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Neuromuscular Predictors of 100m Freestyle Performance in Adolescent Swimmers

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Abstract

Neuromuscular abilities are relevant determinants of performance in swimming speed tests. This study aimed to analyze the relationship between neuromuscular variables and chronometric performance in the 100-meter freestyle test among adolescent swimmers and to identify the main predictors of competitive performance. A quantitative, cross-sectional, correlational study was conducted with 22 adolescent swimmers (aged 14–16 years; 12 females and 10 males). Squat jumps (SJ), countermovement jumps (CMJ), reactivity index (RSI), push-ups, sit-ups, and jump squats were evaluated. Performance was determined by the total time achieved in the 100-meter freestyle test in a semi-Olympic pool. Spearman correlation analysis and multiple linear regression with backward elimination were performed. The final model was statistically significant ($F=8.45$; $p=0.001$), explaining 58.5% of the variance in performance (adjusted $R^2=51.5\%$). The countermovement jump reactive strength index contributed most to performance ($B=-62.97$; $\beta=-0.680$; $p<0.001$), followed by abdominal strength-endurance ($B=-0.296$; $\beta=-0.512$; $p=0.006$) and squat jump contact time ($B=-0.006$; $\beta=-0.399$; $p=0.038$). In conclusion, reactive strength and core-related neuromuscular characteristics were significant predictors of 100-meter freestyle performance in adolescent swimmers. These findings suggest that neuromuscular monitoring may help characterize performance-related capacities; however, longitudinal studies with larger samples are required to confirm causal relationships.

Keywords: *athletic performance, neuromuscular factors, speed, swimming, teenage*

Introduction

Swimming is a complex sport that requires the coordinated interaction of multiple physiological, biomechanical, technical, and neuromuscular factors. Competitive swimming performance is determined by the ability to complete a given distance in the shortest possible time. Events range from 50 to 1500 m and present different energetic and mechanical demands depending on distance and stroke characteristics (Barbosa et al., 2014; Hinojosa-García et al., 2025; Ruiz-Navarro et al., 2025). Among sprint events, the 100 m freestyle is a high-intensity race in which performance depends on the interaction among propulsion, stroke efficiency, energy availability, and the ability to generate high levels of force in short periods. Recent studies have demonstrated that start performance is an important contributor to sprint swimming outcomes across age categories, highlighting the relevance of explosive capabilities during the early phases of a race (Matúš et al., 2024). However, performance in the 100 m freestyle is not determined solely by physical characteristics; technical and biomechanical factors also influence the final race outcome.

Sprint swimming performance is influenced by the interplay of multiple factors, including neuromuscular capacity, technical efficiency, physiological characteristics, and training-related adaptations. A multifactorial approach has been proposed to understand athletic performance, recognizing that isolated physical qualities provide only partial information about competitive outcomes (Mujika et al., 2018). Within this context, strength and power characteristics have received increasing attention in swimming research because the ability to generate force rapidly may contribute to the explosive actions associated with sprint events. Recent evidence highlights the importance of the force–velocity relationship and neuromuscular characteristics as key components in the development of athletic performance (Tauda et al., 2025). In competitive swimmers, dry-land assessments of strength and power may provide complementary information for understanding performance variability, particularly in adolescent athletes undergoing continuous physical development.

Previous studies have identified anthropometric characteristics, physiological capacities, and biomechanical variables as key predictors of swimming performance. Factors such as body composition, stroke mechanics, aerobic and anaerobic capacity, and technical efficiency have been linked to variability in competitive outcomes among young swimmers (Alves et al., 2022; Price et al., 2024; Ruiz-Navarro et al., 2025). Although these determinants explain a substantial share of performance differences, they do not fully capture the neuromuscular demands of explosive actions that characterize sprint swimming.

