

## MEN'S 100-METER FREESTYLE: A TEMPORAL AND BIOMECHANICAL ANALYSIS

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**ABSTRACT.** The men's 100-meter freestyle event represents a benchmark discipline in competitive swimming, marked by biomechanical complexity, intense physiological demands, and distinctive strategic dynamics. With a longstanding tradition in international competitions, this event requires an optimal combination of speed, power, technique, and recovery capacity. The main objective of this research was to analyze the biomechanical and temporal parameters of the world's top swimmers in the 100-meter freestyle, in order to identify execution patterns that can contribute to optimizing performance. The study involved a comparative analysis of twelve elite athletes, examining indicators such as split times across the two 50-meter segments, number of stroke cycles, and stroke amplitude. Data were collected from official international competition sources and interpreted through the lens of applied biomechanics. Findings revealed that the highest-performing athletes exhibit minimal temporal and biomechanical amplitude differences between race segments. Pan Zhanle set a new world record (46.40 s), characterized by a well-balanced start and consistent speed maintenance. The analysis of stroke count highlighted the swimmers' ability to sustain technical stability despite increased metabolic load. The research confirms the hypothesis that top performance in the 100-meter freestyle is decisively influenced by biomechanical balance and strategic effort distribution. Effective strategies are associated with minimal variation in stroke frequency and split times—critical factors in achieving elite-level results. This study provides a relevant analytical framework for coaches and high-performance swimmers, contributing to the development of evidence-based training methodologies in competitive swimming.

**Keywords:** competitive swimming, elite athletes, 100-meter freestyle, comparative analysis

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## INTRODUCTION

Over the years, the 100-meter freestyle event has become a barometer of excellence in competitive swimming. Performances have evolved remarkably, due to advances in training methods as well as innovations in equipment and pool design. The 100-meter freestyle, one of the most spectacular and competitive disciplines in high-performance swimming, has been exemplified by the outstanding progression of Romanian swimmer David Popovici, a true phenomenon of world swimming. Popovici has drawn the attention of the international community through a rare combination of talent, discipline, strategy, and technical innovation. His outstanding achievements—including world titles, European and World records, and remarkable consistency at a young age—served as the inspiration and motivation for choosing this topic. What distinguishes David Popovici is not merely his record-setting achievements, but the way he has redefined the technical and strategic understanding of the 100-meter freestyle, emphasizing efficiency and fluidity over sheer power and explosiveness.

### Hypothesis

The outstanding performance of Chinese swimmer Pan Zhanle in the 100-meter freestyle at the 2024 Paris Olympic Games stands out through the breaking of his own previous world record.

