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ASSOCIATIONS BETWEEN MUSCLE STRENGTH, FLEXIBILITY, AND 50-METER FREESTYLE SWIMMING TIME

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ABSTRACT

This study examined how land-based strength and flexibility relate to 50 m sprint performance in 12 competitive swimmers. Cadet swimmers (n = 7) averaged 13.3 ± 0.49 years of age, 167.0 ± 5.19 cm in height, and 58.7 ± 16.5 kg in body mass; junior swimmers (n = 5) averaged 15.4 ± 0.55 years, 176.0 ± 7.33 cm, 64.2 ± 5.81 kg, and 8.20 ± 1.64 years of training. Pearson correlations revealed that sprint time was moderately negatively associated with push-ups (r = –.38), sit-ups (r = –.63), and long jump (r = –.62), less so with shoulder flexibility (r = –.31), and essentially unrelated to sit and reach (r = –.03). Because long jump and shoulder flexibility were highly collinear (r = .78; VIFs > 7), shoulder flexibility was excluded from regression. An AIC-based stepwise model retained only age-group and sit-up performance, explaining 50% of variance in sprint time, F(2, 9) = 4.50, p = .044. Although the overall model was significant, neither predictor reached individual significance. These results underscore the multifactorial nature of swim speed and suggest that composite land-based assessments, rather than isolated field tests, offer more stable, interpretable sprint performance indices. Future research should employ larger, longitudinal designs and integrate water-based biomechanical measures.

Key words: Swimming performance, core strength, flexibility, strength assessment, motor abilities

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INTRODUCTION

Swimming, a sport of intricate complexity and demanding physical exertion, has garnered considerable scholarly attention due to its rich physiological, technical, and social dimensions (Barbosa, Costa, & Marinho, 2013; Lätt et al., 2010; Özkadı et al., 2022). The multi-layered complexity of swimming is deeply rooted in the sophisticated interplay of biomechanical, anthropometric, and physiological elements that coalesce to shape a swimmer's performance. This combination of factors and their dynamic interactions render swimming a fertile field for scientific exploration and discovery (Lätt et al., 2010; Barbosa et al., 2013). A dominant objective within the research sphere of swimming is enhancing performance and developing efficient training protocols (Barbosa et al., 2013; Lätt et al., 2010; Özkadı et al., 2022). This pursuit has led researchers to delve into a wide array of variables, including but not limited to motor performance and anthropometric characteristics, within the specific context of swimming. A study by Aktug, Iri, and Top (2018) revealed a significant correlation between children and their 50m freestyle swimming performances, indicating the importance of motor skills. Further research by Demirkan et al. (2023) suggested that predictors from anthropometric and motor performance domains could differ with age progression across various swimming styles. These findings underscore the dynamic nature of swimming performance, which evolves in response to changes in a swimmer's physical stature and motor capabilities (Aktug et al., 2018; Demirkan et al., 2023).

The role of strength and power in swimming performance, especially in sprint events, has been frequently discussed in scholarly literature (West et al., 2011; Grant & Kavaliauskas, 2017). According to West et al. (2011), lower body strength and power significantly enhance performance at the start of 50m freestyle races, underscoring their importance during the initial phase. Likewise, Grant and Kavaliauskas (2017) observed improvements in essential physiological factors for swimming success after a 7-week resistance training program targeting young swimmers. These insights imply that incorporating strength and power training may offer potential performance advantages for swimmers, particularly in sprint disciplines (West et al., 2011; Grant & Kavaliauskas, 2017). Nevertheless, despite these findings, the literature lacks a unified view on the relative significance of various elements affecting swimming performance. While some studies underscore the importance of strength and power (West et al., 2011; Grant & Kavaliauskas, 2017), others emphasize the role of flexibility (Jagomägi & Jürimäe, 2005) or aerobic endurance (Demirkan et al., 2023; Özkadı et al., 2022). This divergence in findings reflects an ongoing gap in our understanding of the complex interplay of factors that shape swimming performance (Jagomägi & Jürimäe, 2005; Demirkan et al., 2023; Özkadı et al., 2022).

