Impact of Reaction Time on 50m Freestyle Performance in Male Swimmers: A Differential Analysis Across Qualification Levels

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Abstract

Objective of the study This study investigated the relationship between start reaction time (RT) and 50-meter swimming race performance across different swimmer qualification levels. The precise nature and strength of this relationship may vary significantly depending on an athlete's skill proficiency. A large dataset comprising 2,252 competitive swimmers was analyzed and categorized into Elite (n=471), High-Level (n=574), and Medium-Level (n=1207) groups based on their competitive results.

The overall analysis of the combined sample revealed a statistically significant positive correlation between RT and 50-meter race time ($r=0.5078$, $p<0.0001$), with RT explaining 25.78% of the variance in swimming performance. However, a differential analysis by qualification level demonstrated notable variations. For Elite swimmers, the correlation was $r=0.2083$ ($p<0.0001$, $R2=4.34\%$), indicating a weak but significant association. High-Level swimmers showed the weakest correlation ($r=0.1043$, $p=0.0124$, $R2=1.09\%$). Medium-Level swimmers exhibited the strongest group-specific correlation ($r=0.2404$, $p<0.0001$, $R2=5.78\%$).

While RT is a statistically significant factor influencing overall swimming performance, its predictive power substantially diminishes within more homogenous, higher-qualified groups. The results highlight the general importance of start efficiency in competitive swimming but also underscore the increasing dominance of other performance determinants (e.g., technique, power, endurance) as skill level advances. This differential impact provides valuable insights for targeted coaching strategies, suggesting a varied emphasis on start training based on a swimmer's current qualification level.

Keywords: *Swim Start, Reaction Time, competitive readiness, Swimmer Qualification, swimming.*

Introduction. Competitive swimming demands a complex interplay of physiological attributes, refined technique, and strategic execution. In sprint events, such as the 50-meter freestyle in a 50-meter long course pool (LCM) for male athletes, every fraction of a second is critical [5]. The overall race time is a composite of several phases (the start, swimming propulsion, turns). Among these, the start phase (encompassing the reaction to the starting signal, the dive, the initial underwater glide) is widely recognized as a crucial determinant of performance, often constituting a significant portion of the total event time particularly in short-distance races [3].

Reaction time (RT), the time taken for a swimmer to respond to the starting signal, is the first measurable component of the start phase [4]. A faster RT is perceived as beneficial, potentially allowing a swimmer to gain an early lead and optimize their race strategy from the outset. This initial burst of speed contributes to overall velocity and can influence subsequent phases of the race. Biomechanical studies have consistently highlighted the intricate mechanics of the swimming start (block mechanics, flight phase, entry) are initiated by the reaction to the signal [1, 9].

While the importance of start, including RT, is generally accepted, the precise extent to which RT predicts overall race outcomes, and whether this predictive power varies across different levels of athletic qualification, remains an area requiring more nuanced investigation. Previous research of the relationship between RT and performance often focused on Elite cohorts or general populations [2]. However, a comprehensive analysis that stratifies a large dataset across distinct qualification levels (Elite, High-Level, Medium-Level) to systematically evaluate this relationship is less common. A differential analysis could reveal

whether the emphasis on minimizing RT should be uniform across all swimmers, or if its importance diminishes as athletes reach higher levels of proficiency where other factors like stroke technique and anaerobic capacity might become more dominant.

Understanding these differential impacts holds significant practical implications for coaches and sports scientists. It could inform more targeted training programs, guiding decisions on how much emphasis to place on specific start drills versus other aspects of swimming development at various stages of an athlete's career [7]. It also could contribute to more precise talent identification models by clarifying the specific components of performance that hold greater predictive value at different skill tiers [8].

This study aims to bridge this gap by conducting a detailed differential analysis of the relationship between RT and 50-meter freestyle performance for male swimmers, across Elite, High-Level, and Medium-Level qualification groups, as well as for the combined heterogeneous sample. Our findings seek to provide a clearer, evidence-based understanding of the role of RT in swimming performance, thereby offering valuable insights for optimized training.

