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APPLICATION OF SPORT-SPECIFIC STRENGTH-ENDURANCE EXERCISES FOR MALE ROWERS AGED 17–18 AT DANANG NATIONAL SPORT TRAINING CENTER, VIETNAM

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Abstract:
This study addresses a critical gap in endurance development for adolescent male lightweight rowers by designing and evaluating a rowing-specific strength-endurance training program tailored to their physiological characteristics and competitive demands. Conducted at the Danang National Sports Training Center in Vietnam, this mixed-methods study incorporated literature review, expert interviews (n = 26), pedagogical observations, and a six-month training intervention. Twenty male rowers aged 17–18 were randomly divided into experimental (n = 10) and control (n = 10) groups. The experimental group followed a specialized, periodized endurance training regimen, while the control group continued their regular training. Performance was assessed before and after the intervention using six validated indicators: 2000m rowing time, VO_2max, 1000m split-time variability, pull-up and push-up endurance, and anaerobic power. The experimental group showed statistically significant improvements across all indicators ($p < 0.05$), with gains ranging from 8.2% to 44.2%, while the control group exhibited only marginal, non-significant changes. Key exercises, such as timed 2000m rowing, resistance-based pulling, and 1000m repeated runs, received over 85% consensus among experts for their relevance and effectiveness. These findings underscore the importance of integrating sport-specific, structured strength-endurance training to enhance aerobic and anaerobic capacity, muscular endurance, and pacing efficiency in youth rowing. This study provides a scientifically grounded model for optimizing endurance performance in adolescent rowers and offers practical guidance for coaches and sports training centers, particularly in developing countries. Future research should

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explore long-term adaptations and assess the model's applicability across different age groups and rowing disciplines.

Keywords: rowing, endurance training, adolescent athletes, VO_2max, rowing-specific strength-endurance

1. Introduction

Vietnam has achieved notable success in international rowing competitions, particularly in women's events. However, male lightweight rowers-especially those in the adolescent age group-remain underrepresented in both development initiatives and scientific research. Since rowing was officially introduced nationwide in 1997, the sport has expanded across more than 20 provinces, with the Danang National Sports Training Center emerging as a central hub for nurturing young talent. Despite these advancements, structured training programs specifically targeting endurance development in 17–18-year-old male rowers remain scarce.

Success in rowing, especially in the 2000-meter event, requires a high level of both aerobic and anaerobic endurance, in addition to consistent technical execution. Existing training practices in Vietnam tend to adopt a generalized approach that often overlooks individual physiological maturity and energy system demands. This lack of specificity may contribute to the inconsistent performances observed at regional competitions such as the SEA Games, indicating that current training regimens may be insufficient for preparing young male athletes for elite-level competition.

Furthermore, few studies have systematically developed or assessed endurance training protocols tailored for adolescent male rowers. Most existing literature focuses primarily on general aerobic conditioning, neglecting integrated strength-endurance approaches that are biomechanically aligned with rowing. Moreover, there is a noticeable absence of mixed-method research, combining expert consultation, empirical observation, and controlled intervention trials to validate training strategies in this demographic.

2. Problem Statement

Vietnamese male lightweight rowers exhibit considerable athletic potential; however, their inconsistent performances at regional competitions reveal critical deficiencies in current training methodologies. The Danang National Sports Training Center, a key institution for athlete development, currently lacks a scientifically validated endurance training framework specifically designed for adolescent male rowers. In the absence of such targeted interventions, these athletes face reduced training efficiency, elevated injury risks, and limited success on the competitive stage. Bridging this gap necessitates a comprehensive evaluation of existing endurance capabilities and the development of evidence-based, sport-specific training programs tailored to the physiological and technical demands of rowing.

3. Methods

This study adopted a mixed-methods approach to design and assess a sport-specific strength-endurance training program for 17–18-year-old male lightweight quad scull rowers at the Danang National Sports Training Center.

