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# Imagery and breathing exercises improve swimming performance, mental toughness, and coherence

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# Imagery and Breathing Exercises Improve Swimming Performance, Mental Toughness, and Coherence

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# Abstract

**This randomized controlled trial investigated the effects of a 10-week intervention incorporating imagery and breathing exercises on swimming performance, mental toughness, and cardiac coherence in adolescent swimmers. Nineteen licensed swimmers (aged 13–18 years) were randomly assigned to either an experimental group (n = 9), receiving daily 15-minute imagery and breathing sessions in addition to regular training, or a control group (n = 10), receiving standard training alone. Pre- and post-intervention assessments included 200-meter freestyle performance, the Sports Mental Toughness Questionnaire (SMTQ), and cardiac coherence measured via the Inner Balance HeartMath device. Repeated measures ANOVA revealed significant improvements in cardiac coherence ($p = 0.008$, $\eta^2 = 0.349$) and mental toughness ($p = 0.003$, $\eta^2 = 0.414$) in the intervention group. Although swimming performance improved in both groups ($p < 0.001$), the group × time interaction was not significant ($p = 0.529$), suggesting that improvements may reflect practice effects rather than intervention-specific benefits. *Due to the small sample size (n = 19), the study is best considered a pilot, with findings warranting further investigation in larger, stratified samples to enhance generalizability.* These results highlight the potential psychological benefits of imagery and breathing exercises in youth athletes and support their integration into**

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**training protocols, with future studies needed to confirm performance effects.**

# Introduction

In recent years, the role of mental training in enhancing sports performance has gained significant recognition, complementing traditional physical training approaches. Mental training encompasses a range of psychological techniques, such as imagery, self-talk, and relaxation strategies, aimed at improving athletes' performance, psychological resilience, and overall well-being[1,2]. Originally developed in the 1920s by Johannes Heinrich Schultz, autogenic training focused on mental relaxation and stress management[3-5]. However, contemporary sports psychology has shifted toward broader mental training frameworks, which are increasingly applied to optimize athletic performance across various disciplines[6].

It is well-established that sports performance is not solely dependent on physical capabilities; psychological factors play a critical role in determining success[7]. For instance, an athlete with adequate physical training may underperform if they are not mentally prepared, a phenomenon that became particularly evident during the COVID-19 pandemic when access to physical training facilities was limited[8]. This underscores the importance of mental training as a viable strategy to maintain and enhance performance under challenging circumstances. Swimming, a globally practiced sport, exemplifies the need for an integrated approach combining physiological and psychological preparation, especially at elite levels[9]. Beyond its physical benefits, swimming has been shown to enhance psychological resilience and self-esteem, making it an ideal context for studying mental training interventions[10]. As Michael Phelps famously stated, "Don't put a limit on anything. The more you dream, the farther you get," highlighting the pivotal role of mental preparation in achieving success in swimming.

Mental training techniques, particularly imagery, have been widely studied in swimming, with evidence suggesting their efficacy in improving performance[11,12]. Imagery involves mentally simulating a specific action or scenario, such as visualizing a successful 200-meter freestyle swim, which can enhance motor skill execution and boost confidence[13]. However, much of the existing research has focused on short-term effects, with limited attention to the long-term impact of mental training on performance and psychophysiological outcomes[14,15]. Moreover, while physical training combined with mental training has shown promise in enhancing athletic performance[16], the integration of specific techniques like breathing exercises with imagery remains underexplored. Breathing exercises, which promote heart-mind coherence through heart rate variability (HRV) regulation, are known to improve emotional regulation and stress management, potentially amplifying the effects of imagery[17,18].

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The advent of wearable technologies and biofeedback systems, such as the Inner Balance HeartMath device, offers new opportunities to measure psychophysiological outcomes like heart-mind coherence in real-time. Despite its accessibility, the proprietary coherence score used by the Inner Balance device limits direct comparability with validated HRV indices (e.g., RMSSD, LF/HF ratio), which are standard in physiological research.[9-21] Heart-mind coherence, a measure of synchronized heart and brain activity, is increasingly recognized as a marker of emotional and cognitive balance, which may enhance athletic performance[22]. Similarly, mental toughness, defined as the ability to maintain focus and resilience under pressure, is a critical psychological attribute for swimmers[23]. Yet, few studies have explored how combined imagery and breathing exercises influence these outcomes over an extended period.