Against this backdrop, the present study seeks to clarify the relationship between strength and flexibility variables and swimming speed. Drawing from previous findings and theoretical considerations, we hypothesize that core strength, measured by the number of sit-ups completed in 30 seconds, may be significantly associated with swimming speed. Similarly, other variables such as the standing long jump, sit-and-reach test, push-up count, and shoulder flexibility might also show individual predictive value. However, given the multifactorial nature of swimming performance and the complexity of human movement, these hypotheses remain tentative and require empirical validation (Demirkan et al., 2023; Özkadı et al., 2022; West et al., 2011; Grant & Kavaliauskas, 2017; Jagomägi & Jürimäe, 2005). Scientific inquiry pertaining to swimming performance represents a complex and nuanced field, defined by the dynamic interplay of biomechanical, anthropometric, and physiological variables. Therefore, this research aims to investigate the associations between muscle strength, flexibility, and 50-meter freestyle swimming performance, in order to determine how these physical attributes influence swimming time. As investigations in this area progress, significant potential exists for generating deeper insights to guide evidence-based training strategies and promote more tailored approaches to performance enhancement. We hypothesized that greater muscle strength and higher flexibility are significantly associated with faster (shorter) 50-meter freestyle swimming times.

METHODS

Participants

Before data collection, we conducted an a priori power analysis in G*Power 3.1 (Faul et al., 2009) for a multiple regression (fixed model, R^2 deviation from zero). Assuming a squared multiple correlation (R^2 = 0.6), α = .05, *power* = .80, and two predictors, the analysis indicated a minimum of 11 participants. Our final sample of 12 swimmers was just above this threshold, suggesting sensitivity to detect smaller effects. Therefore, our study comprised twelve male swimmers who volunteered to participate in the current study and represented both the cadet and junior categories. All participants were members of the „Leskovac" Swimming Club in Leskovac, Serbia. Cadet swimmers (n = 7) had a mean age of 13.3 ± 0.49 years, stood 167.0 ± 5.19 cm tall, weighed 58.7 ± 16.5 kg, and reported 5.14 ± 2.67 years of formal training. Junior swimmers (n = 5) averaged 15.4 ± 0.55 years of age, 176.0 ± 7.33 cm in height, 64.2 ± 5.81 kg in body mass, and 8.20 ± 1.64 years of training experience. The criterion for participant selection was that all individuals were healthy and had been engaged in competitive swimming for at least two years. Additionally, all participants competed at the national level and trained six times per week. Detailed descriptions of the participants' physical attributes and fitness parameters are provided in Table 1. This study adhered to the principles outlined in the Declaration of Helsinki and received approval from the institutional ethics committee.

Design

The study employed an observational design, examining the correlation between various strength and flexibility variables and swimming speed. The goal was to minimize error and ensure clarity by maintaining a consistent testing environment and using standardized equipment. To ensure consistency and avoid variability, each participant was measured and performed all tests only once.

Procedures

Participants were asked to perform a series of physical tests, which included push-ups and sit-ups within 30 seconds, a long jump from a standing position, a shoulder flexibility test using a stick, and a sit-and-reach test. Following these tests, participants swam a 50-meter stretch using the crawl stroke as quickly as possible. The time taken to swim this distance (T50) was recorded for each participant. All tests were conducted under similar conditions to maintain consistency.

The 50-meter swimming speed (T50) test assessed the swimming speed in a large pool. Upon the starter's signal, the swimmers commence the race from the starting blocks, and the time is recorded electronically using the Alge Timing Optic 2 electronic timing system.

Push-up and Sit-up Tests:

Push-ups and sit-ups were utilized to assess the endurance of the arm and trunk muscles. The subject begins in the starting position, and upon the signal of the measurer, who also counts the repetitions, the subject performs either a push-up or sit-up and returns to the starting position. The test is performed for 30 seconds, and the total number of repetitions completed by the subject is recorded (Peulić, 2019).