3.1 Literature Review

A systematic review of peer-reviewed journal articles, coaching manuals, and scientific reports was conducted to establish the theoretical foundation and identify endurance demands relevant to competitive rowing.

3.2 Expert Interviews

Two rounds of semi-structured interviews were conducted with 26 rowing experts, including coaches, sports scientists, and referees, to determine appropriate endurance performance indicators and exercise modalities. Test reliability was verified using Pearson's correlation ($r > 0.85$, $p < 0.05$).

3.3 Pedagogical Observations

Observations of routine training sessions were carried out to identify gaps in current coaching practices and to evaluate their alignment with rowing-specific strength-endurance requirements.

3.4 Experimental Design

A six-month training intervention (January–July 2025) was implemented. Twenty male rowers were randomly assigned to an experimental group ($n = 10$) and a control group ($n = 10$). The experimental group followed a customized strength-endurance training protocol, while the control group continued their standard regimen. Performance outcomes were assessed using six validated tests, including 2000m rowing time, VO_2max, upper-body muscular endurance (pull-ups, push-ups), and anaerobic power.

3.5 Statistical Analysis

Data were processed using SPSS software. Pearson correlation was employed to verify test reliability, and both paired and independent-samples t-tests were used to evaluate within-group (pre- vs. post-test) and between-group differences. Statistical significance was set at $p < 0.05$.

4. Results of Research

4.1 Selection of Endurance Tests and Exercises

To establish a reliable basis for assessing and improving endurance performance in adolescent male rowers, this study examined the relationship between specific physical performance indicators and the likelihood of being classified as a Priority 1 athlete during the selection process. Two rounds of expert interviews were conducted, and selection data were analyzed using Pearson correlation coefficients (r) to determine the strength of association between each test and Priority 1 classification rates.

Table 1: Results of Expert Interviews for Selecting Strength Endurance Tests for Male Rowers Aged 17–18

Test	Round 1 (% Priority 1)	Round 2 (% Priority 1)	Correlation (r)	p-value
2000m Rowing Time	97.31	99.15	0.92	< 0.05
VO_2max (Relative)	93.46	93.46	0.9	< 0.05
Pull-up Strength Endurance (Max Reps)	83.92	83.92	0.88	< 0.05
Push-up Strength Endurance (Max Reps)	80.08	80.08	0.87	< 0.05
1000m Split-Time Difference	87.77	87.77	0.89	< 0.05
Anaerobic Power (W/kg)	91.62	91.62	0.91	< 0.05

The results demonstrated consistently strong correlations across all six selected indicators, with r-values ranging from 0.87 to 0.92 ($p < 0.05$). The 2000m rowing time showed the highest correlation (r = 0.92), confirming its critical role as a key benchmark for overall rowing capacity. Both relative VO_2max (r = 0.90) and anaerobic power (W/kg) (r = 0.91) also exhibited high correlations, reinforcing the importance of well-developed aerobic and anaerobic energy systems for elite performance. The 1000m split-time difference (r = 0.89) further highlighted the relevance of pacing consistency, while upper-body strength endurance indicators-pull-ups (r = 0.88) and push-ups (r = 0.87)-provided additional, though slightly less predictive, support for athletic potential.

In parallel, two rounds of expert interviews with 26 experienced coaches and sport scientists were conducted to identify the most appropriate exercises for developing strength-endurance in 17–18-year-old male rowers. Each exercise was evaluated based on three criteria: (1) percentage of Priority 1 selections, (2) mean rating on a 3-point scale (1 = Not suitable; 3 = Highly suitable), and (3) expert consensus (≥85% agreement with score ≥2.5).

The highest-rated exercises included timed 2000m rowing, resistance-based pulling, 1000m repeated runs, continuous 20km rowing, and combined sports activities (e.g., rowing circuits with bodyweight training). These exercises achieved ≥96% Priority 1 selection and mean scores above 2.9 in both rounds, demonstrating strong expert agreement on their effectiveness and relevance. Conversely, exercises falling below the 85% consensus threshold were excluded from the final program due to insufficient suitability.