To address these gaps, this study examined the effects of a 10-week imagery and breathing exercise intervention on 200-meter freestyle swimming performance, mental toughness, and heart-mind coherence in adolescent swimmers. The intervention involved daily 15-minute sessions of structured imagery (visualizing a 200-meter freestyle swim) paired with controlled breathing (4-second inhale, 4-second exhale), performed before bedtime. Outcomes were assessed at baseline and post-intervention, including swimming performance (measured in seconds), mental toughness (assessed via the Sports Mental Toughness Questionnaire), and heart-mind coherence (measured using the Inner Balance HeartMath device). A secondary aim was to explore potential sex-based differences in these outcomes, with findings framed as exploratory due to the small sample size and limited statistical power for subgroup analyses. By integrating imagery with breathing exercises and leveraging biofeedback technology, this study seeks to contribute to the growing body of evidence on mental training in sports, offering practical insights for coaches and athletes aiming to optimize performance through psychological interventions. Given the small sample size, this study serves as a pilot, with findings intended to guide future research with larger, age- and gender-stratified cohorts.

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# Methods

### Study Design

This study was a randomized controlled trial (RCT) designed to evaluate the effects of a 10-week imagery and breathing exercise intervention on 200-meter freestyle swimming performance, mental toughness, and heart-mind coherence in adolescent swimmers. The trial employed a pre-test/post-test control group design with two parallel arms: an experimental group receiving the intervention alongside standard physical training, and a control group receiving only standard physical training. The study was conducted at the facilities of the Pamukkale University Staff Sports Club Swimming Team in Denizli, Türkiye, between June and August 2023. Ethical approval was obtained from the Pamukkale University Ethics Committee (Approval No: E-60116787-020-666811, Date: 18.02.2025/04), and the trial adhered to the Declaration of Helsinki principles. This study was also registered in the ClinicalTrials.gov database (Registration No: NCT06920875-10/04/2025). Written

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informed consent was obtained from all participants and their legal parents, as all participants were under 18 years of age. The study was conducted as an open-label trial due to the nature of the intervention, which involved active participation in imagery and breathing exercises, making blinding of participants and coaches infeasible. To mitigate assessment bias, outcome assessors followed standardized protocols, and measurements (e.g., 200-meter freestyle time, SMTQ, and coherence) were conducted under controlled conditions. However, assessors were not blinded to group allocation, which is acknowledged as a limitation that may introduce bias.

**Participants**

Participants were 19 licensed swimmers aged 13-18 years, actively training with the Pamukkale University Staff Sports Club Swimming Team. The sample size was determined using G*Power software (version 3.1) to achieve 80% power at a significance level of $\alpha = 0.05$, based on an expected medium effect size (Cohen's $d = 0.5$) for the primary outcome (200-meter freestyle performance). The analysis indicated that a minimum of 18 participants was required, and 19 were recruited to account for potential dropouts[6]. The small sample size limits the study's statistical power and generalizability, positioning it as a pilot study.

Inclusion criteria were: (1) age between 13 and 18 years, (2) licensed and actively engaged in competitive swimming, (3) no serious injuries in the past six months, and (4) parental consent for participation. Exclusion criteria included: (1) diagnosed cardiovascular or respiratory conditions, (2) current psychiatric diagnosis or psychological treatment, and (3) major surgery or injury within the past six months. Participants were recruited via an announcement at the swimming club, and those meeting the criteria were enrolled following informed consent procedures.

Participants were randomly assigned to either the experimental group ($n = 9$) or the control group ($n = 10$) using a computer-generated random number sequence, ensuring allocation concealment. Randomization was performed by an independent researcher not involved in data collection or intervention delivery, and group assignments were concealed in sealed opaque envelopes until the start of the intervention. The trial was completed as originally planned, with no early termination. All participants completed the 10-week intervention period, and no interim stopping rules were applied.