Neuromuscular performance has emerged as a key factor in analyzing swimming performance because the ability to rapidly produce and apply force may influence acceleration, propulsion efficiency, and movement economy. Dry-land assessments, such as squat jump (SJ), countermovement jump (CMJ), and reactive strength index (RSI), provide information about lower-body power, rate of force development, and the efficiency of the stretch-shortening cycle, which are essential characteristics for explosive sports actions (Keiner et al., 2021; Loturco et al., 2016). These characteristics may be particularly relevant in sprint swimming, where small differences in force production and neuromuscular coordination can influence final race time.

Although previous research has demonstrated associations between dry-land strength and swimming performance, most studies have focused on elite athletes or isolated performance indicators. In adolescent swimmers, the contributions of neuromuscular variables, including reactive strength, lower-body power, and core strength-endurance, remain underexplored. Adolescence is a critical period marked by rapid growth, neuromuscular development, and changes in physical performance capacity; therefore, identifying specific neuromuscular characteristics associated with swimming performance may provide relevant information for talent development and individualized training prescription.

Evaluating neuromuscular characteristics may complement traditional performance assessments by identifying physical qualities that contribute to swimming efficiency. Lower-body explosive strength and reactive ability may influence actions requiring rapid force production, while core strength-endurance may help maintain body position and optimize force transfer during swimming movements. However, further research is needed to clarify the predictive contribution of these variables to sprint swimming performance in young athletes.

Therefore, this study aimed to analyze the relationship between neuromuscular variables and chronometric performance in the 100-meter freestyle among adolescent swimmers and to identify the primary neuromuscular predictors of competitive performance. We hypothesized that adolescent swimmers with greater lower-body explosive strength, higher reactive strength index values, and better core strength-endurance would achieve faster 100-meter freestyle times.

Methods

Study design

This study employed a quantitative approach, using numerical data from neuromuscular performance assessments of adolescent swimmers. A non-experimental, cross-sectional design with descriptive, correlational, and predictive scope was adopted to analyze the relationship between neuromuscular variables and 100-meter freestyle performance. The study was conducted and reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines to improve methodological transparency and ensure adequate reporting of observational research procedures.

Participants

Twenty-two adolescent swimmers (12 females and 10 males) aged 14–16 years participated in the study. Participants were active members of a competitive swimming program and had at least two years of regular training experience. Anthropometric, body composition, neuromuscular, and performance-related characteristics available in the dataset are presented in Table 1 of the Results section. None of the participants presented musculoskeletal, cardiopulmonary, or neurological conditions that limited their performance during testing. All participants and their legal guardians provided informed consent before participation.

Variables

The dependent variable was the total time (in seconds) recorded during the 100-meter freestyle test.

The independent variables included: Squat Jump flight time (TV_SJ), Squat Jump contact time (TC_SJ), Countermovement Jump flight time (TV_CMJ), and Countermovement Jump reactive strength index (RSI_CMJ); flight and contact times were expressed in milliseconds; Number of push-ups, sit-ups, and jump squats completed in 30 seconds; Age and sex were used to characterize the sample.

These variables were selected based on prior evidence indicating their relevance to performance on swimming speed tests (Bond et al., 2015; Price et al., 2024).

Push-ups were included as an indicator of upper-body strength-endurance because arm propulsion represents an essential component of freestyle swimming. Sit-ups were selected to assess core strength-endurance due to its role in maintaining body alignment and efficient force transfer during swimming. Jump squats were included as a measure of lower-body explosive capacity, considering the contribution of lower-limb power to acceleration and explosive movements in swimming performance.

Sample size

The sample consisted of 22 adolescent swimmers from the competitive program. A sensitivity sample-size analysis was conducted using G*Power 3.1 (Faul et al., 2009) for a linear multiple regression fixed-model analysis evaluating the R^2 deviation from zero. Using a significance level of $\alpha=0.05$, statistical power of 0.80, an expected effect size of $f^2=0.30$ according to Cohen's criteria (Cohen, 1988), and three predictors retained in the final model, the estimated sample size required would be approximately 41 participants. Therefore, the available sample should be considered limited for confirmatory prediction purposes. The findings are interpreted as exploratory and should be confirmed in larger samples with external or cross-validation procedures.