Based on the established criteria, the research team conducted two rounds of expert interviews to identify the most appropriate exercises for developing sport-specific strength endurance in 17–18-year-old male rowers. A total of 26 experts, including experienced rowing coaches and sport scientists, participated in the evaluation process. Each exercise was rated using a 3-point Likert scale (1 = Not suitable, 2 = Moderately suitable, 3 = Highly suitable). In addition, the percentage of Priority 1 selections was recorded, and the level of expert agreement was determined (defined as ≥ 85% of experts assigning a score of at least 2.5). Exercises that received high mean ratings, strong Priority 1 selection rates, and expert consensus were considered effective and practically applicable to rowing-specific endurance development. Conversely, exercises that did not meet the consensus threshold were excluded from the proposed program. The detailed results are presented in Table 2 below.

Table 2: Results of Two Rounds of Expert Interviews for Selecting Strength Endurance Exercises for Male Rowers Aged 17–18 (n=26)

Exercise	**Round 1 (% Priority 1)**	**Round 2 (% Priority 1)**	**Mean Score (1–3)**	**Agreement (% > 85%)**
2000m Timed Rowing	99	99	2.98	> 85
Resistance Pulling Strength Endurance	99	99	2.95	> 85
1000m Repeated Runs	99	99	2.96	> 85
Continuous 20km Rowing	99	99	2.92	> 85
Combined Sports Activities	96	96	2.9	> 85
(Other exercises, e.g., 200m Variable Speed Swimming)	< 85	< 85	< 2.0	< 85

The results from two rounds of expert interviews (n = 26) indicate a high level of consensus regarding the most appropriate exercises for developing strength endurance in 17–18-year-old male rowers. Five exercises met all three selection criteria: a Priority 1 selection rate of ≥ 96%, a mean score of ≥ 2.90 on a 3-point scale, and an expert agreement level of ≥ 85%.

Among these, 2000m timed rowing received the highest overall evaluation, with a mean score of 2.98 and a 99% Priority 1 selection rate in both rounds. This underscores its critical role as both a performance assessment tool and a core component of sport-specific endurance training. Similarly, resistance-based pulling, 1000m repeated runs, and continuous 20km rowing all scored above 2.90 and achieved a 99% Priority 1 selection rate, demonstrating strong expert support for their physiological relevance and application in rowing.

Notably, combined sports activities-such as circuit training involving rowing and bodyweight exercises-also received favorable evaluations (96% Priority 1 selection, mean score = 2.90), reflecting expert appreciation for integrative training methods that target both muscular and cardiovascular endurance in adolescent athletes.

Conversely, other exercises, such as 200m variable speed swimming, did not meet the expert consensus threshold (< 85%) and received considerably lower mean scores (<

2.0), indicating limited relevance and suitability for inclusion in a rowing-specific strength-endurance training regimen.

In summary, these findings validate a core group of expert-endorsed exercises that serve as a scientifically grounded foundation for designing structured strength-endurance programs tailored to the physiological and technical demands of adolescent rowing.

4.2 Pre-Experiment Endurance Assessment

Prior to implementing the experimental training program, a comprehensive pre-intervention assessment was conducted to evaluate the baseline endurance capacity of the study participants. This assessment aimed to ensure group equivalence between the experimental and control groups, thereby establishing a valid basis for subsequent comparisons.

Six key performance indicators were measured, including upper-body muscular endurance (pull-ups and push-ups), aerobic and anaerobic capacity (VO_2max and W/kg), pacing stability (1000m split-time difference), and overall rowing performance (2000m time trial). Independent samples t-tests were performed to detect any statistically significant differences between groups at baseline.

The detailed results of these pre-experiment assessments are presented in Table 3.