**Intervention**

The experimental group underwent a 10-week intervention involving daily imagery and breathing exercises, in addition to their standard physical training. The intervention protocol was adapted for swimmers and consisted of 15-minute sessions performed each night before bedtime. Each session included a structured breathing exercise (4-second inhalation through the nose, 4-second exhalation through the mouth) paired with imagery, where participants visualized performing a 200-meter freestyle swim, focusing on technique, pacing, and successful completion. The

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protocol was standardized across participants, with detailed instructions provided in a written manual. Prior to the intervention, the experimental group received six days of in-person training to ensure proper execution of the techniques.

To enhance compliance, participants in the experimental group were enrolled in a WhatsApp group, where daily reminders and feedback were provided by the research team. Participants were also required to log their adherence in a diary, which was reviewed weekly. To explore the intervention's mechanisms, participants provided qualitative feedback on their experiences, noting the relative influence of imagery versus breathing exercises. The control group continued their standard physical training, consisting of regular swimming practice sessions (5 days per week, 2 hours per session), without any additional mental training. Both groups were coached by the same swimming staff to minimize variability in physical training exposure. No changes to the intervention protocol were made during the trial, and no adverse events were reported.

**Outcome Measures**

Outcome measures were assessed at baseline (pre-test) and immediately following the 10-week intervention (post-test). All assessments were conducted by trained research staff blinded to group allocation, ensuring objectivity in data collection.

- **200-Meter Freestyle Swimming Performance:** Performance was measured as the time (in seconds) to complete a 200-meter freestyle swim in a 25-meter pool. Times were recorded using a manual stopwatch by two independent timers, with the average of the two recordings used for analysis. Participants performed the swim under standardized conditions (e.g., same pool, time of day) to minimize external variability.

- **Mental Toughness**: Mental toughness was assessed using the Sports Mental Toughness Questionnaire (SMTQ)[12], a 14-item self-report measure evaluating confidence, constancy, and control. Scores range from 14 to 56, with higher scores indicating greater mental toughness. The SMTQ has demonstrated good reliability (Cronbach's $\alpha = 0.81$) in adolescent athletes[24].

- **Heart-Mind Coherence:** Heart-mind coherence was measured using the Inner Balance HeartMath device, which provides real-time biofeedback on heart rate variability (HRV) and coherence levels. Coherence scores range from 0 to 5, with higher scores indicating greater synchronization between heart and brain activity, reflecting emotional and cognitive balance. Both average coherence and maximum coherence during a 5-minute measurement period were recorded for each participant. While the Inner Balance system provided an accessible and practical means of assessing coherence, it does not generate raw HRV values in the time or frequency domains. Future research may benefit from integrating ECG-based HRV assessments that report standard indices (e.g., RMSSD, LF/HF ratio) to enhance comparability and physiological specificity. The use of proprietary coherence indices limits comparability with traditional HRV metrics.

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Therefore, subsequent trials may benefit from integrating time- and frequency-domain HRV analyses to better characterize autonomic function. The proprietary coherence score limits direct comparison with standard HRV metrics (e.g., RMSSD, LF/HF ratio). To address this, future studies should incorporate ECG-based HRV measurements to provide validated indices and enhance physiological interpretability.

### Statistical Analysis

Data were analyzed using SPSS (version 26.0). Normality of the data was assessed using the Shapiro-Wilk test, confirming that all variables met the assumptions for parametric tests ($p > 0.05$). A two-way repeated measures ANOVA was conducted to examine the effects of time (pre-test vs. post-test), group (experimental vs. control), and their interaction on each outcome measure (200-meter freestyle performance, mental toughness, heart-mind coherence, and maximum coherence). Significant interactions were followed by Bonferroni post-hoc tests to identify specific group differences at each time point. Effect sizes were calculated using partial eta-squared ($\eta^2$), with values interpreted as small (0.01), medium (0.06), or large (0.14) according to Cohen's guidelines[25].
A secondary analysis used two-way ANOVA to explore the effects of sex (male vs. female), group, and their interaction on the outcome measures at each time point. All statistical tests were two-tailed, with significance set at $p < 0.05$. Data are reported as means ± standard deviations (SD) unless otherwise stated. No participants were lost to follow-up, and intention-to-treat analysis was not required as there were no dropouts.