Methods and Organization of the Study. Participants and Classification. The study utilized a large dataset comprising competitive male swimmers specializing in the 50-meter freestyle event. A total of 2,252 individual race entries were analyzed. Based on official competitive results [10], participants were categorized into three qualification groups: 1) Elite (n=471): swimmers who met top-tier national or international performance standards; 2) High-Level (n=574): swimmers with consistently strong regional or national performances, slightly below the elite; 3) Medium-Level (n=1207): swimmers with developing competitive experience and results typically at local or beginner regional levels.

Data Collection. All data were extracted from official competitive records of 50-meter freestyle races conducted in 50-meter long course pools (LCM) of National Championships, European and World Championships, from 2017 to 2024 [10]. The primary variables collected for each race entry included: 1) Reaction Time (RT): the time (in seconds) from the starting signal to the swimmer's departure from the starting block, measured electronically by fully automated timing systems; 2) Final Time (FT): the total time (in seconds) to complete the race, also measured by official timing systems. Other available data (e.g., athlete's name, score) were used solely for organizational purposes and participant identification and were excluded from the statistical analysis of the RT–FT relationship.

Statistical Analysis. For each qualification group, and for the combined heterogeneous sample, the following statistical methods were applied: 1) Descriptive Statistics: the sample size (n), mean, and standard deviation (SD) were calculated for both RT and FT to provide a comprehensive summary of the central tendency and dispersion of the data within each group; 2) Pearson Correlation Analysis: Pearson's product-moment correlation coefficient (r) was used to quantify the strength and direction of the linear relationship between RT (independent variable) and FT (dependent variable). Corresponding p-values were calculated to assess statistical significance, with $p<0.05$ considered significant; 3) Linear Regression Analysis: simple linear regression models were constructed to predict FT based on RT, and the regression equation (slope and intercept) was determined; 4) Coefficient of Determination (R2): R2 was computed for each regression model to quantify the proportion of variance in FT explained by RT.

Research Results. The analysis revealed distinct patterns in the relationship between reaction time (RT) and 50-meter freestyle performance across the different qualification levels of male swimmers. Table 1 presents descriptive statistics for RT and FT for each group, along with the combined sample.

As expected, Elite swimmers showed the fastest mean RT and lowest mean FT, along with the smallest standard deviations, indicating high consistency in performance. Conversely, Medium-Level swimmers

Table 1. Descriptive Statistics for Reaction Time and Final Time by Qualification Level

Group Level	n	Reaction Time (mean ± SD, s)	Final Time (mean ± SD, s)
Elite	471	0.6431 ± 0.0381	22.0208 ± 0.3100
High-Level	574	0.6607 ± 0.0433	23.2979 ± 0.4594
Medium-Level	1207	0.7127 ± 0.0675	25.8995 ± 1.1032
Combined Sample	2252	0.6849 ± 0.0645	4.4252 ± 1.8504

Table 2. Correlation and Regression Analysis by Qualification Level

Group Level	n	Pearson r (p-value)	Regression Equation	R2 (%)
Elite	471	0.2083 (p<0.0001)	FT = 1.6949 * RT + 20.9309	0.0434 (4.34%)
High-Level	574	0.1043 (p=0.0124)	FT = 1.1054 * RT + 22.5675	0.0109 (1.09%)
Medium-Level	1207	0.2404 (p<0.0001)	FT = 3.9273 * RT + 23.1006	0.0578 (5.78%)

exhibited the slowest mean RT and highest mean FT, accompanied by greater variability. High-Level swimmers showed intermediate characteristics in both RT and FT.

Overall Sample Analysis. In the combined sample of all 2,252 swimmers, a statistically significant positive correlation was observed between RT and FT (r=0.5078, p<0.0001). The linear regression analysis resulted in the following equation: FT = 14.5779 RT + 14.4408.

The coefficient of determination (R2) for the combined sample was 0.2578, indicating that 25.78% of the variance in 50-meter freestyle performance can be explained by differences in RT among swimmers of all qualification levels. This substantial R2 suggests a notable influence of RT on performance across a heterogeneous swimming population.

Differential Analysis by Qualification Level. The analysis of individual qualification groups revealed varying correlation strengths between reaction time (RT) and 50-meter freestyle performance (Table 2).

For Elite swimmers, a weak but statistically significant positive correlation was observed (r=0.2083, p<0.0001), with RT explaining only a small portion of performance variance (R =4.34%). While a faster RT is still beneficial, its predictive power on race time is limited within this highly homogenous group.

