2024, Retos, 61, 1025-1030

The effect of anaerobic interval Air Rowing Training (AIART) on increasing strength endurance of upper body muscles in rowing athletes

El efecto del entrenamiento de remo aéreo a intervalos anaeróbicos (AIART) en el aumento de la fuerza y resistencia de los músculos de la parte superior del cuerpo en atletas de remo

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Abstract. This study aims to explore in depth how interval training with an Air Rower can be optimized to support maximum performance in rowing athletes. The research method applied is a true-experimental design with a pretest-posttest control group design, involving 20 male rowing athletes aged 18-20 years, divided into two groups: the control group (G_1; *n* = 10), and the treatment group (G_2; n = 10). The Anaerobic Interval Air Rower Training (AIART) program was conducted at an intensity of 85-95% HRmax, with a frequency of 3 times per week for 6 weeks. Data was collected by evaluating muscle strength using a dynamometer, while muscle endurance was tested using the upper body pull-up test performed over one minute. Data analysis was conducted using the independent sample t-test, and effect size evaluation was performed using Cohen's d. The results showed a significant increase in the mean delta (Δ) muscle strength between G_1 and G_2 (0.50±0.97 vs 2.50±0.53 kg, p=0.001) and had a large effect size with a Cohen's d value of 2.558. Similarly, the mean Δ muscle endurance showed a significant increase between G_1 and G_2 (0.21±0.67 vs 2.74±0.65 times, p=0.001) and had a large effect size with a Cohen's d value of 3.855. Therefore, it is concluded that the AIART intervention conducted over 6 weeks on rowing athletes is proven to be effective in improving muscle strength and endurance.
Keywords: Muscle strength, muscle endurance, rowing athletes, physical performance

Resumen. Este estudio tiene como objetivo explorar en profundidad cómo se puede optimizar el entrenamiento a intervalos con un Air Rower para respaldar el máximo rendimiento en los atletas de remo. El método de investigación aplicado es un diseño verdaderamente experimental con un diseño de grupo control pretest-postest, en el que participaron 20 deportistas de remo masculinos con edades entre 18 y 20 años, divididos en dos grupos: el grupo control (G_1; n = 10) y el grupo de tratamiento. (G_2;n=10). El programa Anaeróbico Interval Air Rower Training (AIART) se realizó a una intensidad del 85-95% FCmáx, con una frecuencia de 3 veces por semana durante 6 semanas. Los datos se recopilaron evaluando la fuerza muscular utilizando un dinamómetro, mientras que la resistencia muscular se evaluó mediante la prueba de dominadas de la parte superior del cuerpo realizada durante un minuto. El análisis de los datos se realizó mediante la prueba t de muestra independiente y la evaluación del tamaño del efecto se realizó mediante la d de Cohen. Los resultados mostraron un aumento significativo en la fuerza muscular delta media (Δ) entre G_1 y G_2 (0,50 ± 0,97 frente a 2,50 ± 0,53 kg, p = 0,001) y tuvieron un tamaño de efecto grande con un valor d de Cohen de 2,558. De manera similar, la resistencia muscular Δ media mostró un aumento significativo entre G_1 y G_2 (0,21 ± 0,67 frente a 2,74 ± 0,65 veces, p = 0,001) y tuvo un tamaño de efecto grande con un valor d de Cohen de 3,855. Por tanto, se concluye que la intervención AIART realizada durante 6 semanas en deportistas de remo ha demostrado ser eficaz para mejorar la fuerza y la resistencia muscular.
Palabras clave: Fuerza muscular, resistencia muscular, deportistas de remo, rendimiento físico

Fecha recepción: 06-07-24. Fecha de aceptación: 30-09-24
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Introduction

Competitive rowing is characterized by repetitive cyclic muscle actions and high demands on several components of physical fitness such as cardiorespiratory endurance and muscular fitness (Thiele et al., 2020). This sport requires athletes to maintain high aerobic capacity while simultaneously generating significant muscle strength and endurance, particularly in the upper body and arms (Penichet-Tomas et al., 2023). Rowing is one of the most physically demanding sports, combining extensive aerobic endurance training with the need for maximal muscle strength in every phase of the rowing stroke (Winkert et al., 2022). Additionally, this sport involves complex coordination between various muscle groups, making it an ideal model for studying the effects of training on muscular strength and endurance (Volianitis et al., 2020). The continuous and powerful rowing motion places great stress on the cardiovascular system and skeletal muscles, particularly in the hands, arms, and shoulders (Bagheri et al., 2024). Consequently, the ability to sustain prolonged muscle efforts and maintain optimal power output with each stroke is crucial for success in this sport (Ní Chéilleachair et al., 2024). While this research offers preliminary insights into potential ways to improve individual athlete performance, the current protocol and variables make it difficult to draw specific conclusions about direct performance improvements. Nevertheless, these findings may still serve as a foundation for the development of more targeted training programs at national and international levels. Further studies are necessary to fully understand the direct impact of these methods on performance in global rowing competitions. Given the intense physical demands, it is important to explore effective training methods that can enhance these fitness components, particularly with a focus on upper body strength and endurance, which play a key role in a rower's performance.