Measurements

Neuromuscular assessments were performed during controlled testing sessions in a standardized indoor environment. Vertical jump tests were conducted using a validated jump-measurement system (ADR-Jumping), which has been reported as a reliable tool for estimating vertical jump performance (González-Conde et al., 2022). Before testing, the equipment was checked and calibrated according to manufacturer recommendations.

For the Squat Jump (SJ), participants performed a maximal vertical jump from a static semi-squat position without countermovement. For the Countermovement Jump (CMJ), participants performed a rapid downward movement followed by maximal vertical propulsion. Two valid attempts were completed for each jump test, separated by one minute of recovery, and the best performance was retained for analysis.

Push-ups, sit-ups, and jump squats were assessed as functional indicators of upper-body muscular endurance, trunk strength-endurance, and lower-body power, respectively. These variables were selected because swimming performance requires the interaction among propulsion capacity, postural control, force production, and repeated muscular actions, all of which are relevant to sprint swimming performance.

Data analysis

Statistical analyses were performed using IBM SPSS Statistics version 24. Descriptive statistics were calculated for all variables, including mean, standard deviation, minimum, and maximum values. Categorical variables were presented as absolute frequencies and percentages.

Before conducting the regression analysis, bivariate associations between neuromuscular variables and 100 m freestyle performance were examined using Spearman's rank-order correlation coefficients. This non-parametric approach was selected because of the small sample size and the presence of variables with non-normal or discrete distributions. The correlation matrix was used to describe the magnitude and direction of the relationships between candidate predictors and competitive performance.

Subsequently, multiple linear regression analysis was performed to identify neuromuscular variables associated with 100 m freestyle performance. A backward elimination procedure was applied, initially entering seven theoretically relevant predictors supported by previous literature: SJ flight time, SJ contact time, CMJ flight time, CMJ reactive strength index, push-ups, sit-ups, and jump squats.

The backward elimination approach was selected because the study aimed to identify the variables with the greatest explanatory contribution while reducing the number of predictors included in the final model. Predictors with $p>0.05$ were sequentially removed. Considering the limited sample size (n=22), the possibility of model instability and overfitting was considered, and findings were interpreted with caution.

Prior to interpreting the regression model, assumptions of multiple linear regression were evaluated. Linearity and homoscedasticity were examined through scatterplots of standardized residuals against predicted values. Normality of the residuals was assessed using histograms and normal probability plots. Independence of errors was evaluated through residual analysis and the Durbin–Watson statistic. Multicollinearity was assessed using tolerance values and variance inflation factors (VIFs), with VIFs below 5 considered acceptable.

Model performance was evaluated using the coefficient of determination (R^2), adjusted R^2, F-test for overall model significance, standard errors, confidence intervals, and regression coefficients. Statistical significance was set at $p<0.05$. As a sensitivity analysis for the final model, heteroscedasticity-consistent robust standard errors (HC3) were estimated to assess the stability of the regression coefficients given the small sample size.

Ethical considerations

The study complied with the ethical principles of the Declaration of Helsinki and Resolution 8430 of 1993 of the Colombian Ministry of Health, which regulates research involving human subjects. Since the intervention was limited to non-invasive physical tests, it was classified as minimal risk. All participants and their adult guardians signed an informed consent form. The confidentiality of the information was guaranteed by encoding the data. This research was approved by the ethics committee of the National School of Sport under minutes number 320.02-08-2025.

Results

A total of 22 adolescent swimmers (12 females and 10 males) were included in the analysis. Descriptive characteristics of the participants and performance-related variables are presented in Table 1. The variables are reported as mean ± standard deviation, together with minimum and maximum values.