Standing Long Jump Test:

A long-standing jump was employed to evaluate the explosive strength of the leg muscles. The subject performs a two-footed takeoff and lands on a mat as far as possible. A two-footed landing is mandatory. Three jumps are performed, and any incorrectly executed jumps are repeated (Peulić, 2019).

Shoulder Flexibility with Stick Test:

The shoulder flexibility with the stick test was used to assess the flexibility of the shoulder girdle muscles. The test is conducted with the subject's arms forward, holding a baton at one end with one hand and at a predetermined distance from the other. Upon the measurer's signal, the subject performs a rotational movement of the baton, attempting to reduce the distance between the hands. The result is recorded while the hands remain engaged on the baton (Okičić, 2007).

Sit and Reach Test:

The sit and reach test was used to measure the flexibility of the trunk extensor muscles. The subject, seated with legs extended, bends forward without flexing the knees, attempting to touch the farthest point on a meter scale in front of them. The maximum distance reached is recorded (Okičić, 2007).

50-Meter Swimming Speed Test (T50):

The 50-meter swimming speed (T50) test assessed the swimming speed in a large pool. Upon the starter's signal, the swimmers commence the race from the starting blocks, and the time is recorded electronically using the Alge Timing Optic 2 electronic timing system.

Measures

The primary outcome measure was the time to swim 50 meters (T50). Predictor variables comprised the number of push-ups and sit-ups completed in 30 seconds, long jump distance, shoulder flexibility, and sit-and-reach distance. These factors were chosen to reflect different aspects of physical fitness that may affect swimming speed. All measurements were noted in standard units (e.g., seconds, centimeters) for clarity in interpretation.

Data Analysis

All analyses were conducted in R Studio (version RStudio/2024.12.1+563). First, descriptive statistics (means, standard deviations) were computed separately for Cadet and Junior swimmers using the *psych* package. Next, we examined bivariate relationships among 50 m sprint time and all strength and flexibility measures with two-tailed Pearson correlations. To guard against multicollinearity, we calculated variance inflation factors (VIFs) for all predictors using *car*; variables exceeding a VIF threshold of 7 were flagged for removal. Given the high VIF for shoulder flexibility (*VIF* > 7, r = .78 with long jump), that measure was excluded from subsequent modeling. We then fitted a complete multiple linear regression predicting sprint time from age-group (Cadet vs. Junior), push-ups, sit-ups, standing long jump, and forward bend. An AIC-based stepwise selection procedure (both directions) was applied via *MASS::stepAIC()* to identify the most parsimonious model. Standardized (β) and unstandardized coefficients were obtained with *lm.beta*, and R^2, adjusted R^2, *F*-statistic, and residual standard error assessed overall model fit. Finally, model assumptions were checked by inspecting the four classic diagnostic plots (residuals vs. fitted, normal Q–Q, scale–location, and Cook's distance). Throughout, statistical significance was set at α = .05.

RESULTS

Descriptive statistics for cadet (n = 7) and junior (n = 5) swimmers are presented in Table 1. Cadets averaged 167.43 cm in height (*SD* = 5.19), 58.71 kg in weight (*SD* = 16.51), completed 26.86 ± 3.76 push-ups and 27.71 ± 6.60 sit-ups, jumped 190.71 ± 18.35 cm, showed 30.71 ± 8.38 cm of shoulder flexibility and 10.71 ± 1.89 cm on the sit-and-reach, and swam 50 m in 31.48 ± 3.76 s. Juniors averaged 175.80 cm (*SD* = 7.33), 64.20 kg (*SD* = 5.81), 34.60 ± 10.41 push-ups, 32.40 ± 2.61 sit-ups, 238.00

± 25.88 cm in the long jump, 63.80 ± 30.53 cm of shoulder flexibility, 13.00 ± 4.47 cm on the sit-and-reach, and 27.68 ± 1.20 s for 50 m.

