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RESEARCH

Sex-based performance analysis in Olympic triathlon: swimming, cycling, and running at Paris 2024

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Abstract

This study aimed to analyze sex differences in performance across the disciplines of the Olympic triathlon at the 2024 Paris Olympic Games. Performance times in swimming, cycling, running and transitions (T1 and T2) were compared between male ($n = 50$) and female ($n = 51$) athletes. Data were extracted from the official Olympic website and analyzed using the Mann–Whitney U test with effect size (Cohen's d). Quantile regression was applied to examine the relationship between total race time and performance in each discipline of the Olympic triathlon. Male athletes outperformed females across all segments, including swimming, cycling, running, and transitions ($p < 0.001$). Cycling accounted for the largest proportion of total race time in both sexes (49.4% for females, 48.2% for males), while the contribution of running was slightly higher in males (29.8%) than in females (29.5%). Quantile regression revealed that cycling was the most influential predictor of total time among males, whereas running had greater impact among females, particularly in slower athletes ($q = 0.75$). Swimming was a consistent but less prominent predictor in both sexes, especially among faster athletes ($q = 0.25$). Transitions had limited influence in males but showed significant associations with performance among females at specific quantiles, notably in T2. These findings underscore the need for sex-specific training strategies, emphasizing running development in female triathletes and cycling optimization in males, while also considering the role of transitions, especially in draft-legal events.

Keywords Triathlon · Performance analysis · Sex differences · Olympic Games · Endurance sports

Introduction

Triathlon is a multisport discipline comprising three consecutive events: swimming, cycling, and running, interspersed with two transition phases known as T1 (swimming to cycling) and T2 (cycling to running) [1, 2]. Since its debut at the 2000 Sydney Olympics, the sport has experienced significant growth, not only in terms of popularity among professional and amateur athletes, but also in terms of academic and scientific interest [3–6]. This growth is attributed to the challenging nature of triathlon, which requires not only specific skills in each discipline, but also strategic management of transitions, where seconds gained or lost can determine the final outcome [6, 7].

Performance in Olympic-distance triathlon depends on the specific contribution of each segment, where the importance of each can vary depending on race dynamics [8]. Studies have shown that running often stands out as the main determinant of success in high-level competitions, presenting the greatest contribution to overall performance and the strongest correlation with completion time [9, 10]. This predominance is also reflected in the greater variation observed in running times in males competitions, suggesting that this segment should be a primary focus in event preparation [11]. Cycling, in turn, plays an important role, particularly due to the strategic impact of a smooth transition to running, which can influence overall performance [12]. Conversely, swimming shows weaker correlations with total race time and is considered the segment with the least contribution, both in Olympic distances and in long-distance events like the IRONMAN® triathlon [9, 13]. However, these contributions can be influenced by external factors such as weather conditions, course elevation profiles and competitor interactions [8]. Additionally, transitions, though brief, affect the rhythm of subsequent stages and can be decisive. This is especially true for T1, where positioning for cycling can save

Extended author information available on the last page of the article

energy or avoid the need to chase the peloton. In addition to technical and strategic factors, triathlon performance is influenced by physiological and morphological differences between males and females, as previously described in the literature [14]. These sex performance gaps have narrowed over the years and currently range between 12 and 18%, which is influenced by race distance, competitive level, and the growing participation of female athletes [15–17]. Long-duration events, such as the IRONMAN® triathlon, tend to show a smaller performance gap between sexes compared to shorter-distance races, like the Olympic triathlon [18]. This reduced difference may be partly explained by physiological characteristics commonly observed in females, including a higher proportion of type I muscle fibers, greater fat oxidation capacity, and superior fatigue resistance during endurance efforts [19, 20]. However, running stands out as the segment with the largest time disparity between sexes compared to swimming and cycling, suggesting that further studies are needed to understand the factors driving this difference [21].

Although many studies have investigated the contributions of triathlon disciplines to overall performance, there are still gaps in how these sex differences manifest, particularly in recent competitive contexts, such as the Paris 2024 Olympic Games. It is essential to understand whether the patterns observed in previous studies, such as the greater influence of running and cycling, remain valid under current competitive conditions. The aim of the present study was to: (1) compare performance times between male and female triathletes in each of the Olympic triathlon disciplines (swimming, cycling, running, and transitions), (2) investigate the relationships between total race time and individual discipline times, and (3) analyze the percentage distribution of the contributions of swimming, cycling, and running to total time in male and female athletes. We hypothesized that (1) male were faster than female in all individual disciplines and transition times, (2) swimming had the lowest influence on the total race times, and (3) cycling contributed the most to the total race times.