Table 3: Pre-Experiment Endurance Assessment for Male Rowers Aged 17–18, Danang National Sport Training Center, Vietnam (n=20)

Test	Experimental Group (n=10)	Control Group (n=10)	$t_{\text{-statistic}}$	$P_{\text{-value}}$
Pull-up Strength-Endurance (reps)	12 ± 2.5	13 ± 2.3	0.931	0.364
Push-up Strength-Endurance (reps)	29 ± 5.0	28 ± 4.8	0.456	0.654
1000m Split-Time Difference (s)	22 ± 7.8	23 ± 8.2	0.279	0.783
2000m Rowing Time (min:s)	7:15 ± 0:20	7:20 ± 0:22	0.532	0.601
VO_2max (ml/kg/min)	58 ± 3.5	57 ± 4.0	0.595	0.559
Anaerobic Power (W/kg)	7.0 ± 0.7	6.9 ± 0.8	0.297	0.77

($t_{\text{-statistic}} < t_{\text{-value}} = 2.101$)

The data presented in Table 3 indicate that there were no statistically significant differences between the experimental and control groups across all physical performance indicators prior to the intervention. All p-values were greater than 0.05, and all t-values were below the critical threshold ($t_{\text{-value}} = 2.101$), confirming the baseline equivalence of the two groups.

Specifically, upper-body muscular endurance, measured through pull-up and push-up tests, showed comparable results between groups (pull-ups: 12 ± 2.5 vs. 13 ± 2.3 repetitions, $p = 0.364$; push-ups: 29 ± 5.0 vs. 28 ± 4.8 repetitions, $p = 0.654$). The 1000m split-time difference, which reflects pacing control, also demonstrated no meaningful difference (22 ± 7.8 seconds vs. 23 ± 8.2 seconds, $p = 0.783$).

In terms of overall endurance, 2000m rowing times were nearly identical between groups (7:15 ± 0:20 vs. 7:20 ± 0:22, $p = 0.601$). Similarly, aerobic capacity (VO_2max: 58 ± 3.5

vs. 57 ± 4.0 ml/kg/min, $p = 0.559$) and anaerobic power (7.0 ± 0.7 vs. 6.9 ± 0.8 W/kg, $p = 0.770$) showed no statistically significant differences.

These findings confirm that the two groups were homogeneous at baseline, thereby ensuring the internal validity of the experimental design. As a result, any observed changes in post-intervention performance can be attributed with confidence to the effects of the training program rather than to initial group discrepancies.

Based on the results of six specialized performance tests, athletes' outcomes were categorized into five levels: Excellent, Good, Average, Below Average, and Poor, in accordance with established benchmarks used in rowing-specific training.

This classification offers an objective reflection of the athletes' baseline physical condition, serving as a foundation for identifying subgroups requiring focused development, adjusting training curricula appropriately, and enabling accurate assessment of post-intervention progress.

The detailed classification results are presented in Table 4 below.

Table 4: Overall Pre-Experiment Strength Endurance Status for Male Rowers Aged 17–18, Danang National Sport Training Center, Vietnam (n=20)

Test	Mean ± SD	Excellent (%)	Good (%)	Average (%)	Below Average (%)	Poor (%)
Pull-up Strength Endurance (reps)	13 ± 2.5	5	20	50	20	5
Push-up Strength Endurance (reps)	29 ± 5.0	5	25	45	20	5
1000m Split-Time Difference (s)	22 ± 8.0	5	15	50	20	10
2000m Rowing Time (min:s)	7:15 ± 0:20	5	15	45	25	10
VO_2max (ml/kg/min)	58 ± 4.0	5	20	45	25	5
Anaerobic Power (W/kg)	7.0 ± 0.7	5	15	50	25	5

The results in Table 4 illustrate the distribution of baseline strength-endurance performance among 17–18-year-old male lightweight rowers prior to the intervention. Overall, the data show that the majority of athletes fell within the Average category across most test indicators, with fewer individuals achieving Excellent or Good levels, and a notable proportion categorized as Below Average or Poor.