Table 1. Descriptive characteristics of adolescent swimmers and performance-related variables (n=22)

Variable	Mean	SD	Minimum	Maximum
Age (years)	14.32	0.57	14.00	16.00
Swimming experience/training period (years)	10.73	2.46	6.50	15.00
Bone mass (kg)	9.12	1.61	6.60	12.91
Muscle mass (kg)	22.94	4.37	17.49	36.42
Muscle mass (%)	43.27	4.27	36.00	51.00
Fat mass (kg)	14.98	3.51	9.71	21.07
Body fat (%)	28.05	5.29	15.00	36.00
Relative wingspan	1.02	0.03	0.97	1.06
Manouvrier index	98.14	7.91	81.00	115.00
Trunk flexibility (cm)	29.57	9.61	11.50	45.00
Pull-ups (repetitions)	4.09	5.07	0.00	21.00
Push-ups (repetitions)	40.86	22.37	19.00	110.00
Sit-ups (repetitions)	68.27	14.33	45.00	104.00
Squats (repetitions)	50.55	7.66	35.00	64.00
Jump squats (repetitions)	41.86	6.78	32.00	54.00
SJ flight time (ms)	471.41	60.05	361.00	593.00
SJ jump height (cm)	28.65	6.91	17.00	44.10
SJ contact time (ms)	2464.05	545.76	1847.00	3827.00
SJ reactive strength index	0.12	0.03	0.04	0.20
CMJ flight time (ms)	469.41	65.15	353.00	619.00
CMJ jump height (cm)	28.48	7.52	16.30	47.90
CMJ contact time (ms)	1721.05	694.86	627.00	3271.00
CMJ reactive strength index	0.19	0.09	0.05	0.45
100 m freestyle time (s)	76.22	8.27	61.27	97.77
100 m strokes (count)	83.18	10.26	65.00	106.00
100 m SWOLF	159.41	13.89	129.57	182.91

Note. Sex distribution: 12 females and 10 males. Percent variables were multiplied by 100 for reporting. SJ = squat jump; CMJ = countermovement jump; RSI = reactive strength index; SWOLF = swim golf score.

Correlation analysis

Before constructing the regression model, bivariate correlations were computed to examine the relationships between neuromuscular variables and 100 m freestyle performance. Spearman correlation coefficients showed that 100 m freestyle time was negatively associated with CMJ reactive strength index (rho=-0.51; p=0.016), sit-ups (rho=-0.49; p=0.021), and jump squats (rho=-0.54; p=0.010), indicating that higher values in these variables were associated with shorter race times (Table 2). Push-ups were not associated with 100 m freestyle time (rho=0.12; p=0.583).

Table 2. Spearman correlation matrix among 100 m freestyle time and neuromuscular candidate predictors

Variable	100 m time	TV_SJ	TC_SJ	TV_CMJ	RSI_CMJ	Push-ups	Sit-ups	Jump squats
100 m time	1							
TV_SJ	-0.12	1						
TC_SJ	0.17	0.21	1					
TV_CMJ	-0.03	0.81**	0.13	1				
RSI_CMJ	-0.51*	0.36	-0.43*	0.44*	1			
Push-ups	0.12	0.45*	0.47*	0.27	-0.12	1		
Sit-ups	-0.49*	0.01	-0.44*	0.03	0.22	-0.09	1	
Jump squats	-0.53*	-0.07	-0.21	0.10	0.29	0.02	0.47*	1

Note. Values are Spearman rho coefficients. Only the lower triangle is shown. *p<0.05; **p<0.01. TV = flight time; TC = contact time; SJ = squat jump; CMJ = countermovement jump; RSI = reactive strength index.

Multiple linear regression analysis

A multiple linear regression with backward elimination was conducted to identify neuromuscular variables associated with 100 m freestyle performance. The final model was statistically significant ($F=8.45$, $p=0.001$) and explained 58.5% of the variance in 100 m freestyle performance ($R^2=0.585$; adjusted $R^2=0.515$).