Material and methods

Ethical approval

This study was approved by the Institutional Review Board of Kanton St. Gallen, Switzerland, with a waiver of the requirement for informed consent of the participants as the study involved the analysis of publicly available data (EKSG 01/06/2010). The study was conducted in accordance with recognized ethical standards according to the Declaration of Helsinki adopted in 1964 and revised in 2013.

Sample

The sample of this study consisted of 101 athletes who participated in the 2024 Paris Olympic Games, specifically in the triathlon discipline. The group was divided by sex: 50 male and 51 female athletes.

Procedures and data collection

Data for this study were extracted from the official website of the 2024 Paris Olympic Games (https://olympics.com). The variables included total race time and times for each triathlon segment: swimming, transition 1, cycling, transition 2, and running. The data collection was performed manually, ensuring that all records were verified and organized by sex (male and female) and final athlete ranking. Transition times were analyzed separately to assess the impact of these stages on the total race time. All variables were systematically stored in a spreadsheet for subsequent statistical analysis.

Statistical analysis

The normality of the data was assessed using the Shapiro–Wilk test, which indicated a non-normal distribution of the variables analyzed. Based on this result, comparisons between male and female triathletes in swimming, cycling, running, and transition times were performed using the non-parametric Mann–Whitney U test. The effect sizes were calculated using Rosenthal's r, a non-parametric measure that provides robust estimates when normality assumptions are violated. The interpretation of r values followed Cohen's (1988) thresholds: small (0.10–0.29), moderate (0.30–0.49), and large (≥ 0.50). The relationships between total race time and individual discipline times (swimming, cycling, running, and transitions) were assessed using quantile regression models. Total race time was used as the dependent variable, and each discipline time was analyzed separately as an independent variable across the 0.25, 0.50, and 0.75 quantiles, representing faster, intermediate, and slower athletes, respectively. This approach allowed for the evaluation of how the influence of each discipline varied according to performance level. To complement the interpretation of the results, the percentage contribution of each discipline to total race time was calculated and reported for male and female athletes. The significance level was set at $p < 0.05$. All statistical tests were performed with the Statistical Package for the Social Science software (SPSS Statistics 30; IBM, Armonk, NY, USA).

Results

Figure 1 presents boxplots comparing the performance times across disciplines: swimming (Fig. 1A), cycling (Fig. 1B), running (Fig. 1C), and total time (Fig. 1D) between male and female triathletes. In all disciplines, male athletes had significantly lower times than female athletes ($p < 0.0001$). The effect sizes (Rosenthal's r) were strongest in cycling ($r = 0.86$), followed by total time ($r = 0.86$), swimming ($r = 0.79$), and running ($r = 0.77$), indicating consistent and large differences in performance between sexes.

Figure 2 shows boxplots comparing transition 1 (Fig. 2A) and transition 2 (Fig. 2B) times between female and male athletes. In both transitions, male athletes had significantly faster times than female athletes ($p < 0.0001$). The effect sizes (Rosenthal's r) were strong for both transitions, with $r = 0.76$ for transition 1 and $r = 0.66$ for transition 2.

Figure 3 illustrates the distribution of the percentage contribution of swimming, cycling, and running to the total triathlon time for male and female athletes, excluding the transitions. Swimming contributed similarly for both sexes, with the females showing a percentage of 19.9% and males 19.8%. Cycling accounted for the largest portion of the total time, with 49.4% for females and 48.2% for males. Running showed a slightly higher contribution for males (29.8%) compared to females (29.5%). The results highlight that cycling consistently represents the primary segment of time

