, and Noakes, TD. Prediction of triathlon race time from laboratory testing in national triathletes. *Med Sci Sports Exerc* 32: 844–849, 2000.

34. Sleivert, GG and Wenger, HA. Physiological predictors of short-course triathlon performance. *Med Sci Sports Exerc* 25: 871–876, 1993.

35. Tomikawa, M, Shimoyama, Y, and Nomura, T. Factors related to the advantageous effects of wearing a wetsuit during swimming at different submaximal velocity in triathletes. *J Sci Med Sport* 11: 417–423, 2008.

36. Vleck, VE, Bentley, DJ, Millet, GP, and Burgi, A. Pacing during an elite olympic distance triathlon: Comparison between male and female competitors. *J Sci Med Sport* 11: 424–432, 2008.

37. Vleck, VE, Burgi, A, and Bentley, DJ. The consequences of swim, cycle and run performance on overall result in elite olympic distance triathlon. *Int J Sports Med* 27: 43–48, 2006.

38. Wu, SS, Peiffer, JJ, Brisswalter, J, Lau, WY, Nosaka, K, and Abbiss, CR. Influence of age and sex on pacing during Sprint, Olympic, Half-Ironman and Ironman triathlons. Part B. *J Sci Cycling* 3: 49–55, 2014.

39. Wu, SS, Peiffer, JJ, Brisswalter, J, Nosaka, K, and Abbiss, CR. Factors influencing pacing in triathlon. *Open Access J Sports Med* 5: 223–234, 2014.

40. Wu, SS, Peiffer, JJ, Brisswalter, J, Nosaka, K, Lau, WY, and Abbiss, CR. Pacing strategies during the swim, cycle and run disciplines of sprint, Olympic and half-Ironman triathlons. *Eur J Appl Physiol* 115: 1147–1154, 2015.