Considering the heavy physical demands of competitive rowing, optimizing muscular strength and endurance, especially in the upper body, has become a primary focus in training programs (Chang et al., 2024). The upper body, particularly the muscles of the hands and arms, is crucial in converting the rower's energy into effective propulsion through the water (Euiler & Finley, 2022). Research has shown that inadequate muscular strength or endurance can lead to a decline in rowing performance, especially during the final stages of a race when fatigue sets in (Podgórski et al., 2020). For example, a study by Held et al. (2023) demonstrated that inadequate muscular endurance is directly correlated with a loss of stroke efficiency, which can significantly affect an athlete's speed and final results. Although the importance of these muscle groups is clear, there remains a gap in the literature regarding the most effective training methods to enhance their performance. This gap emphasizes the need for further research on specific training interventions that can improve muscle fitness, particularly focusing on methods such as interval training using the Air Rower, which simulates the rowing motion while allowing controlled variations in intensity and duration (Frett et al., 2024).

As training methods in rowing continue to evolve, interval training has gained special attention for its ability to efficiently improve muscular strength and endurance (Liu et al., 2024). Interval training, which combines short periods of intense activity with recovery phases, has proven effective in stimulating the physiological adaptations critical for athletic performance improvement (Prieto-González & Sedlacek, 2022). In the context of rowing, the use of the Air Rower as an interval training tool allows for precise control over the intensity and duration of the workout, simulating the rowing motion (Mikulic & Gulin, 2024). Previous seminal studies have identified key determinants of rowing performance, particularly on the 2,000m ergometer. Ingham et al. (2002) demonstrated that aerobic and anaerobic power are critical predictors of rowing success in elite athletes, while Smith and Hopkins (2012) emphasized the importance of physiological measures such as maximal oxygen uptake (VO2max). Similarly, Mäestu et al. (2005) and Majumdar et al. (2017) highlighted the role of physical and strength variables as predictors of rowing ergometer performance, further supporting the focus of this study. The mechanisms behind the effectiveness of interval training include the increased activity of glycolytic and oxidative enzymes, which support energy production during high-intensity activities (Islam & Gillen, 2023). Additionally, interval training facilitates muscle hypertrophy through the activation of the mammalian target of the rapamycin (mTOR) pathway, which enhances muscle protein synthesis and leads to improved muscle strength (Morcillo-Losa et al., 2024). However, it is important to note that while this study focuses on physiological adaptations such as muscular strength and endurance, these variables do not directly assess rowing performance outcomes. The application of interval training using the Air Rower not only has the potential to strengthen the muscles of the hands and arms but also to improve muscle endurance through more efficient metabolic adaptations. Further research is needed to establish a direct relationship between these physiological improvements and rowing-specific performance. Hence, this study aims to explore in depth how interval training with the Air Rower can be optimized to support maximum performance in rowing athletes.

Material and Methods

This study used a true-experimental method with a pretest-posttest control group design, involving 20 male rowing athletes aged 18-20 years, who competed at the national level, with experience in competitive rowing for at least two years. Their water performance, measured through time trials, placed them in the top quartile of regional competitions. The athletes had a body mass index of 20-22 kg/m², showing normal vital signs including blood pressure, resting heart rate, oxygen saturation, and body temperature. The subjects were randomly divided into two groups: the control group (G_1; n = 10) and the treatment group (G_2; n = 10). All subjects voluntarily provided consent to participate by filling out and signing an informed consent form. All procedures applied in this study adhered to the Declaration of Helsinki of the World Medical Association on ethical conduct for research involving human subjects.