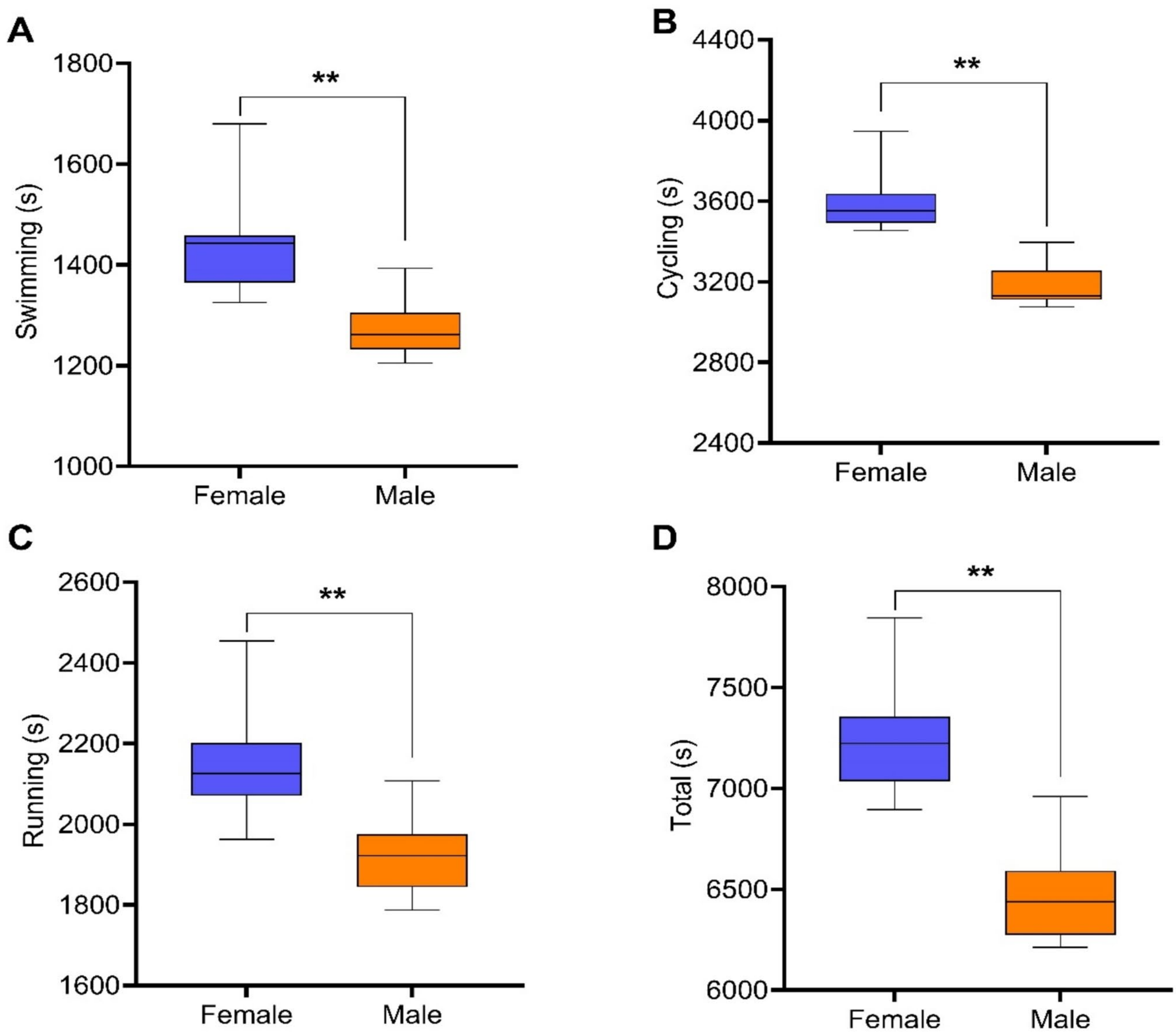

Fig. 1 Distribution of performance times by sex. **A** Swimming times. **B** Cycling times. **C** Running times. **D** Total times. **P < 0,001