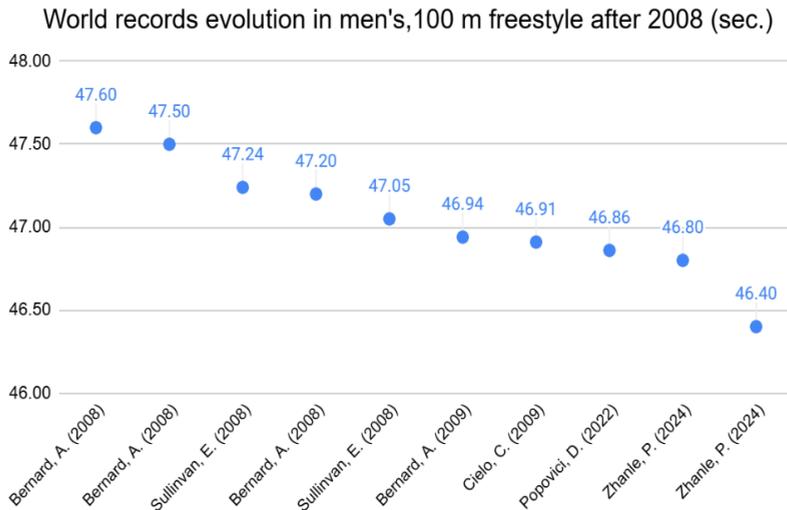


Fig. 1. Progression of world records in men's 100 m freestyle since 2008

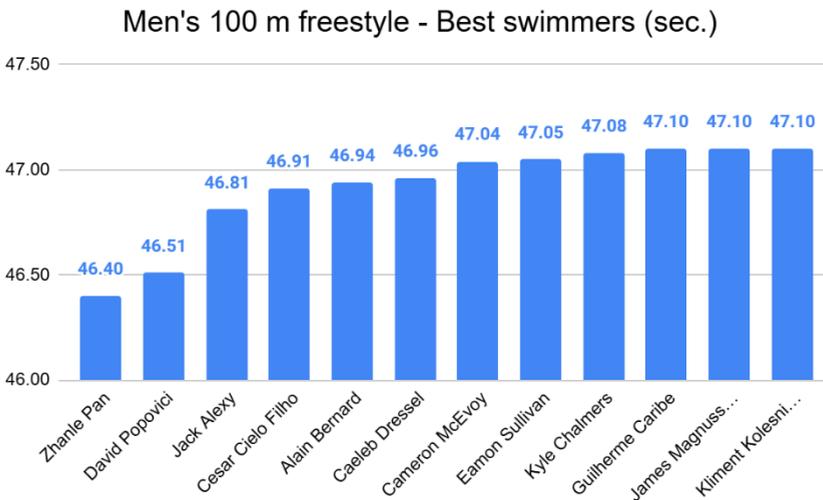
The new world record of 46.40 seconds marks a significant improvement of 0.40 seconds compared to the previous record of 46.80 seconds—a notable difference considering the historical progression of records in this event.

This progression is particularly remarkable given that previous improvements at this level of performance were limited to mere hundredths of a second, as illustrated by the results of other elite swimmers such as David Popovici (46.86) and Cesar Cielo (46.91). Thus, Pan Zhanle's qualitative leap opens a pertinent debate about the human limits of performance in this event and the potential to break the new record in the near future.

The present study is based on the hypothesis that, through an analysis of the times recorded by the highest-performing swimmers in the 100-meter freestyle event, it is possible to identify structural similarities in race execution strategies. More specifically, the research examines the distribution of swimming velocity across the two race segments (the first and second pool lengths) with the aim of identifying common performance patterns or strategic differentiators in execution.

**MATERIAL AND METHODS**

For the purpose of this study, the races performed by the most accomplished athletes in the men's 100-meter freestyle event were analyzed in order to identify common elements related to race strategy and speed distribution.



**Fig. 2.** Top 12 personal best male swimmers in the 100 m freestyle event

According to official World Aquatics rankings, the top 12 swimmers are: Pan Zhanle (China), David Popovici (Romania), Cesar Cielo Filho (Brazil), Alain Bernard (France), Caeleb Dressel (USA), Jack Alexy (USA), Cameron McEvoy (Australia), Eamon Sullivan (Australia), Kyle Chalmers (Australia), Guilherme Caribe (Brazil), James Magnussen (Australia), and Kliment Kolesnikov (Russia).

These athletes were selected based on top performances in major international competitions, representing benchmarks of excellence in contemporary world swimming.

In this study, the performances of the top 12 male swimmers in the 100-meter freestyle were analyzed with the aim of highlighting specific characteristics of race execution and identifying potential consistencies among elite athletes.

The evaluation was conducted based on the following indicators:

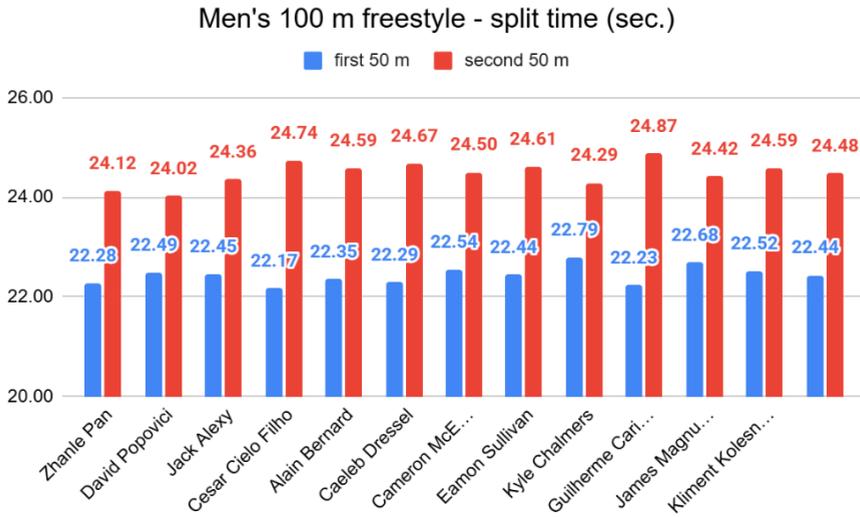
- Split time for the first 50 meters; split time for the second 50 meters; temporal amplitude;
- Number of arm strokes in the first segment of the race; number of arm strokes in the second segment; stroke frequency amplitude.

The data were centralized and subjected to comparative analysis to identify strategic patterns that could explain elite-level performance.

