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The Analysis of the Impact of Gender and Age in Competitive Sports: A Cast Study of Olympic Swimming Finals from 2012 to 2024

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Abstract: The elite swimming performance progression is impacted by variable factors such as training advancements, athlete demographics, and physiological traits. A deep understanding of influencing factors and performance trends allows for the development of optimized training strategies and maximizing athlete's overall performance. This study conducts a comprehensive investigation into the influence of gender and age on Olympic swimming performance across the 2012 to 2024 Olympic Games, with a detailed analysis of performance trends in various strokes and distances. Data from the top eight finalists in each event were subjected to rigorous statistical analysis, employing t-tests and ANOVA to assess progression patterns and age-related shifts. The findings demonstrate that both female and male swimmers exhibited comparable rates of performance progression over the Olympic cycles, with no statistically significant differences in gender-based performance trends. However, notable exceptions were observed in specific events, such as stagnation in the men's 100m freestyle and women's 200m butterfly during certain periods. The age analysis revealed a general upward trend in the ages of competitors, though younger swimmers were more prevalent in endurance events, while older athletes excelled in sprint disciplines like the 50m freestyle. While the Olympic year did not significantly influence age trends, stroke type and distance were identified as key determinants of age variation among competitors. These results provide nuanced insights into the interaction of gender and age with elite swimming performance, with potential implications for optimizing training protocols and talent development in competitive swimming.

Keywords: Olympic swimming, Age and Gender Analysis, Performance Progression Trend.

1. Introduction

In modern times, more studies have tracked swimming performance to analyze its progression trends and human limits. The majority of the scientists were trying to search for the evolution of performance metrics (times and ages) and how athletes continuously push the boundaries of human capabilities [1]. Peaking performance is a significant challenge for swimmers during the Olympic Games [2]. Any valid findings are important for swimmers to achieve their peak performance and for their support team to build strategies [2]. The role of athlete demographics, particularly age and gender as

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key factors influencing sports performance, and scientists were growing interest in understanding whether these variables contribute to performance outcomes in competitive sports.

This study focuses specifically on the impact of gender and age on Olympic swimming performance, finding the relevant data patterns that can be considered in training, physiology, and even societal perceptions regarding gender and age in competitive sports. The research examines the data sets of Olympic swimming finals to investigate how gender and age influence swimming performance across Olympic years from 2012 to 2024. The boarder implications of understanding their trends such as how this data can inform future athlete training, development strategies, and the selection of younger versus older athletes in different events.

This study implements rigorous statistical analysis to examine gender-based differences in performance trends, comparing the progression trajectories, performance peaks, and plateaus of male and female swimmers across multiple Olympic cycles. Additionally, the analysis investigates the influence of age on swimming performance, evaluating whether the age of Olympic finalists significantly impacts various strokes and distances over time. The study further explores shifts in age distributions across Olympic years, identifying temporal trends. To enhance specificity, the analysis is stratified by stroke and distance to detect whether certain events exhibit more pronounced age-related, thereby providing an understanding of these key demographic factors in elite swimming performance.

Performance progression has been tracked and analyzed in sports science since last century, in an attempt to enhance and predict athletic performance. Many studies have approved that swimming performance has been continuously progressed in the past two decades [3, 4]. In 2024, Patoz's mathematical analysis predicted record-breaking performance in freestyle for the 2024 Olympic Games, the predication model indicates that several freestyle events had the potential of record-breaking [5]. In result, the male of 100m freestyle set the new World record in the 2024 Paris Olympics which matched the prediction.

The aging of elite athletes is always a key factor in training development and peak performance [1]. The evolution of aging is a major challenge in peaking performance for athletes [6]. In 2012, Berthelot indicated the age of 21 years old swimmers would achieve their peak performance [6]. However, the change of age in different swimming events varied in the past decade. Few scholars reported that the age of swimmers was increased in the modern time [3,7]. In 2017, Mazzilli revealed the age of swimmers continuing increase for both men and women who won medals in 2 or 3 different Olympic games [7], while Konig reported that there were changes in the age of swimmers in performance in different strokes and distance for both women and men at World championships and Olympic Games [3]. A rise of age in performance for females has been reported in swimming events: 100m and 400m freestyle while men's age tended to be stable [8].