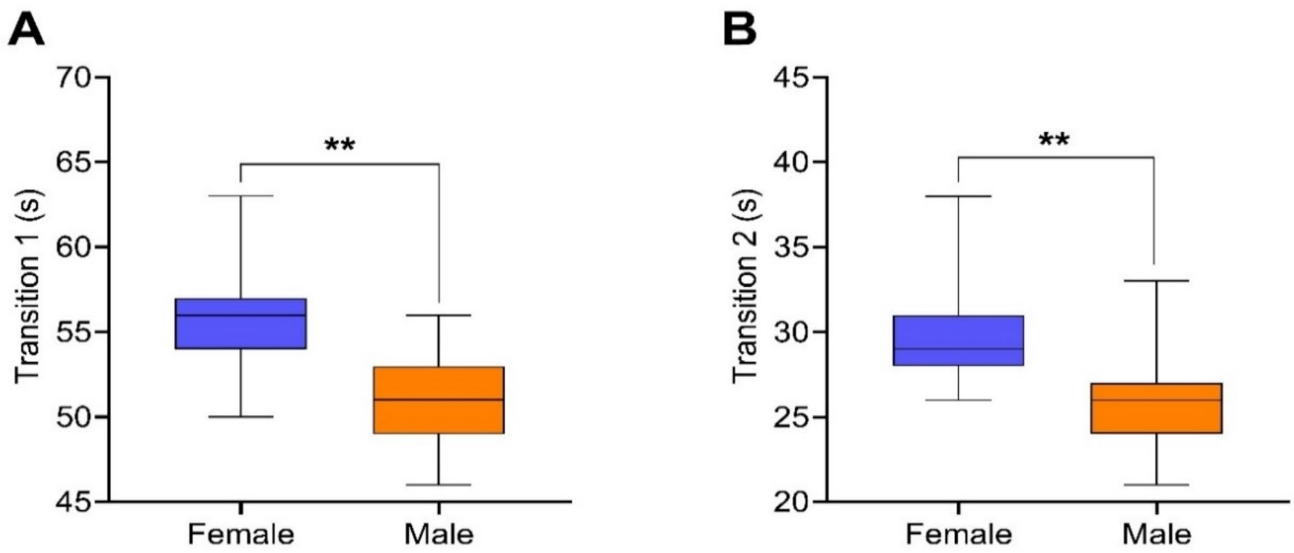

Fig. 2 Distribution of transition times by sex. **A** Transition 1 times. **B** Transition 2 times. **P < 0,001

Fig. 3 Percentage contribution of swimming, cycling, and running to total triathlon time by sex

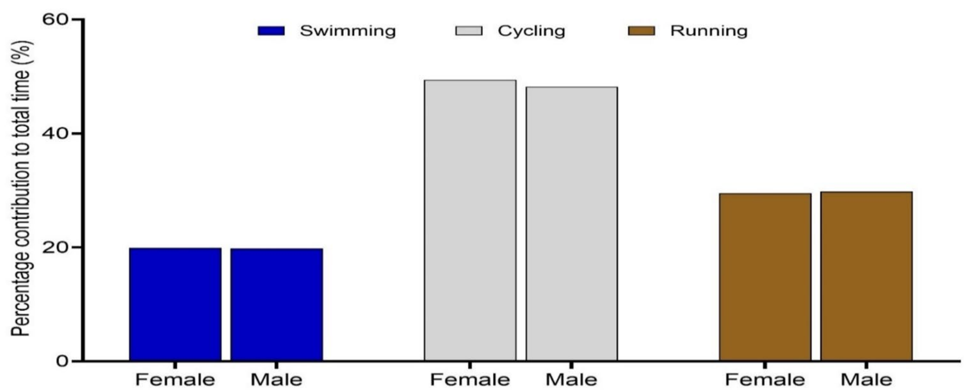

Table 1 Quantile regression coefficients for swimming time in male athletes

Quantile	Coef. (s/1 s)	IC 95%	p-value	Pseudo R^2	MAE
0.25	2.34	1.35–3.33	< 0.001	0.25	117.28
0.50	2.46	1.48–3.43	< 0.001	0.35	98.21
0.75	2.04	0.82–3.26	0.002	0.29	124.58

Quantiles represent different levels of performance (q = 0.25: faster athletes; q = 0.75: slower)

Legend Estimated coefficient in seconds per second (s/1 s), *95% CI* 95% confidence interval, *MAE* mean absolute error

allocation, while swimming and running show relatively balanced contributions across sexes.

Table 1 presents the quantile regression estimates for swimming time in male athletes. Swimming time was significantly associated with total race time across all performance levels. At the 0.25 quantile (representing faster athletes), each additional second in swimming was associated with an increase of 2.34 s in total time (95% CI: 1.35–3.33; p < 0.001). The effect was slightly greater at the median (q = 0.50), with a coefficient of 2.46 s (95% CI: 1.48–3.43; p < 0.001). At the 0.75 quantile (slower athletes), the association remained significant (β = 2.04, 95% CI: 0.82–3.26; p = 0.002), though with slightly reduced magnitude. Pseudo R^2 values ranged from 0.25 to 0.35, and MAE values from 98 to 125 s, indicating moderate explanatory power.

Table 2 presents the quantile regression estimates for cycling time in male athletes. Cycling demonstrated a significant and consistent association with total race time across all performance levels. At the 0.25 quantile (faster athletes), each additional second in cycling was associated with an increase of 1.86 s in total time (95% CI: 1.35–2.38; p < 0.001). This association slightly increased at the median (q = 0.50), with a coefficient of 1.99 s (95% CI: 1.62–2.36; p < 0.001), and remained stable at the 0.75 quantile (slower athletes), with a coefficient of 2.01 s (95% CI: 1.57–2.45; p < 0.001). The pseudo R^2 ranged from 0.47 to 0.54,

Table 2 Quantile regression coefficients for cycling time in male athletes

Quantile	Coef. (s/1 s)	IC 95%	p-value	Pseudo R^2	MAE
0.25	1.86	1.35–2.38	< 0.001	0.47	83.20
0.50	1.99	1.62–2.36	< 0.001	0.54	70.33
0.75	2.01	1.57–2.45	< 0.001	0.52	87.44

Quantiles represent different levels of performance (q = 0.25: faster athletes; q = 0.75: slower)