High-Level swimmers exhibited the weakest correlation among all groups (r=0.1043, p=0.0124). The corresponding R2 was the lowest at 1.09%, indicating that RT has a negligible explanatory power for performance variance in this particular group.

Among Medium-Level swimmers, the correlation was statistically significant and slightly stronger than that of the Elite and High-Level groups (r=0.2404, p<0.0001). RT explained 5.78% of the variance in their performance, representing the highest R2 value among the individual qualification levels.

These results are illustrated in Figure 1, which presents the linear regression lines for each group and the combined sample, highlighting the distinct slopes and scatter patterns across the different groups.

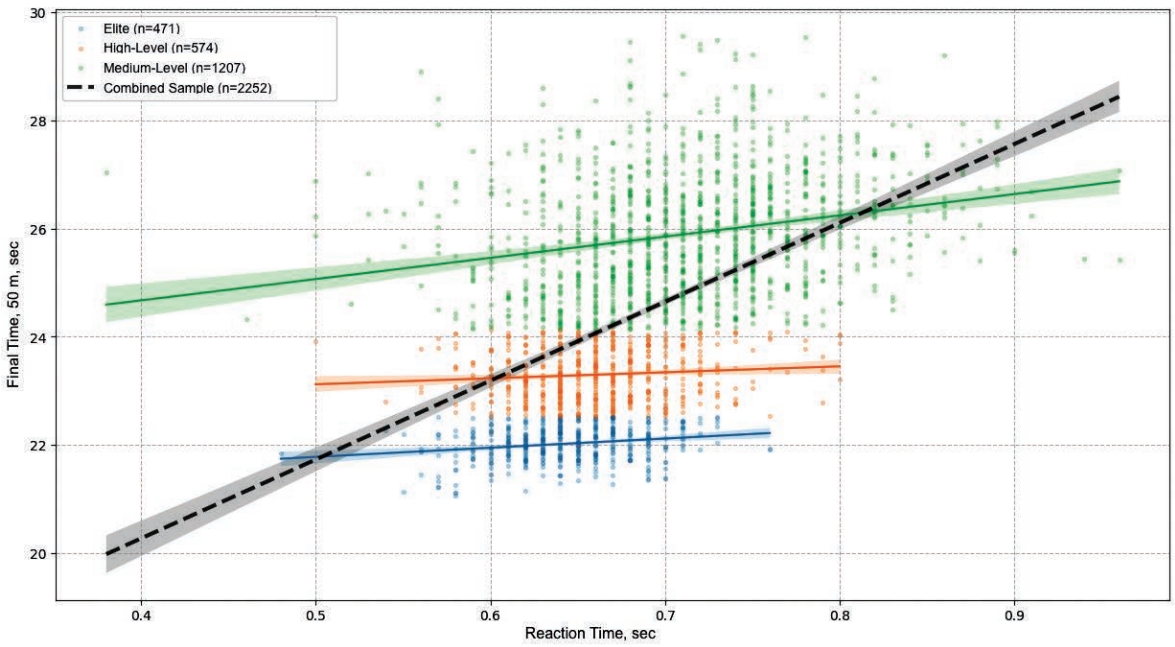

Figure 1. The Linear Regression: Final Time vs Reaction Time Across The Different Groups

Discussion. This study aimed to elucidate the nuanced relationship between start reaction time (RT) and 50-meter freestyle performance in male swimmers, specifically exploring how this relationship varies across different qualification levels. The findings provide a comprehensive perspective, highlighting both a significant overall impact of RT and a distinct differential effect across Elite, High-Level, and Medium-Level swimmers.

The most striking finding is the substantial and statistically significant positive correlation (r=0.5078) observed in the combined sample of 2,252 swimmers, with RT explaining 25.78% of the variance in 50-meter race time. This result underscores the general importance of a quick start in competitive swimming when considering a broad spectrum of athletes. Across all competitive levels, faster RT are consistently associated with better overall race performance. This aligns with intuitive understanding and provides a strong foundational argument for incorporating start training into general swimming development programs. The larger variance in RT and final times across the combined heterogeneous group likely amplifies this correlation, as greater differences in RT between individuals lead to more pronounced differences in overall race outcomes.