For pull-up strength endurance, 50% of athletes performed at an average level, while only 5% reached the excellent range. Similarly, push-up performance was concentrated in the average (45%) and good (25%) ranges, suggesting moderate upper-body endurance across the cohort.

The 1000m split-time difference, a key indicator of pacing control, also revealed that 50% of rowers performed at an average level, while 30% scored below average or poor, reflecting limitations in energy regulation and race consistency.

Performance in the 2000m rowing test, representing overall endurance, was more varied: only 20% achieved good to excellent levels, while 35% fell below average or poor, indicating a general need for improvement in sustained aerobic capacity.

In terms of physiological measures, VO_2max followed a similar pattern, with 45% of athletes in the average range and 30% falling below average, further highlighting the inconsistency in aerobic conditioning. Anaerobic power also showed a concentration around the average (50%), but with 30% performing below expected standards.

In summary, the distribution of performance levels suggests that while the group possesses a foundational level of strength-endurance, there is substantial room for improvement, particularly among athletes in the lower performance brackets. These results support the implementation of a targeted, sport-specific training intervention to elevate performance across the full spectrum of athletes.

4.3 Post-Experiment Endurance Outcomes

Table 5 presents the post-experiment endurance performance outcomes of 17–18-year-old male lightweight rowers at the Danang National Sports Training Center, comparing results between the experimental group and the control group (n = 10 each). While the experimental group underwent a structured, rowing-specific strength-endurance training intervention over a six-month period, the control group followed their standard training regimen.

The table reports the mean ± standard deviation (SD) for each performance indicator after the intervention, alongside the percentage improvement from pre-test values and the $p_{\text{-values}}$ derived from independent $t_{\text{-tests}}$. These metrics provide insight into the effectiveness of the applied training program and the extent to which it influenced endurance development in the experimental group relative to the control group. The detailed results are summarized in Table 5 below.

The results in Table 5 clearly demonstrate the positive impact of the strength-endurance training intervention on the experimental group when compared to the control group across all six performance indicators. Post-test improvements were significantly greater in the experimental group, with all between-group comparisons reaching statistical significance ($p < 0.05$).

In terms of upper-body muscular endurance, the experimental group exhibited substantial gains in both pull-ups (38.46% improvement, $p = 0.01$) and push-ups (35.7% improvement, $p = 0.005$), compared to only modest improvements in the control group (12.0% and 11.1%, respectively). These differences were statistically significant, with $p = 0.002$ for pull-ups and $p = 0.001$ for push-ups.

The experimental group also showed remarkable improvement in pacing stability, as evidenced by the 1000m split-time difference, which decreased by 44.2% ($p = 0.01$), compared to just 8.7% in the control group. The between-group comparison yielded a statistically significant result ($p = 0.005$), indicating enhanced control over energy output throughout the race distance.

Table 5: Post-Experiment Endurance Assessment for Male Rowers Aged 17–18, Danang National Sports Training Center, Vietnam (n = 20)

Test	Experimental Group (n=10) Post Mean ± SD	% Improvement	$p_{\text{-value}}$	Control Group (n=10) Post Mean ± SD	% Improvement	$t_{\text{-statistic}}$	$P_{\text{-value}}$
Pull-up Strength-Endurance (reps)	18 ± 2.2	38.46	0.01	14 ± 2.8	12.0	3.552	0.002
Push-up Strength-Endurance (reps)	38 ± 4.0	35.7	0.005	30 ± 5.2	11.1	3.856	0.001
1000m Split-Time Difference (s)	12 ± 4.5	44.2	0.01	20 ± 6.5	8.7	-3.200	0.005
2000m Rowing Time (min:s)	6:45 ± 0:12	8.2	0.001	7:25 ± 0:18	2.1	-5.847	< 0.001
VO_2max (ml/kg/min)	60 ± 2.8	8.1	0.01	56 ± 3.5	2.9	2.822	0.011
Anaerobic Power (W/kg)	7.2 ± 0.5	9.1	0.01	6.5 ± 0.6	2.4	2.834	0.011

($t_{\text{-statistic}} > t_{\text{-value}} = 2.101$)

Note: For performance indicators measured in time (e.g., 1000m split-time, 2000m rowing time), a reduction in value indicates an improvement in performance. Therefore, negative percentage changes in these variables reflect enhanced endurance and efficiency.