## RESULTS

Analysis of split times in the first half of the race reveals clear tendencies regarding start strategy and effort distribution. Split times for the first 50 meters ranged between 22.17 seconds (Cesar Cielo Filho) and 22.79 seconds (Kyle Chalmers), with an average of 22.44 seconds. Swimmers such as Cesar Cielo Filho (22.17 s) and Pan Zhanle (22.28 s) demonstrate an aggressive race approach, characterized by an initial burst of speed typical of athletes with pronounced anaerobic qualities and exceptional acceleration capacity. This strategy aims to gain an early advantage and maintain control of the race from a leading position.

A second group of swimmers, including David Popovici (22.49 s) and Jack Alexy (22.45 s), prefer a more conservative race approach, marked by a slightly lower speed during the first half of the event, conserving energy for the second segment. In contrast, athletes such as Kyle Chalmers (22.79 s) and James Magnussen (22.68 s) adopt a slower start in the initial part of the race. This choice may indicate an energy-conservation strategy designed to sustain a more consistent pace throughout the event. It may also reflect a superiority of the aerobic system, allowing for a gradual increase in intensity without a significant decline in efficiency toward the end of the race.



**Fig. 3.** Split times in the men's 100 m freestyle event

The second segment (last 50 meters) is critical for final success, reflecting the swimmer's ability to sustain speed under lactate pressure and energy depletion. In this segment, the recorded times show greater variation, ranging from 24.02 seconds (David Popovici) to 24.87 seconds (Guilherme Caribe), with an average of 24.48 seconds. It is remarkable that David Popovici not only registers the fastest time on the second length but even a faster split than some athletes achieved on the first segment, confirming his reputation as a specialist in the *negative split* (a second half faster than the first). Zhanle Pan also falls within the optimal performance range (24.12 s), indicating an ability to maintain a pace close to his initial rhythm even after an explosive first segment.

Conversely, athletes such as Cesar Cielo Filho (24.74 s), Caeleb Dressel (24.67 s), and Alain Bernard (24.59 s) record significant decreases in speed, suggesting either a sharp metabolic decline or an excessively demanding anaerobic effort during the first part of the race.

This distribution of times in the second segment highlights clear physiological and biomechanical differences among the athletes: those with an endurance-oriented profile (e.g., Popovici) are capable of sustaining a strong finish, whereas pure sprinters tend to experience a considerable drop in performance due to insufficient oxidative capacity.

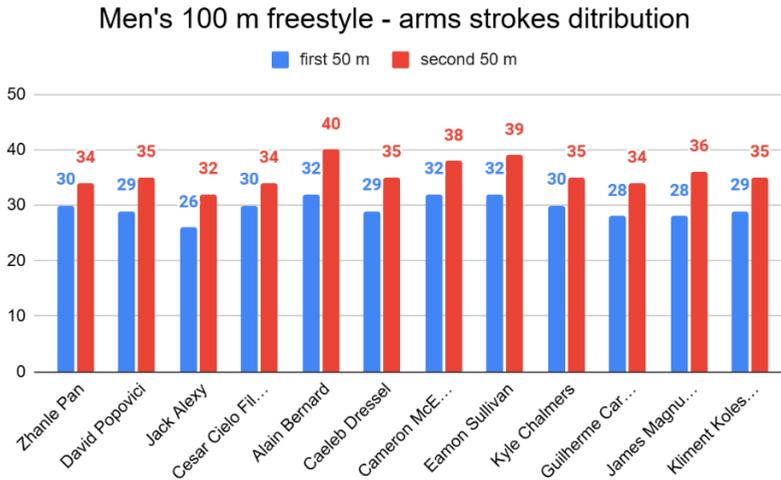
The temporal amplitude, calculated as the difference between the time of the second segment and that of the first segment of the race, provides an integrative

view of rhythmic balance in race execution. This value varies significantly, ranging from 1.50 seconds (Kyle Chalmers) to 2.57 seconds (Cesar Cielo Filho), highlighting major strategic and physiological differences among athletes.

A reduced amplitude reflects a high level of consistency and metabolic efficiency, allowing for an almost equal distribution of effort between the two segments of the race. This model is considered ideal from both a physiological and biomechanical standpoint and serves as a reference for modern sprint-endurance-oriented training methodologies.

At the opposite end, Cielo Filho (2.57 s) and Dressel (2.38 s) exhibit a pronounced decrease in speed during the second half of the race. This decline can be attributed to the rapid depletion of phosphocreatine reserves and the accumulation of lactate, as well as to a swimming style excessively focused on power rather than energy conservation.

Despite registering a moderate amplitude (1.84 s), Zhanle Pan manages to maintain a relatively constant speed despite an explosive start. This indicates a mixed physiological profile, combining strong anaerobic capacity with superior biomechanical efficiency.