Table 1. Descriptive Statistics by Category

Variable	N	Minimum	Maximum	Mean	Std. Dev
			Cadet		
Body Height (cm)	7	162.00	175.00	167.43	5.19
Body Weight (kg)	7	42.00	90.00	58.71	16.51
Push-ups (n)	7	20.00	30.00	26.86	3.76
Sit-ups (n)	7	17.00	35.00	27.71	6.60
Long jump (cm)	7	160.00	215.00	190.71	18.35
Shoulder flexibility (cm)	7	15.00	40.00	30.71	8.38
Sit and reach (cm)	7	10.00	15.00	10.71	1.89
T50 (s)	7	28.60	39.50	31.48	3.76
			Junior		
Body Height (cm)	5	167.00	185.00	175.80	7.33
Body Weight (kg)	5	59.00	74.00	64.20	5.81
Push-ups (n)	5	22.00	45.00	34.60	10.41
Sit-ups (n)	5	30.00	36.00	32.40	2.61
Long jump (cm)	5	200.00	270.00	238.00	25.88
Shoulder flexibility (cm)	5	10.00	84.00	63.80	30.53
Sit and reach (cm)	5	10.00	20.00	13.00	4.47
T50 (s)	5	26.10	29.30	27.68	1.20

Legend: N – number of participants, Min – minimal result, Max – maximal result, Mean – mean, Std. Dev – standard deviation

Pearson correlations among 50 m sprint time, push-ups, sit-ups, standing long jump, shoulder flexibility, and forward bend are displayed in Figure 1. Sprint time was moderately negatively associated with push-ups (r = –0.38), sit-ups (r = –0.63), and long jump (r = –0.62), and showed a smaller negative association with shoulder flexibility (r = –0.31); it was essentially unrelated to sit and reach (r = –0.03). Push-ups correlated strongly with sit-ups (r = 0.66), moderately with long jump (r = 0.46), and only weakly with shoulder flexibility (r = 0.18) and sit and reach (r = 0.13). Sit-ups were moderately related to long jump (r = 0.57) and shoulder flexibility (r = 0.28) but not to sit and reach (r = –0.12). The strongest intercorrelation was between long jump and shoulder flexibility (r = 0.78), while shoulder flexibility and forward bend shared a moderate association (r = 0.54). All other correlations were small (r < 0.30).

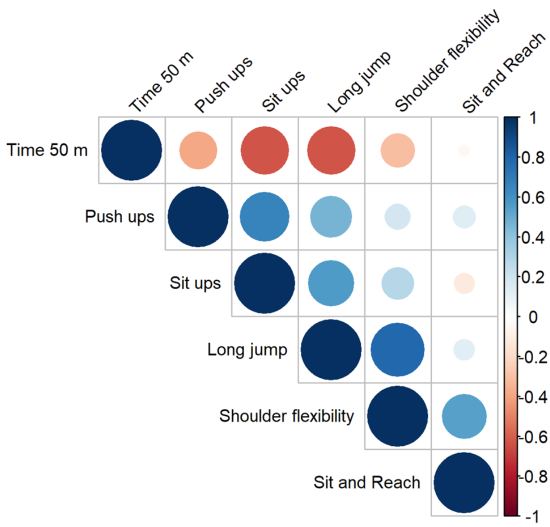

Figure 1. Correlogram of Pearson correlations among 50 m sprint time, push-ups, sit-ups, standing long jump, shoulder flexibility, and forward bend. Circle size and color intensity reflect the strength and direction of each association.

An initial multiple regression including group, push-ups, sit-ups, long jump, and sit and reach accounted for 53.7 % of the variance in 50 m sprint time (R^2 = .54, adjusted R^2 = .15), but did not reach significance, $F(5, 6) = 1.39$, p = .347. A subsequent stepwise regression retained only age group and sit-ups, yielding a significant model that explained 50.0 % of the variance (R^2 = .50, adjusted R^2 = .39), $F(2, 9) = 4.50$, p = .044. In this final model, group (Junior vs. Cadet) produced an unstandardized coefficient of β = −2.45, SE = 1.76, $t(9)$ = −1.39, p = .197, and sit-up performance produced β = −0.29, SE = 0.16, $t(9)$ = −1.81, p = .104.