The final regression model retained three predictors: squat jump contact time (TC_SJ), countermovement jump reactive strength index (RSI_CMJ), and sit-ups. Regression coefficients and diagnostic statistics are presented in Table 3.

Table 3. Final multiple linear regression model predicting 100 m freestyle performance

Predictor	B	β	SE	t	p	95% CI for B	Tolerance	VIF
Constant	123.481	—	11.977	10.310	<0.001	98.319 to 148.643	—	—
TC_SJ	-0.006	-0.399	0.003	-2.240	0.038	-0.012 to -0.000	0.728	1.374
RSI_CMJ	-62.965	-0.680	15.509	-4.060	<0.001	-95.549 to -30.382	0.823	1.216
Sit-ups	-0.296	-0.512	0.094	-3.150	0.006	-0.493 to -0.098	0.873	1.146

Note. Dependent variable: 100 m freestyle time (seconds). Final backward-elimination model: $R^2=0.585$, adjusted $R^2=0.515$, $F(3, 18)=8.45$, $p=0.001$, Durbin-Watson =2.00. B = unstandardized coefficient; β = standardized coefficient; SE = standard error; CI = confidence interval; VIF = variance inflation factor. HC3 robust sensitivity analysis supported the stability of RSI_CMJ and sit-ups, while TC_SJ showed a borderline association.

The estimated regression equation was:

Time100m = 123.481 - 0.006(TC_SJ) - 62.965(RSI_CMJ) - 0.296(Sit-ups)

Where: Time100m = 100-meter freestyle performance time (seconds), TC_SJ = squat jump contact time (milliseconds), RSI_CMJ = countermovement jump reactive strength index, Sit-ups = number of sit-ups completed in 30 seconds.

Among the retained predictors, RSI_CMJ showed the strongest standardized association with performance ($B=-62.965$; $\beta=-0.680$; $p<0.001$), followed by sit-ups ($B=-0.296$; $\beta=-0.512$; $p=0.006$) and squat jump contact time ($B=-0.006$; $\beta=-0.399$; $p=0.038$). Because the dependent variable was race time, negative coefficients indicate that higher values of these predictors were associated with shorter 100 m freestyle times. In the HC3 robust sensitivity analysis, RSI_CMJ ($p=0.002$) and sit-ups ($p=0.010$) remained statistically significant, whereas TC_SJ showed a weaker borderline association ($p=0.065$).

Regression diagnostics

The assumptions of multiple linear regression were examined before interpretation of the model. Residual analysis indicated an approximately normal distribution of errors, supported by the histogram, normal probability plot, and Shapiro-Wilk test of residuals ($p=0.977$). The residuals versus predicted values plot showed no evident systematic pattern, supporting the visual assumption of homoscedasticity. Independence of errors was supported by the Durbin-Watson statistic ($DW=2.00$).

Multicollinearity analysis indicated acceptable tolerance values and variance inflation factors. VIF values ranged from 1.15 to 1.37, indicating no evidence of problematic multicollinearity among predictors.

Residual diagnostic plots are presented in Figure 1, including the normal probability plot, standardized residuals versus predicted values, residual sequence analysis, and histogram of standardized residuals.