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# Results

This randomized controlled trial (RCT) aimed to evaluate the effects of a 10-week imagery and breathing exercise intervention on 200-meter freestyle swimming performance, mental toughness, and heart-mind coherence in 19 adolescent swimmers aged 13-18 years (mean age = 13.27 ± 1.21 years, range: 13-18 years; mean swimming experience = 6.26 ± 2.53 years, range: 6-11 years) from the Pamukkale University Staff Sports Club Swimming Team. Participants were randomly allocated to an experimental group (n = 9) receiving the intervention alongside standard physical training or a control group (n = 10) receiving only standard physical training. All 19 participants completed the trial, with no dropouts or exclusions. Baseline characteristics were comparable between groups, with no significant differences in age, swimming experience, or pre-test outcome measures (all $p > 0.05$). Outcomes were assessed at baseline (pre-test) and post-intervention (post-test), with results reported as means ± standard deviations (SD) unless otherwise stated. Due to the small sample size (n = 19), the study is considered a pilot, and sex-based analyses are framed as exploratory and hypothesis-generating rather than confirmatory, as the underpowered subgroup analyses and non-significant group × sex interactions limit definitive conclusions.

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**Participant Flow and Baseline Data**

Of the 19 swimmers enrolled, all met the inclusion criteria (aged 13-18 years, licensed swimmers, no recent injuries, parental consent) and were randomized: 9 to the experimental group and 10 to the control group (Fig.1). No participants were lost to follow-up, and all completed the pre-test and post-test assessments. Baseline data revealed no significant group differences: 200-meter freestyle performance (control: 232.50 ± 9.79 s, experimental: 217.32 ± 22.95 s, $p = 0.162$), mental toughness (control: 48.00 ± 3.94, experimental: 43.00 ± 6.22, $p = 0.462$), heart-mind coherence (control: 1.07 ± 0.27, experimental: 1.14 ± 0.58, $p = 0.980$), and maximum coherence (control: 2.30 ± 0.67, experimental: 2.43 ± 1.16, $p = 0.395$). Sex distribution was balanced, with 10 males and 9 females, and no significant sex-based differences were observed at baseline (all $p > 0.05$).

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**Fig. 1.** CONSORT 2025 Flow Diagram

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### Heart-Mind Coherence

Heart-mind coherence, measured using the Inner Balance HeartMath device, showed a significant time group interaction effect ($F(1, 17) = 9.099$, $p = 0.008$, $\eta^2 = 0.349$, moderate effect size). At baseline, coherence levels were similar across groups (control: 1.07 ± 0.27, experimental: 1.14 ± 0.58, total: 1.10 ± 0.44). Post-intervention, the experimental group exhibited a substantial increase (2.26 ± 0.78), while the control group showed a modest rise (1.28 ± 0.63), resulting in a total post-test mean of 1.74 ± 0.85. Bonferroni post-hoc tests confirmed a significant difference between groups at post-test ($p < 0.05$), with the experimental group surpassing the control group (Table 1)(Figure 1). Exploratory sex-specific analysis revealed that males in the experimental group (2.28 ± 0.70) and females (2.23 ± 1.10) improved more than their control counterparts (males: 1.02 ± 0.28, females: 1.45 ± 0.76), but the group × sex interaction was not significant ($F(1, 15) = 0.455$, $p = 0.510$, $\eta^2 = 0.029$) (Table 2a, 2b, Fig. 2). These findings are hypothesis-generating, as the small sample size limits the power for confirmatory subgroup analyses.

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**Fig. 2.** Density Plots of Intervention Outcomes: Mental and Physical Measures by Group and Gender.

### Maximum Coherence

Maximum coherence showed no significant time group interaction ($F(1, 17) = 0.309$, $p = 0.585$, $\eta^2 = 0.018$, negligible effect size). Baseline values were comparable (control: 2.30 ± 0.67, experimental: 2.43 ± 1.16, total: 2.36 ± 0.91). Post-

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intervention, both groups improved (control: 3.33 ± 1.30, experimental: 3.85 ± 1.24, total: 3.57 ± 1.27), with a significant main effect of time ($F(1, 17) = 12.089$, $p = 0.003$, $\eta^2 = 0.416$, moderate effect), but no group difference ($p = 0.394$) (Table 1.). Exploratory sex-specific analysis indicated that experimental males (3.70 ± 0.88) and females (4.16 ± 2.00) slightly outperformed controls (males: 2.92 ± 1.25, females: 3.60 ± 1.38), but the group × sex interaction was not significant ($F(1, 15) = 0.027$, $p = 0.872$, $\eta^2 = 0.002$) (Table 2a, 2b, Fig. 2). These results are hypothesis-generating due to the underpowered subgroup analyses.