The Anaerobic Interval Air Rower Training (AIART) program was conducted at an intensity of 85-95% HRmax, based on prior studies that demonstrate significant anaerobic energy system engagement at this range in highly trained individuals, particularly when performing intense, repetitive efforts with short recovery periods (Faelli et al., 2022). The training protocol used heart rate (HRmax) to control the intensity of the training sessions (Munir et al., 2024). Monitoring heart rate during exercise using Polar H10 heart rate sensor (Pranoto et al., 2024). While heart rate was a commonly used measure in endurance sports, research by Seiler & Kjerland (2006) has shown that HRmax may become less reliable at very high intensities due to variations in cardiovascular responses. Despite this limitation, HRmax was chosen for its practicality in this study. Future research should employ power-based metrics to ensure more precise control and individualization of training loads. The training frequency was 3 times weekly for 6 weeks (Table 1). The AIRT program focused on the glycolytic endurance energy system, which supports the energy systems utilized by rowing athletes, thereby optimizing their athletic performance.

Data collection was conducted through two tests: pretest (0 weeks) and posttest (6 weeks). Hand muscle strength was evaluated using a manual dynamometer (CAMRY EH01®, China). The dynamometer was placed in the participant's hand, after which the researcher gave the verbal cue "squeeze" to start the test and "relax" to end the test (Huerta Ojeda et al., 2021). The maximum duration for the grip test was 3 seconds (Huerta Ojeda et al., 2021). Meanwhile, muscle endurance was tested using upper-body pull-ups performed for one minute, in contrast to the protocol outlined in Negrete et al. (2013), which utilized shorter intervals. This was adjusted to accommodate the specific demands of rowing and to better simulate the prolonged muscle contractions that occur during races. (Negrete et al., 2013).

Statistical analysis was performed using SPSS Version 21.0. Descriptive statistical analysis, normality testing, and hypothesis testing using paired sample t-test and independent sample t-test were applied in this study. Additionally, effect size was evaluated using Cohen's d. Cohen classified effect sizes as small (d = 0.2), medium (d = 0.5), and large (d ≥ 0.8). Data was considered to show a significant difference in hypothesis testing if $p \leq 0.05$.

Table 1.
Anaerobic Interval Air Rower Training Protocol

Components	Details		
Week	1-2	3-4	5-6
Frequency	3x/week (Tuesday, Thursday, Saturday)		
Intensity	85% HRmax	90% HRmax	95% HRmax
Type	Interval		
Time	30-40 minutes/session (includes: warm-up, core exercise, and cool-down)		
Duration	6 minggu		
Set	3	4	5
Repetition	6 times	6 times	6 times
Rest between Sets	3 minutes	3 minutes	3 minutes
Rest between Repetitions	90 seconds	90 seconds	90 seconds
Working Time between Repetitions	30 seconds	30 seconds	30 seconds
Tool	HC003 Air Row (HC003 Air Row, Sidea Fitness Company, 47035 Gambettola - FC - ITALY)		

Results

The results of the study showed that no significant differences were found in the average characteristics of the subjects between the two groups, as detailed in Table 2. Meanwhile, Table 3 presents the average data of muscle endurance and strength results between pre-, post-, and delta (Δ) in both groups. (G_1 vs G_2).

The results of paired sample t-test analysis on muscle strength (kg) between pretest and posttest in G_1 (11.70±2.45 vs 12.20±2.44, p=0.138) and G_2 (11.90±2.38 vs 14.40±2.55, p=0.001) and had a large effect size with a Cohen's d value of 1.015.

The results of paired sample t-test analysis on muscle endurance (repetition times) between pretest and posttest in G_1 (47.82±5.78 vs 48.03±5.92, p=0.363) and G_2 (47.99±5.59 vs 50.73±6.13, p=0.001) and had a small effect size with a Cohen's d value of 0.467.

Table 2.
Characteristics of study participants

Parameters	n	Groups (mean±SD)		p-Value
		Control (G_1)	Treatment (G_2)	
Resting heart rate, bpm	10	64.20±4.83	64.10±4.48	0.962
Oxygen saturation, %	10	98.40±0.69	98.10±1.19	0.505
Systolic blood pressure, mmHg	10	114.10±3.45	114.60±4.41	0.781
Diastolic blood pressure, mmHg	10	70.90±7.55	71.50±2.59	0.816
Body temperature, °C	10	35.33±1.26	35.75±0.89	0.402
Weight, kg	10	59.90±2.08	60.60±4.01	0.632
Height, m	10	1.68±0.04	1.69±0.05	0.417
Body mass index, kg/m^2	10	21.28±0.64	21.09±0.92	0.602
Age, yrs	10	19.10±0.88	19.60±0.97	0.241

Description: Mean ± Std. Deviation (mean±SD). The *p*-value was obtained using paired sample t-test analysis.