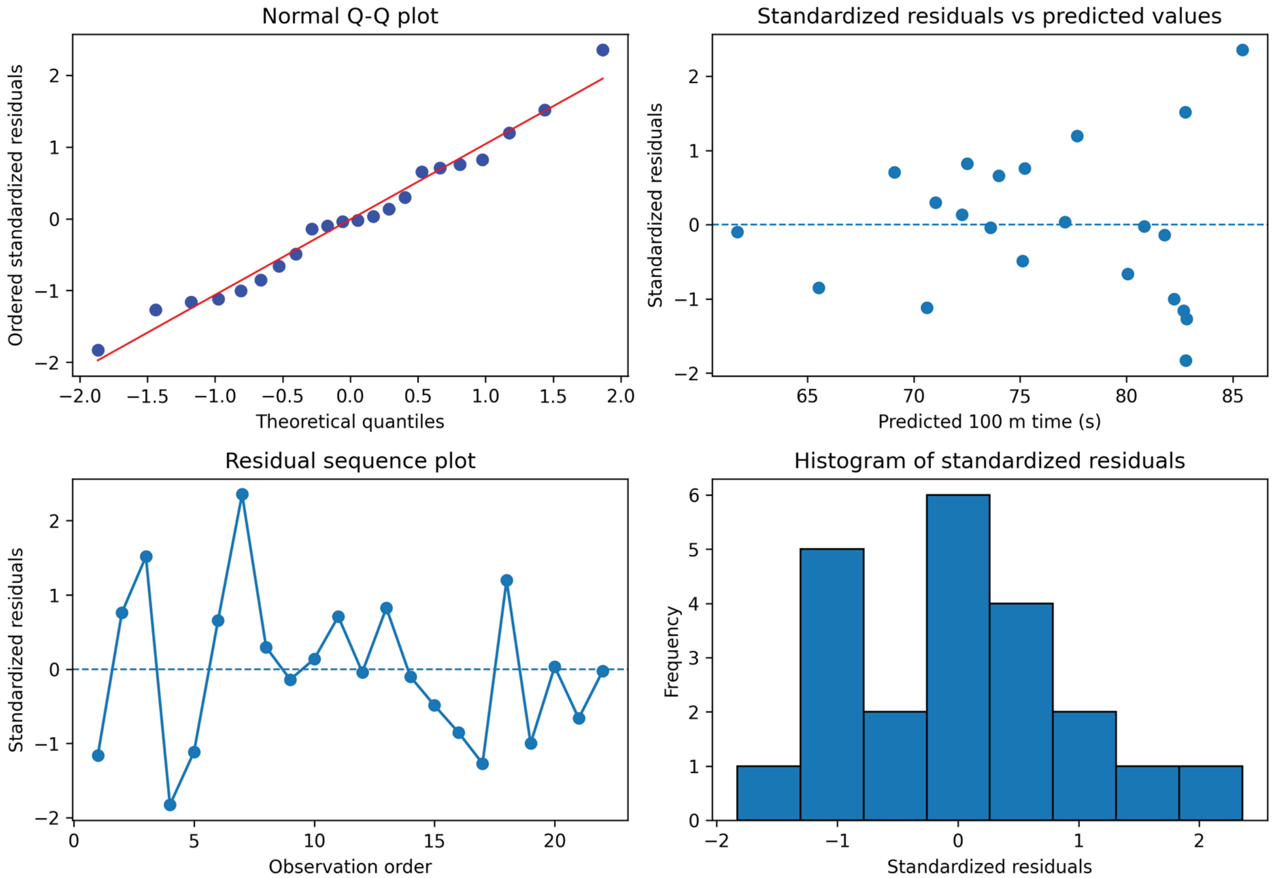

Figure 1. Residual diagnostic plots for the final regression model predicting 100 m freestyle performance

Discussion

The present study analyzed the association between neuromuscular characteristics and 100 m freestyle performance in adolescent swimmers. The final regression model explained a relevant proportion of the variability in swimming time, suggesting that reactive strength, squat jump contact characteristics, and core strength-endurance are neuromuscular characteristics associated with sprint swimming performance. However, given the cross-sectional design, limited sample size, and exploratory model-selection procedure, these findings should be interpreted as relationships among variables rather than as causal or definitive predictive effects.

The relevance of neuromuscular qualities in sprint swimming is consistent with previous research indicating that dry-land performance measures can provide complementary information regarding swimming performance. Morouço et al. (2011) reported significant associations between dry-land strength and power measures and swimming performance in competitive swimmers, suggesting that the ability to generate force outside the water may be related to performance outcomes. Similarly, Keiner et al. (2021) demonstrated that upper- and lower-body strength characteristics were associated with block start, turn performance, and overall sprint swimming performance, highlighting the contribution of neuromuscular capacities during high-intensity swimming events.