Legend Estimated coefficient in seconds per second (s/1 s), *95% CI* 95% confidence interval, *MAE* Mean absolute error

Table 3 Quantile regression coefficients for running time in male athletes

Quantile	Coef. (s/1 s)	IC 95%	p-value	Pseudo R^2	MAE
0.25	1.02	0.99–1.04	< 0.001	0.52	95.30
0.50	1.07	0.51–1.63	< 0.001	0.38	94.28
0.75	2.31	1.63–2.99	< 0.001	0.27	124.87

Quantiles represent different levels of performance (q = 0.25: faster athletes; q = 0.75: slower)

Legend Estimated coefficient in seconds per second (s/1 s), *95% CI* 95% confidence interval, *MAE* Mean absolute error

Table 4 Quantile regression coefficients for Transition 1 time in male athletes

Quantile	Coef. (s/1 s)	IC 95%	p-value	Pseudo R^2	MAE
0.25	7.83	– 10.16 to 25.83	0.39	0.01	178.25
0.50	-0.67	– 34.65 to 33.32	0.97	0.00	151.34
0.75	18.00	– 17.85 to 53.85	0.32	0.04	184.70

Quantiles represent different levels of performance (q = 0.25: faster athletes; q = 0.75: slower)

Legend Estimated coefficient in seconds per second (s/1 s), *95% CI* 95% confidence interval, *MAE* Mean absolute error

indicating strong explanatory power, with MAE values between 70 and 87 s.

Table 3 presents the quantile regression estimates for running time in male athletes. The strength of association between running and total race time varied considerably across performance levels. At the 0.25 quantile (faster athletes), each additional second in running was associated with an increase of 1.02 s in total time (95% CI: 0.99–1.04; p < 0.001). At the median (q = 0.50), the coefficient remained similar (β = 1.07, 95% CI: 0.51–1.63; p < 0.001), while at the 0.75 quantile (slower athletes), the association became stronger, with each second in running adding 2.31 s to the total time (95% CI: 1.63–2.99; p < 0.001). The pseudo R^2 ranged from 0.27 to 0.52, with MAE between 94 and 125 s.

Table 5 Quantile regression coefficients for Transition 2 time in male athletes

Quantile	Coef. (s/1 s)	IC 95%	p-value	Pseudo R^2	MAE
0.25	19.78	– 0.89 to 40.45	0.06	0.04	172.36
0.50	29.00	– 1.61 to 59.61	0.06	0.04	145.54
0.75	15.00	– 17.90 to 47.90	0.36	0.04	180.58

Quantiles represent different levels of performance (q = 0.25: faster athletes; q = 0.75: slower)

Legend Estimated coefficient in seconds per second (s/1 s), *95% CI* 95% confidence interval, *MAE* Mean absolute error

Table 6 Quantile regression coefficients for swimming time in female athletes

Quantile	Coef. (s/1 s)	IC 95%	p-value	Pseudo R^2	MAE
0.25	1.83	1.38–2.27	< 0.001	0.35	138.24
0.50	1.94	1.19–2.70	< 0.001	0.30	119.20
0.75	1.47	0.76–2.17	< 0.001	0.26	140.33

Quantiles represent different levels of performance (q = 0.25: faster athletes; q = 0.75: slower)

Legend Estimated coefficient in seconds per second (s/1 s), *95% CI* 95% confidence interval, *MAE* Mean absolute error

Table 4 presents the quantile regression results for Transition 1 (T1) in male athletes. The association between T1 time and total race time was not statistically significant at any of the quantiles analyzed. At the 0.25 quantile (faster athletes), the coefficient was 7.83 s (95% CI: –10.16 to 25.83; p = 0.39), indicating a non-significant trend toward a positive effect. At the median (q = 0.50), the relationship remained non-significant and nearly null (β = –0.67, 95% CI: –34.65 to 33.32; p = 0.97). At the 0.75 quantile (slower athletes), the coefficient increased to 18.00 s, but again lacked statistical significance (95% CI: –17.85 to 53.85; p = 0.32). Pseudo R^2 values ranged from 0.00 to 0.04, and MAE from 151 to 185 s.

Table 5 presents the quantile regression results for Transition 2 (T2) in male athletes. Across all quantiles, the association between T2 time and total race time was not statistically significant. At the 0.25 quantile (faster athletes), the coefficient was 19.78 s (95% CI: –0.89 to 40.45; p = 0.06), indicating a trend toward significance. At the median (q = 0.50), the effect increased to 29.00 s (95% CI: –1.61 to 59.61; p = 0.06), but still did not reach statistical significance. At the 0.75 quantile (slower athletes), the association weakened, with a coefficient of 15.00 s (95% CI: –17.90 to 47.90; p = 0.36). Pseudo R^2 values remained low (0.04 across quantiles), and MAE ranged from 145 to 181 s.