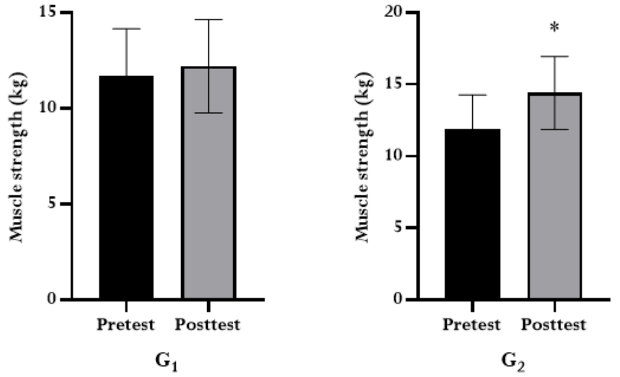

Figure 1. The comparison of muscle strength (kg) between pretest and posttest in both groups. Description: The *p*-value was obtained using paired sample t-test analysis. Effect size evaluation using Cohen's d. *$p \leq 0.05$

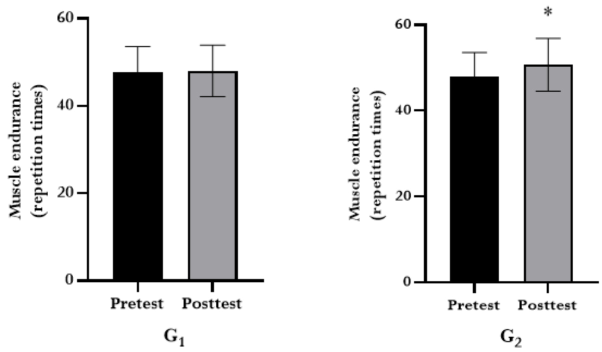

Figure 2. The comparison of muscle endurance (time) between pretest and posttest in both groups. Description: The *p*-value was obtained using paired sample t-test analysis. Effect size evaluation using Cohen's d. *$p \leq 0.05$

Table 3.
The comparison of muscle strength between pre and post-, and delta (Δ) in both groups.

Parameters	n	Groups (mean±SD)		p-Value	Mean (95% CI)	Effect size
		Control (G_1)	Treatment (G_2)			
Pre-muscle strength (kg)	10	11.70±2.45	11.90±2.38	0.855	-0.20 (-2.47 to 2.07)	-
Post-muscle strength (kg)	10	12.20±2.44	14.40±2.55	0.064	-2.20 (-4.55 to -0.15)	-
Δ-muscle strength (kg)	10	0.50±0.97	2.50±0.53*	0.001	-2.00 (-2.75 to -1.25)	2.558
Pre-muscle endurance (repetition times)	10	47.82±5.78	47.99±5.59	0.948	-0.17 (-5.51 to 5.18)	-
Post-muscle endurance (repetition times)	10	48.03±5.92	50.73±6.13	0.329	-2.71 (-8.37 to 2.96)	-
Δ-muscle endurance (time)	10	0.21±0.67	2.74±0.65*	0.001	-2.54 (-3.16 to -1.92)	3.855

Description: The *p*-value was obtained using independent sample t-test analysis. Effect size evaluation using Cohen's d. *$p \leq 0.05$. (-) The effect size test was not carried out because there was no significant difference.

Discussion

The results of this study show that the application of interval training using the Air Rower significantly increased hand muscle strength and endurance in the intervention group compared to the control group, which did not receive any intervention. The increase in hand muscle strength observed in the intervention group aligns with previous research by Morcillo-Losa et al. (2024), which indicated that high-intensity interval training is capable of stimulating muscle hypertrophy through the activation of the mTOR pathway, which plays a critical role in muscle protein synthesis. However, it is important to note that this study did not directly assess muscle hypertrophy or heavy load training. Therefore, the conclusions drawn regarding muscle strength improvements are limited to the specific variables measured, such as hand grip strength and endurance, and should be interpreted with caution. While interval training may contribute to improvements in muscle strength, its specific impact on muscle adaptation under heavy training loads was not assessed in this study.

The cellular and molecular adaptations occurring during interval training can be explained by several mechanisms. High-intensity interval training stimulates an increase in the activity of glycolytic enzymes such as phosphofructokinase (PFK) and lactate dehydrogenase (LDH), which are known to support anaerobic energy production through the glycolytic pathway in high-intensity interval training protocols (Araujo Bonetti DE Poli et al., 2024). However, the protocol used in this study did not match the intensity levels of those referenced, and thus the specific enzyme activities were not directly measured or confirmed.