In the present study, the countermovement jump reactive strength index (RSI_CMJ) showed the strongest standardized association with 100 m freestyle performance. This finding is consistent with previous evidence suggesting that reactive strength reflects the ability to efficiently utilize the stretch-shortening cycle (SSC), which may be relevant during explosive actions such as starts and turns. Loturco et al. (2016) reported relationships between dry-land power assessments and sprint swimming performance, suggesting that measures such as CMJ and SJ may provide information related to neuromuscular efficiency and explosive capacity in swimmers. Nevertheless, the current results do not allow us to determine whether improvements in reactive strength would directly enhance swimming performance.

The association observed between neuromuscular variables and sprint swimming performance should be interpreted within a broader performance framework. Recent evidence suggests that strength development, force production, and neuromuscular activation patterns are relevant components of athletic performance; however, their contributions depend on the specificity of the sport task and their interaction with technical factors (Fernández Ortega et al., 2025; Tauda et al., 2025). In swimming, this interaction is particularly important because dry-land strength qualities may contribute to performance-related actions but do not fully capture the demands of aquatic propulsion (Chalkiadakis et al., 2023).

The association observed for squat jump contact time should be interpreted cautiously because it reflects a dry-land neuromuscular characteristic rather than a direct swimming-specific mechanical variable. In addition, this variable was retained in the final model but showed weaker stability in the robust sensitivity analysis. Dry-land jump assessments have been used as practical indicators of explosive strength (Knihs et al., 2024; Santos et al., 2024) because they evaluate the ability to generate force rapidly, a characteristic that may contribute to performance during phases requiring acceleration and high propulsive demands. Previous studies have highlighted that sprint swimming performance is multifactorial and influenced by interactions among physiological, biomechanical, anthropometric, and neuromuscular factors (Price et al., 2024; Ruiz-Navarro et al., 2025). Therefore, neuromuscular assessments should be considered as complementary indicators rather than isolated determinants of competitive performance.

Push-ups were not associated with 100 m freestyle time in the Spearman bivariate analysis and were not retained in the final regression model. Although push-ups are commonly used to assess upper-body muscular endurance, this test may not fully capture the specific demands of swimming propulsion. Swimming performance depends on the interaction among strength, power production, stroke mechanics, technical efficiency, and the ability to apply force effectively against the water (Barbosa et al., 2014; Ruiz-Navarro et al., 2025). Similar considerations have been reported in the literature, in which the relationship between dry-land strength measures and swimming performance appears to depend on the specificity of the task evaluated (Morouço et al., 2011).

The relationship between core strength-endurance and swimming performance observed in this study aligns with previous research highlighting the importance of trunk stability and postural control in aquatic sports. Rivera-Rujana et al. (2024) emphasized the importance of lumbo-pelvic stability and postural control in athletes, suggesting that trunk function may contribute to efficient movement patterns. In swimming, maintaining body alignment and minimizing unnecessary oscillations may enhance technical efficiency; however, the present findings should be interpreted as an association, not as evidence that increased core strength alone improves performance.

Jump squats showed a significant Spearman bivariate association with shorter 100 m freestyle time, but this variable was not retained in the final regression model after adjustment for the other neuromuscular indicators. This finding suggests that lower-body explosive capacity may be related to sprint swimming performance at the bivariate level, although its independent contribution was not confirmed in the final multivariable model. Hernández et al. (2025) reported associations between strength-oriented training approaches and physical performance variables in young swimmers, while Price et al. (2024) emphasized that sprint swimming performance depends on the interaction among multiple physical and technical factors.

From a practical perspective, the results suggest that assessing reactive strength and core-related capacities may provide useful information for athlete monitoring and physical profiling among adolescent swimmers. However, recommendations for plyometric or core-strength training should be approached with caution because the present study did not evaluate training interventions. Although these capacities may be targets for performance development, experimental studies are needed to determine whether specific training strategies improve sprint swimming outcomes.