The most notable performance enhancement was observed in 2000m rowing time, a key indicator of overall endurance. The experimental group improved by 8.2% (from ~7:15 to 6:45 min:s), while the control group showed only a 2.1% gain. The large t-value (-5.847) and extremely low *p*-value (< 0.001) highlight the strong efficacy of the intervention.

Physiologically, the experimental group experienced significant gains in both VO_2max (8.1% improvement, $p = 0.01$) and anaerobic power (9.1%, $p = 0.01$), indicating enhanced cardiorespiratory capacity and energy system development. These improvements were statistically superior to those in the control group, which showed minimal changes (VO_2max: 2.9%; anaerobic power: 2.4%).

In summary, the findings confirm the effectiveness of the specialized strength-endurance training program in significantly improving rowing-specific performance, muscular endurance, and physiological capacity in adolescent male lightweight rowers. The intervention yielded both statistically and practically meaningful improvements across all tested domains.

Table 6 provides a side-by-side comparison of endurance-related performance outcomes for both the experimental and control groups before and after the six-month intervention. This within-group analysis aims to evaluate the degree of improvement resulting from the specialized strength-endurance training program applied to the experimental group, compared with the standard routine followed by the control group. The results reveal substantial and consistent improvements across all performance indicators in the experimental group, including upper-body muscular endurance, pacing stability, rowing performance, and both aerobic and anaerobic capacity. In contrast, the control group showed only modest gains or, in some cases, no meaningful change. Statistical analysis using paired sample t-tests confirmed that the observed improvements in the experimental group were statistically significant ($p < 0.05$) across all variables, thereby reinforcing the effectiveness of the intervention.

Detailed comparisons of pre- and post-intervention performance are presented in Table 6 below.

Table 6: Comparison of Pre- and Post-Intervention Results Male Rowers Aged 17–18, Danang National Sports Training Center, Vietnam (n = 20)

Indicator	Group	Pre-Test (Mean ± SD)	Post-Test (Mean ± SD)	% Improvement	p-value
Pull-up Strength-Endurance (reps)	Experimental	12 ± 2.5	18 ± 2.2	38.46	0.002
	Control	13 ± 2.3	14 ± 2.8	12.00	> 0.05
Push-up Strength-Endurance (reps)	Experimental	29 ± 5.0	38 ± 4.0	35.70	0.001
	Control	28 ± 4.8	30 ± 5.2	11.10	> 0.05
1000m Split-Time (s)	Experimental	22 ± 7.8	12 ± 4.5	-44.2	0.005
	Control	23 ± 8.2	20 ± 6.5	-8.7	> 0.05
2000m Rowing Time (min:s)	Experimental	7:15 ± 0:20	6:45 ±0:12	-8.2	< 0.001
	Control	7:20 ± 0:22	7:25 ± 0:18	+2.1 (decline)	> 0.05
VO_2max (ml/kg/min)	Experimental	58 ± 3.5	60 ± 2.8	8.10	0.011
	Control	57 ± 4.0	56 ± 3.5	-2.9 (decline)	> 0.05
Anaerobic Power (W/kg)	Experimental	7.0 ± 0.7	7.2 ± 0.5	9.10	0.011
	Control	6.9 ± 0.8	6.5 ± 0.6	-2.4 (decline)	> 0.05

Note: For performance indicators measured in time (e.g., 1000m split-time, 2000m rowing time), a reduction in value indicates an improvement in performance. Therefore, negative percentage changes in these variables reflect enhanced endurance and efficiency.