The increase in the activity of these enzymes enables muscles to break down glucose more efficiently into ATP, providing a quick source of energy for muscle contraction during intensive training (Nitzsche et al., 2020). Additionally, increased training intensity triggers mitochondrial proliferation, which enhances the oxidative capacity of muscles and supports increased ATP production through oxidative phosphorylation (Slavin et al., 2024). These adaptations are crucial for improving muscle endurance, as they allow the muscles to sustain performance under high workloads for longer periods.

Interval training is also known to enhance insulin sensitivity in skeletal muscles, which accelerates glucose uptake by muscle cells during and after exercise (Peng et al., 2024). This increased insulin sensitivity is also associated with elevated expression of the GLUT4 protein, the primary glucose transporter in skeletal muscles, which plays an essential role in facilitating glucose uptake into muscle cells (Flores-Opazo et al., 2020). With more glucose available in the muscles, there is an increased substrate supply for energy production through both glycolytic and oxidative pathways, supporting enhanced muscle endurance and faster recovery (Flockhart & Larsen, 2024).

The improvement in muscle endurance in the intervention group also supports findings from the study by Atakan et al. (2021), which found that interval training can increase the oxidative capacity of muscles by enhancing the activity of oxidative enzymes such as citrate synthase and succinate dehydrogenase. These enzyme activities support mitochondrial efficiency in energy production, which is crucial in sports like rowing, where muscle endurance is key to success in long-distance races (Schünemann et al., 2023). Additionally, neuromuscular adaptations occur, where improved coordination between agonist and antagonist muscles reduces energy wastage during rowing movements, thereby increasing stroke efficiency (Duchene et al., 2024).

Although this study demonstrates the significant benefits of interval training, several limitations must be acknowledged. First, the sample size used in this study was relatively small, which may limit the generalization of the findings to a broader population. The relatively short duration of the intervention may also not reflect the long-term effects of interval training on muscle strength and endurance. Furthermore, variations in individual responses to interval training, which may be influenced by factors such as age, initial fitness level, and previous training experience, could affect the results. Therefore, further studies with larger sample sizes, longer intervention durations, and stricter control of variables that may influence outcomes are necessary to confirm these findings.

The comparison between the intervention and control groups also highlights the importance of a structured training approach. Athletes in the control group, who did not receive interval training, showed stagnation in their muscle strength and endurance. This underscores the efficacy of interval training as a superior training method, especially in the context of highly demanding sports like rowing.

Future research is recommended to explore variations in interval training protocols, such as different work and rest durations, to determine the most effective combination. Additionally, long-term studies that evaluate the effects of interval training over an extended period will provide deeper insights into the potential benefits and risks of this training method. Studies could also examine how physiological responses to interval training differ based on age, gender, and initial fitness level of athletes, providing a basis for developing more individualized training programs.

Overall, this study shows that interval training using the Air Rower has a significant positive impact on increasing hand muscle strength and endurance in rowing athletes. The physiological adaptations hypothesized to occur, such as increased glycolytic and oxidative enzyme activity, improved insulin sensitivity, and mitochondrial proliferation, are known to support energy metabolism efficiency. However, these adaptations were not directly observed in this study, and further research is needed to confirm their presence in response to this training protocol. Although this study is limited by the small sample size and short intervention duration, the results indicate great potential for interval training as an important component of rowing training programs. Further comprehensive research will be necessary to strengthen these findings and broaden their application in wider contexts.

Conclusion

This study reports that interval training using the Air Rower significantly improves upper body muscle strength and endurance, as measured by hand grip strength and upper-body pull-up performance, in rowing athletes. These results align with the focus of this study on upper body strength and endurance, as stated in the title. However, conclusions related to cellular and molecular adaptations, such as increased glycolytic and oxidative enzyme activity, mitochondrial proliferation, and enhanced insulin sensitivity, cannot be drawn, as these variables were not directly assessed in this study. Despite limitations such as the small sample size and short intervention duration, these findings provide a strong basis for recommending interval training as an integral part of rowing training programs. Further research with larger sample sizes and longer durations is needed to strengthen these findings and explore variations in training protocols and physiological responses based on individual athlete characteristics.

Conflict of interest statement

All authors consciously declare that they have no conflict of interest in this study.

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