Table 6 presents the quantile regression estimates for swimming time in female athletes. Swimming time showed a significant positive association with total race time across

Table 7 Quantile regression coefficients for cycling time in female athletes

Quantile	Coef. (s/1 s)	IC 95%	p-value	Pseudo R^2	MAE
0.25	1.83	1.37 – 2.30	< 0.001	0.35	123.25
0.50	1.67	1.17 – 2.16	< 0.001	0.43	98.18
0.75	1.63	0.94 – 2.32	< 0.001	0.39	114.32

Quantiles represent different levels of performance (q = 0.25: faster athletes; q = 0.75: slower)

Legend Estimated coefficient in seconds per second (s/1 s), *95% CI* 95% confidence interval, *MAE* Mean absolute error

Table 8 Quantile regression coefficients for running time in female athletes

Quantile	Coef. (s/1 s)	IC 95%	p-value	Pseudo R^2	MAE
0.25	1.40	1.16–1.63	< 0.001	0.47	113.31
0.50	1.99	1.47–2.51	< 0.001	0.47	90.16
0.75	2.43	1.99–2.87	< 0.001	0.43	119.74

Quantiles represent different levels of performance (q = 0.25: faster athletes; q = 0.75: slower)

Legend Estimated coefficient in seconds per second (s/1 s), *95% CI* 95% confidence interval, *MAE* Mean absolute error

Table 9 Quantile regression coefficients for Transition 1 time in female athletes

Quantile	Coef. (s/1 s)	IC 95%	p-value	Pseudo R^2	MAE
0.25	18.33	– 12.05 to 48.72	0.23	0.05	190.41
0.50	39.40	5.49–73.31	0.02	0.12	150.08
0.75	44.86	15.86–73.86	0.003	0.12	173.45

Quantiles represent different levels of performance (q = 0.25: faster athletes; q = 0.75: slower)

Legend Estimated coefficient in seconds per second (s/1 s), *95% CI* 95% confidence interval, *MAE* Mean absolute error

Table 10 Quantile regression coefficients for Transition 2 time in female athletes

Quantile	Coef. (s/1 s)	IC 95%	p-value	Pseudo R^2	MAE
0.25	41.40	19.89–62.91	< 0.001	0.14	182.82
0.50	45.50	14.19–76.81	0.005	0.12	150.47
0.75	52.88	18.79–86.96	0.003	0.13	191.76

Quantiles represent different levels of performance (q = 0.25: faster athletes; q = 0.75: slower)

Legend Estimated coefficient in seconds per second (s/1 s), *95% CI* 95% confidence interval, *MAE* Mean absolute error

all performance quantiles. At the 0.25 quantile (representing faster athletes), each additional second in swimming was associated with a 1.83-s increase in total time (95% CI: 1.38–2.27; p < 0.001). This effect was slightly higher at the median (q = 0.50), with a coefficient of 1.95 s (95% CI: 1.19–2.70; p < 0.001), indicating a consistent influence of swimming on total race time even among intermediate performers. At the 0.75 quantile (slower athletes), the effect remained significant (β = 1.47, 95% CI: 0.76–2.17; p < 0.001), albeit with reduced magnitude. Pseudo R^2 values ranged from 0.26 to 0.35, and MAE values were between 119 and 140 s, suggesting moderate explanatory power of the models.

Table 7 presents the quantile regression results for cycling time in female athletes. A significant and consistent association was observed between cycling and total race time across all quantiles. At the 0.25 quantile (faster athletes), each second added to the cycling segment increased the total time by 1.83 s (95% CI: 1.37–2.30; p < 0.001). This association remained significant and of similar magnitude at the median (q = 0.50), with a coefficient of 1.67 s (95% CI: 1.17–2.16; p < 0.001), and at the 0.75 quantile (slower athletes), with a coefficient of 1.63 s (95% CI: 0.94–2.32; p < 0.001). These results reinforce the role of cycling as a strong predictor of overall performance in female triathletes. Pseudo R^2 ranged from 0.35 to 0.43, with MAE values between 98 and 123 s.