Table 2. Stepwise Model: Coefficients & Fit Statistics

Predictor	**Unstd β**	Std β	**t**	**p**	**R**	**Adj R^2**	**Residual SE**	**F**	**p**
Group (Junior)	-2.448	-.363	-1.393	.197	.50	.39	2.714	4.50	.044
Sit-ups	-.289	-.471	-1.808	.104					

Unstd. Beta = Unstandardized regression coefficients values, Beta = Standardized regression coefficients values, t = Standardized regression coefficients significance tests, p = Standardized regression coefficients level of significance, R= Multiple regression coefficient, Adj R^2 = Adjusted multiple regression coefficient, Residual SE = residual standard error, F= Multiple regression analysis significance tests, P = Multiple correlation level of significance.

DISCUSSION

This study set out to untangle how land-based strength and flexibility measures relate to 50 m swim speed in a small sample of competitive swimmers. Drawing on a framework that views sprint performance as the product of intertwined biomechanical, neuromuscular, and maturational factors (Barbosa, Costa, & Marinho, 2013), we first fitted a comprehensive model including age-group, push-ups, sit-ups, standing long jump, sit and reach, and shoulder flexibility. However, diagnostics revealed that standing long jump and shoulder flexibility were so highly correlated (r = .78; *VIFs* > 7) that retaining both would destabilize estimates, so we omitted shoulder flexibility. Applying AIC-based stepwise regression to the remaining predictors yielded a parsimonious model in which only age-group and sit-up endurance were retained. This final model explained roughly half of the variance in sprint time and was statistically significant overall, underscoring the joint importance of maturation and core endurance. However, neither predictor was individually significant at conventional thresholds. In other words, the combined contribution of these factors, rather than any single land-based test, reliably relates to swim speed in our swimmers. Complementary Pearson correlations showed that faster sprint times co-occurred with better push-up, sit-up, and long-jump outcomes (r from –.38 to –.63), weaker associations with shoulder flexibility (r = –.31), and virtually no link to sit and reach (r = –.03), while the strongest intercorrelation was between long jump and shoulder flexibility. Taken together, these findings might reinforce the multifactorial framework of swimming performance (Barbosa, Costa, & Marinho, 2013) and extend prior biomechanical work (Lätt et al., 2010; Maszczyk et al., 2012) by showing that, especially in small samples, composite land-based models offer a more stable window into sprint capability than isolated measures.

Our results resonate with Okičić et al. (2012), who found that while a set of motor abilities collectively predicted swimming results, no single variable showed statistical significance. This supports the notion that the impact of physical qualities may be more noticeable at the multivariate level. However, other studies (Hawley et al., 1992; Johnson et al., 1993) have found significant individual relationships between swimming performance and power-related metrics, especially swimming-specific power and arm and leg strength. The non-significance of dryland measures in our study may be due to the lack of specificity to aquatic movement patterns. The potential role of sit-ups in our findings contrasts with prior research that highlights other predictors (Aktug et al., 2018; Demirkan et al., 2023; Dimitric, Cokorilo, & Bogdanovski, 2016). For instance, Dimitric et al. (2016) reported that arm span and leg strength were significant predictors of swimming performance among adolescent female swimmers. The contrast between their findings and ours may be attributed to methodological differences, age-related factors, or the performance test specificity. Notably, although flexibility is often regarded as a critical component of swimming technique, it did not emerge as an individually significant predictor in our analysis. This outcome diverges from earlier studies (Jagomägi & Jürimäe, 2005; Özkadı et al., 2022), which highlighted the importance of specific joint flexibility, such as knee and ankle mobility, in swimming performance. One possible explanation for this discrepancy is the general nature of the flexibility tests used in our study. These results suggest that future research should incorporate more precise, joint-specific flexibility assessments to better capture their potential influence on swimming outcomes.