Table 6 presents a comparative analysis of pre- and post-intervention performance for both the experimental and control groups. The results clearly show that the **experimental group experienced statistically significant improvements** across all measured indicators ($p < 0.05$), while the control group demonstrated **only minor improvements or even declines**, none of which reached statistical significance.

In the **pull-up test**, the experimental group improved by **38.46%** (from 12 to 18 repetitions, $p = 0.002$), compared to just a **12% gain** in the control group, which was not statistically significant ($p > 0.05$). A similar trend was observed in **push-up performance**, where the experimental group improved by **35.7%** ($p = 0.001$), while the control group's improvement of **11.1%** was again not significant.

For the **1000m split-time difference**, a critical indicator of pacing control, the experimental group showed a remarkable **44.2% reduction**, indicating better race consistency, while the control group improved only **8.7%**, a non-significant change ($p > 0.05$).

In terms of **overall endurance**, measured by the **2000m rowing time**, the experimental group reduced their average time by **8.2%** (from 7:15 to 6:45, $p < 0.001$), while the control group actually showed a **2.1% decline** in performance-suggesting potential regression due to lack of targeted adaptation.

Physiological indicators also showed clear divergence. The **VO_2max** of the experimental group increased by **8.1%** ($p = 0.011$), while the control group experienced a **2.9% decline**, which was not statistically significant. Likewise, **anaerobic power** improved by **9.1%** in the experimental group ($p = 0.011$), while the control group declined by **2.4%**, again without significance.

In summary, these results confirm the **efficacy of the targeted strength-endurance intervention**, which produced significant improvements in muscular endurance, pacing, and physiological performance. The control group, which did not receive the specialized training, failed to achieve comparable progress, further validating the value of the intervention protocol.

4.4 Proposed Chart for Comparative Analysis

To visually represent the outcomes of the intervention, a **bar chart** is proposed to compare the **percentage improvements** across all six performance tests between the **experimental** and **control** groups. This graphical presentation enhances interpretability by clearly illustrating the **magnitude of improvement** resulting from the tailored strength-endurance training program.

The chart highlights the significant advantage gained by the experimental group in every measured indicator, including muscular endurance, aerobic capacity, anaerobic power, and rowing-specific performance, thereby reinforcing the effectiveness of the targeted intervention, as detailed in the statistical results above.