As many studies have conducted detailed analysis across multiple World class level competitions and Olympic cycles for swimming, particularly with a focus on investigation of changes in age and performance trend [2]. However, there were very few discussions on the gender impact of competitive swimming. Therefore, it is necessary to continuously find a deep understanding of age and gender factors in swimming performance progression that will help develop more scientific training programs from coaches, and allow athletes reach to maximum performance and approach or exceed human limits.

2. Research Method

2.1. Data Sources and Collection Methods

The datasets were collected from the Olympic Swimming Official Record Book of 2012, 2016, 2020 and 2024. The research time frame was chosen between 2012 to 2024, because the technology brought

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a “super-suit” that enhanced swimmer’s performance tremendously in 2008 Beijing Olympic, but it was banned by FINA in the beginning of 2010. The top 8 Olympic swimmer’s performance and age (finalists) from each event were selected. A total of 640 swimming final performances were collected (320 from females, 320 from males). The events were included and analyzed: 50m freestyle, 100m freestyle, 200m freestyle, 400m freestyle, 100m breaststroke, 200m breaststroke, 100m backstroke, 200m backstroke, 100m butterfly, 200m butterfly.

2.2. Data Measurement and Inspection Methods

The finalists’ performance, age mean, and progression rate were assessed with a t-test for the difference between men's and women's progression of performance across four Olympic periods in each stroke and distance. The average age of 2020 finalists were one year older because the 2020 Olympics was postponed to 2021. The two-way ANOVA was implemented to gain a further understanding of the impact of variable factors on performance progression. A P-value results in less than 0.05 sets as the rejecting the null hypothesis for statistically significant differences between men's and women’s performance. The age of Olympic swimmers’ data variation was analyzed by applying two-way ANOVA to examine the effect of the Olympic year and different stroke and distance on ages. The program of Python was implemented to analyze both T-Test and ANOVA.

2.3. Research Hypothesis

This study hypothesizes that both women and men swimming performance continuously improve in the past decade, and there is gender difference of progression trends in Olympic swimming. Another hypothesis of this study is the age of Olympic swimmers continuously increased across the four Olympics from 2012 to 2024, however, there is a significant difference between each stroke and distance.

3. Research Result

3.1. Impact of the Gender in Swimming Performance Across the Olympics

The progression rate indicates that most of swimming performance increased across the Olympics (2012-2024) for both men and women (Table 1), except 100m freestyle, 200m butterfly for male and 200m backstroke and 200 butterfly for females from 2012 to 2016. From 2016 to 2020, both 400m freestyle and 200m backstroke performance decreased for male and women’s 200 butterfly continuously decreased for two Olympic periods. There are more performances that were not improved from the 2020-2024 Olympics: 200m freestyle, 100, backstroke, 100m and 200m breaststroke for men and 100m backstroke, 200m breaststroke, and 100m butterfly for women.

The performance of gender of this study shows that men and women gain similar progression trends in each stroke and distance from 2012 to the 2024 Olympics (Figure 1).

The t-test gave the results that there is no significant difference between women and men performance progression across the Olympic years. All tested p-values were larger than 0.05, which means that it failed to reject the null hypothesis ($p>0.05$) (Table 2).

Table 1: Olympic Swimming Finalist Progression Rate (2012-2024).

Stroke	Distance	20212-2016		2016-2020		2020-2024	
		Men	Women	Men	Women	Men	Women
Freestyle	50	-0.05	-0.90	-0.32	0.00	-0.37	-0.17
Freestyle	100	0.19*	-0.91	-0.67	-0.83	-0.21	-0.08
Freestyle	200	-0.11	-0.98	-0.58	-0.10	0.34*	-0.01

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Table 1: (continued).