**Mental Toughness**

Mental toughness, assessed via the Sports Mental Toughness Questionnaire, demonstrated a significant time-group interaction ($F(1, 17) = 11.988$, $p = 0.003$, $\eta^2 = 0.414$, moderate effect size). Baseline scores were higher in the control group (48.00 ± 3.94) than the experimental group (43.00 ± 6.22), with a total mean of 45.63 ± 5.61. Post-intervention, the control group declined (44.80 ± 12.22), while the experimental group increased (54.22 ± 5.30), yielding a total post-test mean of 49.26 ± 10.51. Post-hoc analysis confirmed a significant group difference at post-test ($p < 0.05$) (Table 1.). Exploratory sex-specific analysis showed experimental females (57.33 ± 6.80) slightly outperformed males (52.66 ± 4.22) and controls (males: 43.75 ± 13.91, females: 45.50 ± 12.30), but the group × sex interaction was not significant ($F(1, 15) = 0.092$, $p = 0.766$, $\eta^2 = 0.006$) (Table 2a, 2b, Fig. 2). These findings are hypothesis-generating, as the small sample size limits confirmatory conclusions.

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| Measure | Group | Time | Mean ± SD | ANOVA (Time, Group, Time × Group) |
|---|---|---|---|---|
| **Heart-Mind Coherence (HMC)** | Control | Pre | 1.07 ± 0.27 | Time: F=5.44, p=0.032, $\eta^2$=0.24<br>Group: F=9.10, p=0.008, $\eta^2$=0.35<br>Time × Group: F=9.10, p=0.008, $\eta^2$=0.35* |
| | | Post | 1.28 ± 0.63 | |
| | Experimental | Pre | 1.14 ± 0.58 | |
| | | Post | 2.26 ± 0.78 | |
| **Maximum Coherence** | Control | Pre | 2.30 ± 0.67 | Time: F=12.09, p=0.003, $\eta^2$=0.42<br>Group: F=0.77, p=0.394, $\eta^2$=0.04<br>Time × Group: F=0.31, p=0.585, $\eta^2$=0.02 |
| | | Post | 3.33 ± 1.30 | |
| | Experimental | Pre | 2.43 ± 1.16 | |
| | | Post | 3.85 ± 1.24 | |
| **Mental Toughness (SMTQ)** | Control | Pre | 48.00 ± 3.94 | Time: F=3.71, p=0.071, $\eta^2$=0.18<br>Group: F=0.60, p=0.451, $\eta^2$=0.03<br>Time × Group: F=11.99, p=0.003, $\eta^2$=0.41* |
| | | Post | 44.80 ± 12.22 | |
| | Experimental | Pre | 43.00 ± 6.22 | |
| | | Post | 54.22 ± 5.30 | |
| **200m Freestyle (s)** | Control | Pre | 232.50 ± 9.79 | Time: F=38.13, p<0.001, $\eta^2$=0.69<br>Group: F=4.13, p=0.058, $\eta^2$=0.20<br>Time × Group: F=0.41, p=0.529, $\eta^2$=0.02 |
| | | Post | 227.00 ± 8.88 | |
| | Experimental | Pre | 217.32 ± 22.95 | |
| | | Post | 210.54 ± 22.72 | |

**Table 1.** Comparison between groups

SMTQ: Sports Mental Toughness Questionnaire, HMC: Heart-Mind Coherence * Significantly from Experiment Total # Significantly from the Last Total & Experiment Significantly from the last + Experiment Significantly more ^ Significantly from the Last Control. * $p < 0.05$ within-group comparison; # $p < 0.05$ between groups at post-test; & indicates effect size $d > 0.5$.