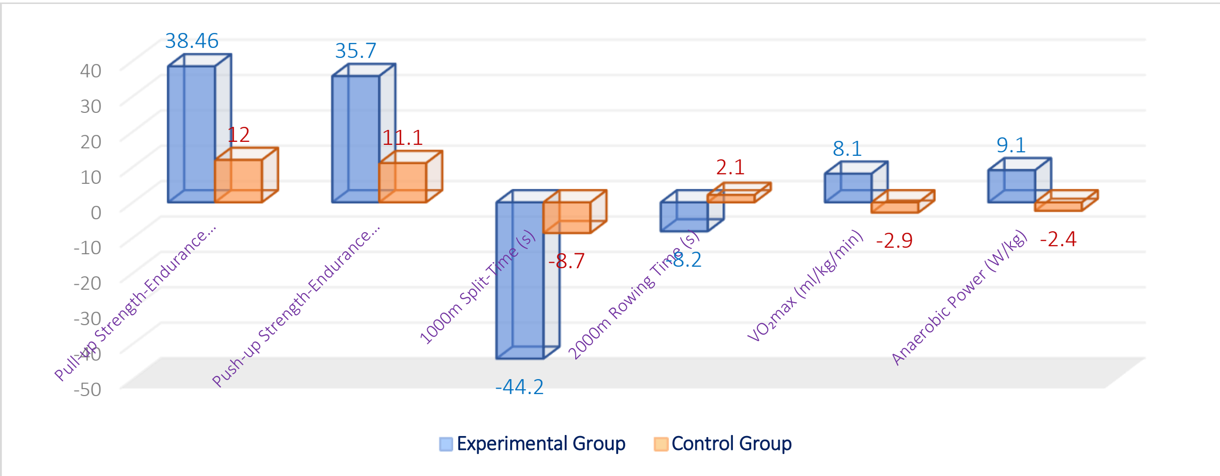

Figure 1: Comparison of Growth Rates Between the Two Groups

5. Discussion

The findings of this study provide robust empirical support for the effectiveness of a structured, rowing-specific strength-endurance training program tailored for 17–18-year-old male lightweight rowers. The statistically significant improvements observed across all six performance indicators in the experimental group underscore the superiority of targeted, sport-specific training protocols over generalized endurance regimens commonly used in adolescent rowing development.

The observed enhancement in 2000m rowing performance reflects not only improved aerobic capacity but also refined technical execution. This outcome aligns with previous research by Cosgrove *et al.* (1999) and Ingham *et al.* (2002), both of whom identified aerobic power as a key determinant of rowing success. The decrease in 2000m completion time in the experimental group indicates a positive adaptation to both central and peripheral physiological demands of high-intensity endurance rowing.

Significant improvements in VO_2max and pacing consistency further confirm the efficacy of the intervention in enhancing cardiorespiratory fitness and race control. These outcomes correspond with the principles advocated by Mujika (2021), who emphasized the importance of periodized endurance training in youth athletes, and Seiler's (2010) model of polarized training that integrates low-intensity aerobic base work with strategically placed high-intensity sessions.

Notably, the gains in anaerobic power and muscular endurance suggest that the training program effectively stimulated both glycolytic and oxidative energy pathways. This dual-system development is crucial for rowing, a sport requiring sustained force output over extended durations. The importance of muscular endurance for stroke maintenance and fatigue resistance is well documented in the work of Tesch (1983), further validating the design of the present training protocol.

The high level of expert consensus (>85%) on the selected training exercises, combined with validated testing procedures, reinforces the study's methodological rigor. The use of expert interviews, as well as alignment with the athlete development model proposed by Jones *et al.* (2020), ensures that the intervention was both evidence-based and practically relevant for adolescent athletes.

In addition, training intensity monitoring-a frequently neglected aspect in youth programs-was carefully managed in this study through structured intensity zones (80–95% effort) and periodic performance testing. This approach directly addresses concerns raised by Treff *et al.* (2021) regarding training load and recovery balance in adolescent rowers and supports the notion that well-calibrated programs can promote optimal adaptations without elevating the risk of overtraining.

Overall, the program's effectiveness is attributed not only to the statistically significant performance gains but also to the integration of sound physiological principles, expert validation, and practical application. These results support the broader implementation of individualized, sport-specific endurance training models in youth rowing development systems, particularly in contexts where training resources and scientific oversight may be limited.

6. Conclusion

This study demonstrated that a structured, rowing-specific strength-endurance training program can significantly enhance performance among 17–18-year-old male lightweight rowers. Through a scientifically grounded, evidence-based approach combining expert consultation, systematic observation, and controlled experimentation, the intervention led to statistically significant improvements across all measured indicators, including muscular endurance, aerobic capacity, anaerobic power, pacing control, and 2000m rowing performance.

The findings confirm that traditional, non-individualized training programs may be insufficient to meet the physiological demands of competitive rowing in adolescent male athletes. In contrast, individualized and periodized interventions, tailored to the unique energy system requirements and technical demands of rowing, offer clear advantages in optimizing performance development.

Moreover, the application of validated testing protocols and expert-reviewed exercises ensures the practical relevance and replicability of the training model. These results contribute valuable insights to the field of youth athletic development and offer a replicable model for rowing federations and training centers aiming to enhance competitive outcomes.

In conclusion, this study supports the integration of scientifically designed endurance programs into national youth rowing curricula. With proper implementation and monitoring, such programs can serve as a catalyst for improving athlete preparedness, reducing injury risk, and raising the overall standard of performance in competitive rowing.

Conflict of Interest Statement

The authors declare no financial conflicts of interest related to this research.

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