Freestyle	400	-0.57	-0.43	0.03*	-0.16	-0.26	-0.55
Backstroke	100	-0.90	-0.46	-0.46	-0.80	0.13*	0.34*
Backstroke	200	-0.46	0.50*	0.63*	-0.85	-0.51	-0.10
Breaststroke	100	-1.04	-0.21	-0.64	-0.93	1.16*	-0.06
Breaststroke	200	-0.57	-0.01	-0.13	-0.47	0.63*	0.64*
Butterfly	100	-0.77	-0.81	-1.23	-0.88	-0.12	0.59*
Butterfly	200	0.46*	0.19*	-0.30	0.30*	-0.88	-0.33
*Progression rate was not improved by Olympic swimmers							

Table 2: The Paired T-Test Results of Stroke and Distance.

Stroke	Distance	T-Statistic	P-Value
Freestyle	50	0.29	0.80
	100	1.01	0.42
	200	0.63	0.60
	400	0.89	0.47
Backstroke	100	-0.45	0.70
	200	0.05	0.97
Breaststroke	100	0.38	0.74
	200	-0.29	0.80
Butterfly	100	-1.60	0.25
	200	-1.03	0.41

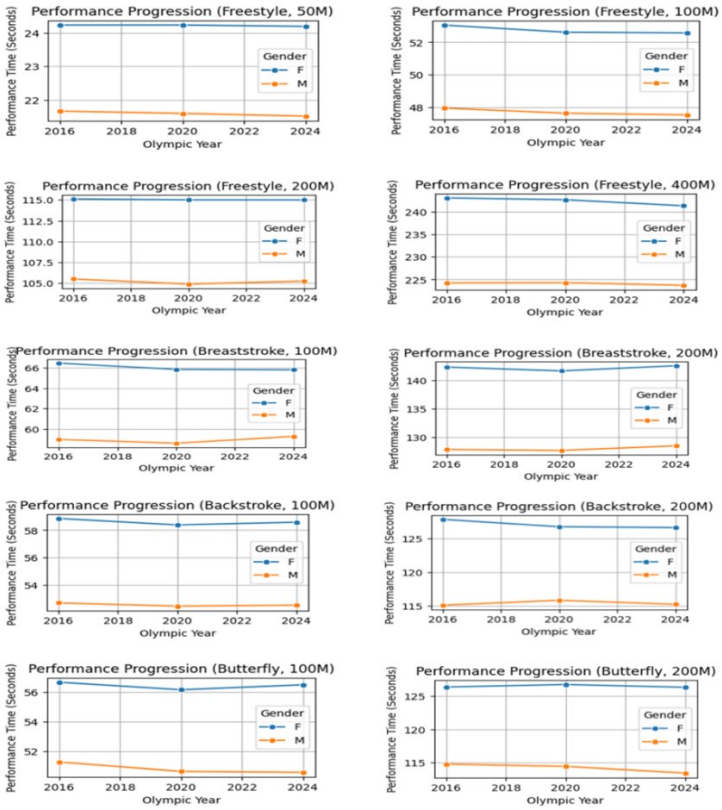

Figure 1: Performance Progression for Stroke and Distance across Olympic Games (2012-2024).

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The ANOVA test summarized that Olympic Year has a statistically significant effect on performance progression (p= 0.161), while gender, stroke, and distance, and their interactions do not have significant effects on the performance progression in the model (Table 3).

Table 3: The Gender of Analysis of Variation (ANOVA) Summary.

	Sum of Squares(ss)	Degree of Freedom (df)	F-Statistic (F)	P-Value (PR(>F))
Gender	0.0132	1.0	0.0522	0.8202
Stroke	0.2796	3.0	0.3679	0.7764
Distance	0.9985	3.0	1.3138	0.2819
Olympic Year	2.2997	2.0	4.5387	0.0161*
Gender:Stroke	0.6091	3.0	0.8014	0.4997
Gender:Distance	0.0709	3.0	0.0932	0.9633
*p-value<0.05				

3.2. Impact of Swimmers' Age Across the Olympics

From 2012 to the 2024 Olympics, it can be seen that the average age of finalists in certain strokes and distances change over time (Figure 2). The age of 50m freestyle swimmers is a lot older than all other analyzed strokes and distance, and the event of 200m backstroke, 200m butterfly and 400m freestyle have relatively younger athletes (under 22 years old). The data reveals that all selected events age increased from the past decade, except the 200m butterfly and 400m freestyle.