Table 8 shows the quantile regression estimates for running time in female athletes. The influence of running on total race time increased progressively across quantiles. At the 0.25 quantile (faster athletes), each additional second in the run segment was associated with a 1.40 s increase in total time (95% CI: 1.16–1.63; p < 0.001). At the median (q = 0.50), this association became stronger (β = 1.99, 95% CI: 1.47–2.51; p < 0.001), and it peaked at the 0.75 quantile (β = 2.43, 95% CI: 1.99–2.87; p < 0.001), indicating that running had a greater impact on race outcome among slower-performing athletes. The models demonstrated good explanatory capacity, with pseudo R^2 values ranging from 0.43 to 0.47, and MAE between 90 and 120 s.

Table 9 presents the quantile regression results for Transition 1 (T1) in female athletes. The association between T1 time and total race time intensified across performance levels. At the 0.25 quantile (faster athletes), the effect was not statistically significant (β = 18.33 s, 95% CI: –12.05 to 48.72; p = 0.23). However, the relationship became significant at the median (β = 39.40 s, 95% CI: 5.49 to 73.31; p = 0.02) and was even stronger at the 0.75 quantile (β = 44.86 s, 95% CI: 15.86 to 73.86; p = 0.003), indicating that transition efficiency plays a more prominent role among slower female athletes. The explanatory power of the models increased with performance level, with pseudo R^2 values rising from 0.05 to 0.12 and MAE ranging from 150 to 190 s.

Table 10 presents the quantile regression results for Transition 2 (T2) in female athletes. T2 demonstrated a consistently significant and strong association with total race time across all performance levels. At the 0.25 quantile (faster athletes), each additional second in T2 was associated with an increase of 41.40 s in total race time (95% CI: 19.89–62.91; $p < 0.001$). The effect remained significant at the median ($\beta = 45.50$ s, 95% CI: 14.19–76.81; $p = 0.005$) and was even more pronounced at the 0.75 quantile ($\beta = 52.88$ s, 95% CI: 18.79–86.96; $p = 0.003$). These findings highlight the substantial influence of T2 on overall performance among female athletes, particularly in those with lower performance. Pseudo R^2 values ranged from 0.12 to 0.14, with MAE between 150 and 192 s.

Discussion

This study aimed to investigate performance differences between male and female athletes in the Olympic triathlon by analyzing swimming, cycling, running, and transition times. Our hypothesis predicted that males would have faster race times in all disciplines, that swimming would have the lowest influence on total race time, and that cycling would contribute the most to overall time. The main findings partially confirmed this hypothesis. As expected, males achieved significantly faster times in all disciplines. Cycling and running emerged as the strongest predictors of total time, with cycling having greater influence among males and running among females. Contrary to our initial expectations, transitions showed limited impact on overall performance among male athletes, with no statistically significant associations observed across quantiles. However, among female athletes, both T1 and T2 displayed significant contributions to total race time, particularly in intermediate and slower performers, suggesting that transition efficiency may play a more decisive role in female triathlon performance.

Performance differences by sex in the triathlon disciplines

Initially, the results showed that male achieved faster times in all disciplines—swimming, cycling, and running – as well as in transitions 1 and 2 compared to female. All effect sizes were very large, indicating substantial differences in all variables analyzed. The largest effect was observed in cycling, suggesting that this discipline exhibits the largest time disparities between the sexes. The faster time observed in male than in female in the present study was consistent with previous studies conducted on the 2002 International Triathlon Union (ITU) Lausanne World Cups [22], the 2000–2008 World Championship and Olympic Games events [23], the 'Zürich Triathlon' [24], the 2008–2012 ITU's championships [14] and the Olympic distance triathlon at the 2009–2014 ITU World Championships [25]. One interpretation of these sex differences – from a physiological perspective – was the superior scores of male in aspects such as aerobic capacity ($\dot{V}O_2$max) and body size [26]. For instance, a comparative study of athletes competing in a national Olympic distance triathlon found that female had higher fat mass, lower lean mass, $\dot{V}O_2$max, maximal aerobic speed and speed at the anaerobic threshold than male [27]. Higher aerobic capacity, in turn, was associated with better performance in Olympic distance triathlon [28, 29]. Interestingly, in elite male, the Olympic distance triathlon race time could be predicted by both anthropometric (pelvic and shoulder width) and physiological characteristics (maximum respiratory rate, running pace at 3-mmol.L-1 blood lactate and maximum blood lactate) [28]. In male, Olympic triathlon race time was also strongly related to running speed at the anaerobic threshold [29]. In addition to the abovementioned morphological and physiological parameters, reported that other aspects such as hormonal, psychological, and social factors, such as the lower participation rate of female, should also be considered when interpreting sex differences in triathlon [30].

Distribution and impact of the disciplines on the total time

The data show that cycling accounted for the largest portion of the total time in both sexes (49.4% for female and 48.2% for male), while the contribution of swimming was similar for both of them (19.9% for female and 19.8% for male). The difference was slightly higher in running, contributing 29.8% of the total time among male and 29.5% among female.