Limitations and future research

Several limitations should be considered when interpreting the findings of this study. First, the relatively small sample size (n=22) and the use of a backward-selection regression procedure may affect the stability of regression coefficients and increase the risk of model overfitting. The sensitivity sample-size analysis indicated that approximately 41 participants would be required for a three-predictor regression model assuming f^2=0.30, α=0.05, and power =0.80. Although the final model showed adequate explanatory capacity and no evidence of problematic multicollinearity, the results should be considered exploratory and require confirmation in larger samples with appropriate validation procedures.

Second, the cross-sectional design limits the interpretation of the observed relationships. Although neuromuscular variables were associated with 100 m freestyle performance, the present study does not allow for the establishment of causal relationships or the determination of whether changes in these characteristics would improve swimming performance (Funai et al., 2025). Longitudinal studies are necessary to evaluate the temporal relationship between neuromuscular development and competitive performance.

Third, biological maturation status was not assessed. Adolescence is characterized by considerable variability in growth and maturation processes, which may influence muscle development, strength expression, neuromuscular performance, and swimming outcomes. Future studies should incorporate maturation indicators to better differentiate the influence of biological development from training-related adaptations.

Fourth, although the study objective considered the relevance of explosive actions involved in phases such as starts and turns, these race components were not directly measured. Variables such as block start performance, underwater velocity, turn efficiency, stroke mechanics, stroke frequency, and technical parameters were not included in the present analysis. Therefore, references to these race phases should be interpreted as theoretical contexts that support the potential relevance of neuromuscular characteristics, rather than as directly evaluated mechanisms.

Additionally, both male and female swimmers were included in the analysis; however, sex-specific analyses were not performed due to the limited sample size. Given that biological, anthropometric, and neuromuscular differences between sexes may influence performance characteristics during adolescence, future studies with larger samples should consider stratified analyses or sex-specific models.

Future research should incorporate longitudinal and intervention-based designs to determine whether targeted neuromuscular training strategies, such as plyometric or core-strength programs, influence sprint swimming performance. Furthermore, integrating sport-specific biomechanical assessments with physiological, neuromuscular, and maturation-related variables may provide a more comprehensive understanding of the determinants of performance in adolescent swimmers.

Conclusions

The present study identified significant associations between neuromuscular characteristics and 100 m freestyle performance among adolescent swimmers. The final regression model indicated that the CMJ reactive strength index, squat jump contact time, and sit-up performance accounted for variability in swimming performance; however, given the cross-sectional design, small sample size, and exploratory nature of the model selection, these findings should not be interpreted as evidence of causal effects.

Among the variables analyzed, the countermovement jump reactive strength index showed the strongest standardized association with performance, suggesting that reactive strength may be a relevant neuromuscular characteristic in the physical profile of adolescent sprint swimmers. Core strength-endurance, assessed through sit-ups, also remained independently associated with race time and showed stable results in the robust sensitivity analysis.

From a practical perspective, the findings suggest that monitoring reactive strength and core-related capacities may inform athlete profiling and training planning. Squat jump contact time may provide complementary information, but its interpretation should be approached with caution because its statistical stability was weaker than that observed for RSI_CMJ and sit-ups. Recommendations for plyometric or core-strength training should be viewed as potential practical considerations based on observed associations rather than definitive evidence of training effectiveness. Future intervention studies are needed to determine whether targeted training strategies improve sprint swimming performance.

Finally, sprint swimming performance is influenced by multiple interacting factors. Although the present model explained more than half of the variability in performance, additional determinants, including stroke mechanics, technical efficiency, start and turn performance, physiological characteristics, anthropometric factors, and biological maturation, may also contribute to competitive outcomes. Future research integrating these variables through longitudinal and biomechanical approaches may provide a more comprehensive understanding of the determinants of performance in adolescent swimmers.

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Conflict of Interest
The authors reported no potential conflict of interest.

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