The ANOVA analysis revealed that there is no significant effect of Olympic year on the age of finalists (p>0.05) (Table 4). And there is no significant interaction between Olympic years and stroke and distance from the ANOVA analysis. However, the analysis indicates that there is significant effect of different stroke and distance on the age factor (p=0.0003).

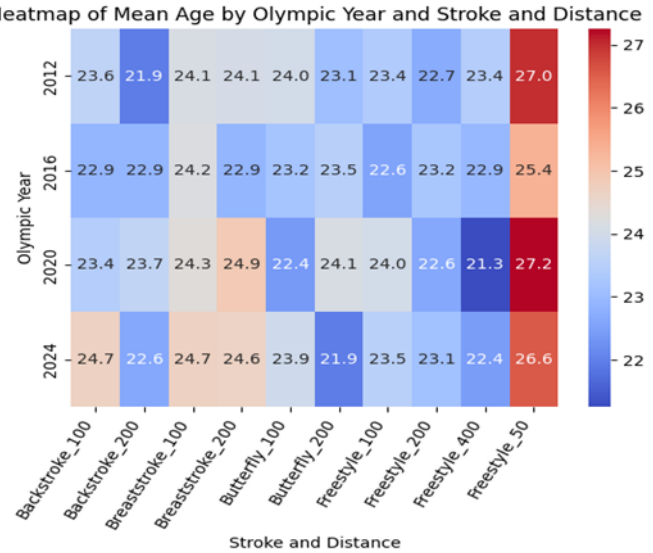

Figure 2: The Heatmap of Mean age by Olympic Year, Stroke and Distance.

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Table 4: The Age of Analysis of Variance (ANOVA) Summary

	Sum of Squares(ss)	Degree of Freedom (df)	F-Statistic (F)	P-Value (PR(>F))
Olympic Year	2.6919	3.0	0.3888	0.7616
Stroke and Distance	96.253	9.0	4.6339	0.0003*
Interaction (Olympic Year and Stroke& Distance)	29.7383	27.0	0.4772	0.9768
*p-value<0.05				

4. Discussion

4.1. Impact of Gender and Swimming Performance

As main finding of this study, the progression trend analysis demonstrated that swimming performance improved for both men and women over the Olympic periods, with few exceptions in men's performance in the 100m freestyle and 200m butterfly, and women's performance in the 200m backstroke and 200m butterfly showed no improvement from 2012 to 2016 Olympics. Interestingly, men's performance in the 400m freestyle and 200m backstroke declined from the 2016 to 2020 Olympics, while the 200m butterfly for women continuously decreased across two Olympic cycles. In the 2020 to 2024 Olympic period, more performance dropped in both women and men, particularly in men's 200m freestyle, 100m backstroke, both the 100m and 200m breaststroke, and women's 100m backstroke, 200m breaststroke, and 100m butterfly performance decreased as well. Overall, all performance improved for men compared 2012 to 2024, while women's performance in 200m breaststroke and 200m butterfly did not improve over time.

Despite these variations in progression rates, the paired t-test revealed no statistically significant differences in performance progression between men and women. The p-values for all tested comparisons exceeded the significance threshold of 0.05, indicating that the null hypothesis could not be rejected. These findings suggest that, despite the observed fluctuations in specific events, the overall progression trend was similar for both genders across the four Olympic Games (2012-2024). The lack of significant differences in performance progression aligns with previous research suggesting that the difference between women and men narrows as the distance grows longer and may be impacted by physiological limits and morphological features [9]. In 2012, Stanua reported similar results that both females and males continue to develop their performance, but the difference between women's and men's performance is smaller in longer swimming distances [10]. The fact that both genders displayed comparable trends reinforces the thought that advancements in training, technology, and conditioning techniques may be benefiting male and female athletes equally over time [11].