Regarding associations with total time, quantile regression confirmed that cycling and running were the strongest predictors, with cycling being more influential among male athletes and running gaining prominence among females, especially at higher quantiles (i.e., slower athletes). Swimming showed a consistent and statistically significant association with total time across all quantiles in both sexes, although with lower coefficients. Notably, this influence was slightly more pronounced among faster female athletes.

Transitions, while accounting for a small proportion of total time, revealed a more substantial role than initially anticipated. In particular, Transition 2 (T2) showed a strong and consistent association with overall performance in female athletes, regardless of performance level. In male athletes, however, T2 did not reach statistical significance in any quantile, although a trend was observed among faster and intermediate performers. Transition 1 (T1) also had a significant association with total race time among female athletes at the median and slower quantiles, but no such association was found in males.

The finding that cycling and running were the most important splits for total performance is consistent with previous research on this race distance [12, 31, 32]. For instance, Fernández-Revelles analyzed the males' performance at the 2000 Sydney Olympic Games and found that the running split best predicted the total race time, followed by swimming and cycling. In the males Olympic triathlon at the 2004 Athens Olympics, the same research group [32] found that cycling had the greatest impact on race time, followed by running and swimming. In addition, the males final ranking in the Olympic triathlon depended mainly on running, followed by cycling and swimming [33]. In elite Olympic distance triathlon athletes, regardless of sex, greater performance differences were observed among ranking groups in running and cycling than in swimming [12]. These findings are also supported by physiological data, which show stronger associations of race time with running and cycling $\dot{V}O_2max$ and economy, while swimming tends to present greater variability and weaker correlations [34, 35].

In summary, although swimming represents a smaller proportion of total time, its consistent predictive value across all quantiles and both sexes highlights its strategic importance. This aligns with previous findings suggesting that early positioning in the swim segment can influence subsequent pack dynamics, especially during the cycling leg [36]. Likewise, transitions—particularly T1—can be decisive for positioning in the bike pack, further supporting their relevance in draft-legal events such as the Olympic triathlon.

Limitations and practical applications

A limitation of this study was its exclusive focus on data from the Paris 2024 Olympic Games, which may restrict the generalizability of the results to other competitions, such as long-distance events or those held under different environmental conditions. In addition, the lack of individual information – such as prior experience, training status and body composition – limited a more detailed analysis of the factors influencing performance differences between the sexes. The reliance solely on final times also prevented the assessment of strategic variables, such as pacing and effort distribution across disciplines. Finally, the data analysis was performed through correlation studies, which may underestimate the importance of short activities (low perceptual contribution to overall race time), such as transitions, for overall triathlon performance. Despite these limitations, the findings provide valuable insights for personalized training approaches. For example, based on the larger variability observed among females in this sample, specific technical improvements and optimized transitions could be targeted to reduce time losses. The lower variability observed among males suggests that technical and recovery strategies may be more consolidated in this group and could serve as reference points for female athletes. Furthermore, the study suggests that integrating technical and physical aspects into training may be beneficial in short- and middle-distance triathlons, where minor differences in segment execution can significantly influence overall performance.

Conclusion

In summary, male achieved significantly faster times than female across all disciplines of the Olympic triathlon at the Paris 2024 Games, including swimming, cycling, running and transitions. Cycling was the main contributor to total time in both sexes, followed by running and swimming. Among male, cycling had the greatest influence on total time, while among female, running emerged as the strongest predictor, especially in slower athletes. Transitions, particularly Transition 2, also showed a significant association with performance in female athletes, highlighting their strategic relevance in draft-legal races. These findings reinforce the need for sex-specific training approaches focused on the segments with the greatest impact on final performance.

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Author contributions Luciano Bernardes Leite obtained the data and drafted the manuscript, Luciano Bernardes Leite, Bruno de Cássio Coelho and Pedro Forte performed the statistical analysis and prepared methods and results, Pantelis T. Nikolaidis, Sasa Duric, Marilia Santos Andrade, Ivan Cuk, Katja Weiss, Thomas Rosemann, and Beat Knechtle helped in drafting the final version. All authors read and approved the final manuscript.

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Data availability Availability of Data and Materials For this study, we have included official results and split times from the official race website. The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare no competing interests.

Ethical approval This study was approved by the Institutional Review Board of Kanton St. Gallen, Switzerland, with a waiver of the requirement for informed consent of the participants as the study involved the analysis of publicly available data (EKSG 01/06/2010). The study was conducted in accordance with recognized ethical standards according to the Declaration of Helsinki adopted in 1964 and revised in 2013.

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