**Fig. 4.** Men's 100 m freestyle – arm strokes distribution

The number of arm strokes performed during the first segment of the race represents a key biomechanical indicator for assessing an athlete's technical efficiency in the acceleration phase. On average, the swimmers analyzed recorded between 26 and 32 strokes, with the lowest value observed for Jack Alexy (26) and the highest for Alain Bernard (32), yielding an average of 29.58 strokes.

A lower stroke count in this portion of the race generally suggests efficient glide and greater stroke amplitude, reflecting well-calibrated biomechanics conducive to energy economy. Conversely, a higher stroke count may be interpreted in two ways: either as a result of an intentionally aggressive strategy with increased stroke frequency, or as an indication of reduced stroke amplitude, which requires additional effort to maintain speed.

In the second segment of the race, the number of arm strokes increases significantly for all swimmers, ranging from 33 (Jack Alexy) to 40 (Alain Bernard), with an average of 35.58 strokes. This increase is physiologically and biomechanically natural, as in the final part of the race, swimmers compensate for decreased strength and amplitude by increasing frequency to sustain velocity.

Swimmers such as Alain Bernard (40 strokes) exhibit a marked increase in frequency, which may indicate a substantial reduction in propulsive efficiency due to fatigue. In contrast, athletes such as Pan Zhanle (34) and Cesar Cielo Filho (34) maintain a high frequency within a balanced biomechanical range, demonstrating superior technical control.

It is noteworthy that at this stage of the race, stroke frequency control becomes a critical factor: an excessive increase can lead to technical imbalances, while a frequency that is too low cannot compensate for the loss of muscular power. The difference between the number of strokes executed in the second segment compared with the first reflects the degree of biomechanical adaptation to fatigue and can serve as an indicator of an athlete's overall technico-physiological efficiency.

The smallest differences were recorded by Pan Zhanle and Cesar Cielo Filho (+4 strokes), indicating a remarkable ability to maintain biomechanical consistency even under maximal effort. This level of stability is characteristic of high-performance athletes with strong physical conditioning and refined technical preparation.

Conversely, larger amplitudes—such as those observed in Alain Bernard and James Magnussen (+8 strokes)—may signal either a deterioration in technical efficiency during the final seconds of the race or a deliberate strategy to increase frequency as a compensatory response to muscular fatigue and reduced stroke amplitude. The greater the difference in stroke count, the higher the athlete's susceptibility to biomechanical control loss and postural imbalances, which may negatively affect forward velocity and overall race efficiency.

## **DISCUSSION**

The results obtained in this study confirm the working hypothesis and align with the main objective formulated — namely, to identify execution patterns in the men's 100-meter freestyle event through a comparative analysis of swimming speed distribution and stroke frequency across race segments.

The remarkable performance of Pan Zhanle, culminating in the establishment of a new world record (00:46.40), is supported by a balanced biomechanical and temporal profile, reflected in the reduced amplitude of both split times and stroke frequency between the two race segments. Specifically, a temporal amplitude of 1.84 seconds and a +4 stroke difference between segments indicate a controlled, efficient, and reproducible race strategy at an elite level.

A comparison of these findings with existing literature further reinforces the conclusions. The study conducted by Emel Cetin et al. (2017) demonstrated that experienced swimmers manage to maintain a consistent stroke length, compensating only minimally for reductions in propulsive amplitude. Similarly, López-Plaza et al. (2024) showed that the stability of *stroke rate* and *stroke length* throughout the race—known as *stroke steadiness*—is a determining factor for high performance in sprint events. Both studies support the premise that minimal biomechanical and energetic variations are positively correlated with competitive results.

Furthermore, recent research by Morais et al. (2022, 2023) confirmed that low biomechanical amplitude and consistent race strategies are common characteristics among elite athletes in international competitions.

Nevertheless, the present study also has certain limitations. Firstly, the sample selection focused exclusively on top-level athletes (the 12 best swimmers worldwide), which restricts the generalizability of the conclusions to mid-level or amateur populations. Secondly, the absence of a full analysis of physiological variables (e.g., oxygen consumption, lactate concentration, heart rate) limits the depth of understanding regarding the metabolic mechanisms underlying effort distribution. In addition, the lack of direct integration of video analysis reduces the precision of dynamic assessments of stroke technique.

On the other hand, by correlating biomechanical data (stroke count), temporal data (split times), and final results (total time), this study provides an interpretive model applicable to performance evaluation in competitive contexts. It also offers a valuable reference framework for the planning of elite-level training programs.