However, the differential analysis by qualification level reveals a critical distinction. While the correlation remains statistically significant across all groups, its strength and explanatory power (R2) are notably diminished within the more homogeneous, higher-qualified categories. For Medium-Level swimmers, RT exhibited the strongest group-specific correlation (r=0.2404, R2=5.78%). This suggests that for swimmers at this stage, improvements in RT still contribute measurably to overall performance. Given the relatively larger individual differences in skill and physical attributes at the medium level, a quicker reaction to the signal can still provide a tangible competitive edge, as these athletes might not yet possess the highly refined technique or power to compensate for a slower start. Therefore, for Medium-Level swimmers, dedicated training focused on improving reaction time is indeed a valuable and highly recommended aspect of their development. It represents a relatively accessible avenue for performance enhancement, and the return on investment for such training is likely to be higher compared to more advanced groups.

Conversely, for Elite swimmers, the correlation was considerably weaker (r=0.2083, R2=4.34%), and for High-Level swimmers, it was the weakest of all groups (r=0.1043, R2=1.09%). This significant drop in the coefficient of determination (from 25.78% in the combined group to less than 6% in individual groups) strongly indicates that as swimmers progress to higher qualification levels, RT becomes a far less dominant factor in explaining overall race performance. Elite and High-Level swimmers have already optimized many aspects of their starts, and their RTs fall within a very narrow, highly efficient range (e.g., mean RT of 0.6431s for Elite). At these levels, the marginal gains from further minute improvements in RT are likely to be overshadowed by superior technical execution, powerful propulsion, efficient turns, and enhanced anaerobic capacity throughout the swimming phase [6, 11]. Therefore, for Elite and High-Level swimmers, while maintaining optimal RT is important, concentrating significant training time exclusively on improving RT may be less time-efficient compared to focusing on other, more impactful determinants of performance. These might include advanced stroke mechanics, underwater phase optimization, turn efficiency, strength and power development, and specific endurance training that directly contributes to sustained speed over 50 meters.

The finding that the High-Level group exhibited the weakest correlation (even weaker than Elite) is particularly interesting. This could be due to a combination of factors. Perhaps this group represents a transitional phase where the homogeneity of skill levels is less defined than in the Elite group, but the ceiling for RT improvement is already approaching, leading to a more diffuse relationship. Alternatively, other performance factors might show even greater variability in this group, further diluting the relative impact of RT. This finding may require further investigation.

This study's findings provide practical implications for coaching strategies. For developing swimmers (Medium-Level), emphasizing start training and reducing RT can yield tangible benefits. As swimmers advance, the focus should strategically shift towards continuous refinement of technique, power output, and race strategy, with RT maintenance rather than primary improvement becoming the goal.

Conclusions. Based on the comprehensive analysis of 2,252 male competitive swimmers in 50-meter freestyle long course events, the following conclusions can be drawn:

1. Start reaction time (RT) is a statistically significant factor influencing 50-meter freestyle perfor-

mance across the entire spectrum of competitive male swimmers. For the combined heterogeneous sample, RT explains a considerable portion (25.78%) of the variance in race outcomes, highlighting its general importance in competitive swimming.

2. The predictive power of RT on 50-meter race performance varies significantly across different qualification levels. While a fast start is universally desirable, its relative importance as a training focus evolves with a swimmer's progression through the qualification ranks.

3. For Medium-Level swimmers, RT shows the strongest group-specific association with performance (R2=5.78%). It is advisable for coaches to focus on specific RT training for swimmers at this level, as improvements in RT can still offer a noticeable advantage and contribute to overall performance enhancement.

4. For Elite and High-Level swimmers, while RT remains a statistically significant component of performance, its explanatory power (R2<5%) is considerably diminished. At these advanced stages, resources and training emphasis should shift towards other determinants of performance, such as highly refined technique, explosive power, and race-specific endurance, rather than disproportionately focusing on marginal improvements in RT. The exceptionally narrow range of RTs means that other factors account for the vast majority of performance variance.

5. These findings offer valuable insights for individualized training program design, emphasizing the need for a differential approach to start training based on a swimmer's current qualification level.

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