4.2. Impact of Age on Swimming Performance

The study also revealed trends in the age of Olympic finalists, particularly in relation to specific strokes and distances. While the overall age of athletes increased over the past decades, two events like 200m butterfly and 400m freestyle as exceptions where the age of finalists did not follow this upward trend. Additionally, the 50m freestyle event consistently featured older athletes compared to other strokes and distances, while younger athletes tended to dominate events like the 200m backstroke, 200m butterfly, and 400m freestyle, where finalists were typically under 22 years old. In 1988, Schulz described the change in age is associated with different distances, particularly long distances are associated with younger athletes [12].

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The two-way ANOVA analysis found no significant effect of the Olympic year on the age of swimmers, with p-values greater than 0.05, it's suggesting that the general trend in age across the years does not exhibit meaningful fluctuations. Similarly, there was no significant interaction between the Olympic year, strokes and distances in terms of age impact. However, a significant effect of stroke and distance on age was detected (p=0.0003), indicating that particular strokes and distances are associated with older or younger athletes. This finding is consistent with a few studies suggesting that sprinters (e.g., 50 freestyles) often peak later in their athletic careers compared to athletes competing in longer distances or more technically demanding strokes (e.g., 200m butterfly) [1].

The analysis of age trends also sheds light on the relationship between age and event specialization. While it might be expected that swimmers become younger over time due to the increasing physical demands of elite competition, the data reveal a more complex picture. In some events, particularly sprinting, older athletes maintain their competitive edge, whereas younger athletes excel in more technically demanding or endurance-based events.

The study findings offer critical insights into the influence of gender and age on swimming performance in recent Olympic cycles. The absence of statistically significant differences in performance progression between female and male athletes underscores the role of advancements in sports science, training methodologies, and technological innovations, which appear to have benefited both genders equally. This convergence in performance trends suggests that both female and male swimmers are approaching the upper limits of human performance at a similar rate. Moreover, the analysis of age trends highlights a nuanced relationship between age and event specialization. Contrary to the expectation that the increasing physical demands of elite competition would favor younger swimmers, the data reveal a more complex scenario. Older athletes maintain a competitive edge in sprint events, such as the 50m freestyle, while younger swimmers tend to excel in technically demanding or endurance-based events like the 200m butterfly or 400m freestyle. This finding challenges the assumption that aging uniformly impairs performance across all swimming events, indicating that event-specific physiological demands and training adaptations play a crucial role in performance longevity. Both male and female swimmers appear to follow similar trajectories in reaching performance peaks, shaped by event-specific characteristics and advances in athletic preparation.

5. Conclusion

In conclusion, this study aimed to explore the impact of gender and age on Olympic swimming performance from 2012 to 2024, focusing on trends across different strokes and distances. The analysis revealed several key findings that contribute to our understanding of performance progression in elite swimming. Both female and male swimmers exhibited significant improvements in performance over the four Olympic cycles, though certain events, such as the men's 100m freestyle and women's 200m butterfly, showed no improvement during specific periods. Despite these fluctuations, no statistically significant differences were found in the progression rates between men and women, indicating similar trends in performance enhancement for both genders. This suggests that advancements in training methods and technology have benefited female and male swimmers equally, narrowing the gender performance gap, particularly in longer-distance events. The study also highlighted the role of age in swimming performance. While the age of Olympic swimmers generally increased over the past decade, certain events like the 200m butterfly and 400m freestyle displayed a decline in age. Additionally, the 50m freestyle consistently featured older athletes, while younger swimmers tended to dominate more technical or endurance events such as the 200m backstroke and 400m freestyle. Overall, the findings emphasize the complex relationship between age, gender, and swimming performance. While performance progression is similar for men and women, age trends vary depending on the event. These insights are crucial for understanding how physiological factors

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and event specialization influence performance, potentially informing future training strategies and talent development in competitive swimming.

While this study provides important insights, it is not without limitations. The analysis was restricted to finalist performances, which may not capture broader trends across all Olympic swimmers. Future research could expand the data set to include more top performers and as well as more Olympic cycles. Moreover, the inclusion of variables such as training methods, injury history, and technological advancements could further elucidate the factors contributing to performance trends across both genders and age groups.

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