For future research, it is recommended to expand the sample by including both male and female athletes, as well as younger age categories, to outline a model of progressive performance development. Moreover, the integration of 3D video analysis technologies and physiological parameters could provide deeper insights into the relationship between biomechanics, race strategy, and final performance outcomes.

## CONCLUSIONS

The results obtained from the analysis of temporal and biomechanical parameters in the men's 100-meter freestyle event clearly support the study's hypothesis—that elite swimmers' top performances can be understood and differentiated by examining how they structure their races, particularly in terms of speed distribution and stroke dynamics across the two race segments.

The exceptional performance of Chinese swimmer Pan Zhanle, marked by setting a new world record of 00:46.40 seconds at the Paris 2024 Olympic Games, is validated and explained in light of the biomechanical and temporal data. This time represents a significant improvement over his previous record of 00:46.80, constituting a 0.40-second enhancement. Considering that the progression of world records in this event has typically occurred in minimal increments, his achievement exceeds the standard evolutionary trend observed in this discipline.

Compared with other elite athletes such as David Popovici and Cesar Cielo Filho, Pan Zhanle demonstrates a balanced distribution of effort across both pool lengths. His time in the first segment (22.28 seconds) ranks among the faster splits, though not excessively so, while his second-segment time (24.12 seconds) is one of the most stable, indicating high efficiency in maintaining speed under metabolic fatigue. This equilibrium is reflected in a moderate temporal amplitude (1.84 seconds), signaling a coherent strategy that balances the initial impulse with controlled effort during the final phase of the race.

Regarding stroke count analysis, the data reveal a general tendency for increased frequency in the second half of the race. However, the variations between segments are crucial for biomechanical profiling. Pan Zhanle and Cesar Cielo Filho both recorded a +4 stroke amplitude, suggesting an ability to sustain a stable and efficient technique until the race's end. In contrast, swimmers such as Alain Bernard and James Magnussen showed increases of up to +8 strokes, reflecting a pronounced decline in technical efficiency, likely caused by accumulated fatigue and reduced propulsive amplitude.

Therefore, the integration of temporal and biomechanical analysis confirms the existence of distinct strategic patterns in race execution. A high-performance profile can be characterized by reduced amplitudes both in temporal and biomechanical dimensions, indicating optimal adaptation to race demands. The execution model demonstrated by Pan Zhanle—based on a controlled start, consistent return phase, and balanced biomechanical frequency—emerges as one of the most efficient approaches in elite swimming.

In this respect, the study's hypothesis is supported not only empirically but also functionally, providing a valuable explanatory framework for understanding the mechanisms underlying elite performance and opening new perspectives for optimizing race strategies, particularly in anticipation of future major competitions.

### **AUTHOR CONTRIBUTIONS**

All contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript. All authors have read and agreed to the published version of the manuscript.

### **CONFLICT OF INTEREST**

The authors declare that there are no financial or personal conflicts of interest that have influenced this study.

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### **REFERENCES**

- Cetin, E., Akdağ, E., & Aktop, A. (2017). Comparison of some kinematic parameters in the 100 m freestyle performances of different age groups. *The European Proceedings of Social and Behavioural Sciences*, *10*, 92–98.  
<https://doi.org/10.15405/epsbs.2017.06.10>
- Colwin, C. (2002). Breakthrough swimming. *Human Kinetics*.
- López-Plaza, D., Morán-Navarro, R., Sillero-Quintana, M., & González-Badillo, J.J. (2024). Stroke steadiness as a determinant factor of performance in 100 m freestyle in young swimmers. *Sports*, *12*(4), 107. <https://doi.org/10.3390/sports12040107>
- Maglischo, E. W. (2003). Swimming fastest. *Human Kinetics*.
- Morais, J. E., Silva, A. J., Barbosa, T. M., & Marinho, D. A. (2022). Race level comparison and variability analysis of 100 m freestyle sprinters competing in the 2019 European Championships. *Journal of Human Kinetics*, *82*(1), 271–281.  
<https://doi.org/10.2478/hukin-2022-0067>
- Morais, J. E., Marinho, D. A., Barbosa, T. M., & Forte, P. (2023). Stroke frequency–stroke length combinations of junior and senior swimmers in 50 m freestyle. *Journal of Sports Science & Medicine*, *22*(1), 156–162.  
<https://www.jssm.org/volume22/iss1/cap/jssm-22-156.pdf>
- MySwimSplits. (n.d.). Top 100 m freestyle swim analysis. Retrieved on August 17, 2025, from <https://myswimsplits.com/top-100m-freestyle-swim-analysis/>
- World Aquatics. (n.d.). *Athletes and results*. Retrieved on August 15, 2025, from <https://www.worldaquatics.com/>