Despite these insights, several important limitations qualify our conclusions. First, our small, cross-sectional sample limited statistical power and precluded any causal inferences; longitudinal tracking of the same swimmers would be needed to determine how changes in strength and flexibility drive improvements in swim speed over a season or career. Second, we relied exclusively on generalized dry-land field tests, which, while practical, do not measure the sport-specific neuromuscular coordination, stroke mechanics, and critical hydrodynamic forces in sprint swimming. Incorporating in-pool assessments (e.g., stroke index, push-off force, turn velocity) would provide a more direct window into speed's biomechanical and physiological determinants. Third, although we screened for multicollinearity and removed shoulder flexibility, other unmeasured factors such as limb lengths, body composition, limb-segment power, and technical proficiency undoubtedly influence test scores and sprint performance but were not captured here. Fourth, our use of data-driven stepwise regression, while helpful for parsimony, risks capitalizing on chance associations; replication in larger, independent samples with pre-specified predictor sets is essential to confirm the robustness of our findings. Finally, external influences, including training history, periodization strategy, nutrition, sleep quality, and psychological readiness, can acutely affect physical test performance and swim outcomes, yet were beyond this study's scope.

Nevertheless, the singular prominence of sit-up endurance in our final model aligns with evidence that a strong, stable core enhances body alignment, reduces drag, and improves force transmission during each stroke cycle (Mu-Yeop et al., 2021). This suggests that, besides classic power and plyometric exercises, coaches should prioritize core-specific endurance and stabilization drills, such as dynamic plank variations and resisted trunk rotations, that closely mimic the continuous trunk demands of sprint swimming. At the same time, our correlation analyses remind us that push-ups and long-jump performance remain moderately linked to speed, indicating value in maintaining a balanced dry-land regimen that develops upper-body pushing strength and lower-limb power. Looking ahead, future research should adopt a multidimensional, interdisciplinary approach. Larger and more diverse cohorts (across age groups, sexes, and performance levels) tracked longitudinally will help disentangle maturation effects from training adaptations. Integrating dry-land and in-water assessments, such as tethered swims, load-cell starts, and wearable accelerometers, will bridge the gap between field tests and actual swim mechanics. Moreover, incorporating anthropometric profiling, muscle architecture (via ultrasound), and neuromuscular fatigue markers (e.g., EMG during repeated sprints) can clarify how physical traits interact with technique to drive speed. Finally, exploring the role of recovery practices (sleep, nutrition, periodization) and psychological factors (motivation, arousal) will yield a truly holistic model of sprint performance. Therefore, our findings reinforce that no single dry-land test suffices to predict swim speed; instead, composite models that respect the sport's multifactorial nature and are validated across land and water offer the most reliable insights. For practitioners, this means designing individualized training plans that blend core endurance, power development, and technical skill work, tailored to each athlete's unique strengths and developmental stage.

CONCLUSION

In summary, our findings suggest that no single dry-land measure fully predicts 50 m swim speed in youth athletes; instead, performance emerges from the interplay of maturation and core endurance. Although we began with a broad suite of strength and flexibility tests, stepwise regression distilled the model to age-group and sit-up capacity, explaining half of the variance in sprint time. At the same time, long jump, push-ups, sit and reach, and shoulder flexibility proved redundant once multicollinearity was addressed. Correlation patterns further underscored these interdependencies, with only sit-ups showing a uniquely strong link to swimming speed. These results reinforce the need for a holistic, integrated approach to swimmer development that blends targeted core-endurance work with power and technical drills, rather than relying on individual field tests. Given our small sample, these conclusions remain preliminary; future research should employ larger, more diverse cohorts and combine land- and water-based assessments to build robust, generalizable models of sprint performance.

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