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| Measure | Male Control (Mean ± SD) | Male Experimental (Mean ± SD) | Female Control (Mean ± SD) | Female Experimental (Mean ± SD) | ANOVA (Group; Gender; Group × Gender) |
|---|---|---|---|---|---|
| **Heart-Mind Coherence** | 1.17 ± 0.44 | 1.20 ± 0.71 | 1.00 ± 0.89 | 1.03 ± 0.28 | F=0.09, p=0.980, $\eta^2$=0.00; F=1.68, p=0.999, $\eta^2$=0.00; F=0.99, p=0.986, $\eta^2$=0.00 |
| **Maximum Coherence** | 2.20 ± 0.87 | 2.26 ± 1.03 | 2.36 ± 0.59 | 2.76 ± 1.59 | F=1.96, p=0.395, $\eta^2$=0.66; F=4.00, p=0.295, $\eta^2$=0.80; F=0.13, p=0.728, $\eta^2$=0.13 |
| **Mental Toughness (SMTQ)** | 49.75 ± 4.27 | 41.33 ± 6.74 | 46.83 ± 3.60 | 46.33 ± 4.04 | F=1.27, p=0.462, $\eta^2$=0.56; F=0.07, p=0.836, $\eta^2$=0.07; F=2.70, p=0.121, $\eta^2$=0.15 |
| **200m Freestyle (s)** | 228.99 ± 11.99 | 213.20 ± 27.18 | 234.84 ± 8.36 | 225.56 ± 10.35 | F=14.87, p=0.162, $\eta^2$=0.94; F=7.85, p=0.218, $\eta^2$=0.89; F=0.15, p=0.706, $\eta^2$=0.01 |

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**Notes**: SMTQ: Sports Mental Toughness Questionnaire. Numerical values use decimal points (e.g., 1.07 ± 0.27). F-values rounded to two decimal places, p-values to three decimal places or p<0.001. *p<0.05 indicates significant Group × Gender interaction (exploratory due to small sample size).

**Table 2a.** Comparison Between Genders (Pre-Intervention)

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| Measure | Male Control (Mean ± SD) | Male Experimental (Mean ± SD) | Female Control (Mean ± SD) | Female Experimental (Mean ± SD) | ANOVA (Group; Gender; Group × Gender) |
|---|---|---|---|---|---|
| **Heart-Mind Coherence** | 1.02 ± 0.28 | 2.28 ± 0.70 | 1.45 ± 0.76 | 2.23 ± 1.10 | F=0.62, p=0.575, $\eta^2$=0.38; F=18.48, p=0.146, $\eta^2$=0.95; F=0.46, p=0.510, $\eta^2$=0.03* |
| **Maximum Coherence** | 2.92 ± 1.25 | 3.70 ± 0.88 | 3.60 ± 1.38 | 4.16 ± 2.00 | F=41.47, p=0.098, $\eta^2$=0.98; F=30.03, p=0.115, $\eta^2$=0.97; F=0.03, p=0.872, $\eta^2$=0.00 |
| **Mental Toughness (SMTQ)** | 43.75 ± 13.91 | 52.66 ± 4.22 | 45.50 ± 12.30 | 57.33 ± 6.80 | F=50.61, p=0.089, $\eta^2$=0.98; F=4.84, p=0.272, $\eta^2$=0.83; F=0.09, p=0.766, $\eta^2$=0.01* |
| **200m Freestyle (s)** | 221.45 ± 9.34 | 206.52 ± 26.66 | 230.70 ± 6.97 | 218.59 ± 11.89 | F=91.29, p=0.066, $\eta^2$=0.99; F=56.77, p=0.084, $\eta^2$=0.98; F=0.03, p=0.864, $\eta^2$=0.00 |

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**Notes**: SMTQ: Sports Mental Toughness Questionnaire. Numerical values use decimal points (e.g., 1.07 ± 0.27). F-values rounded to two decimal places, p-values to three decimal places or p<0.001. *p<0.05 indicates significant Group × Gender interaction (exploratory due to small sample size).

**Table 2b.** Comparison Between Genders (Post-Intervention)

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### 200-Meter Freestyle Swimming Performance

Post-intervention, the control group improved to 227.00 ± 8.88 s (1.8% improvement), and the experimental group to 210.54 ± 22.72 s (3.8% improvement, though not statistically attributable to the intervention*), with a total mean of 219.20 ± 18.*44 s. A significant main effect of time was observed ($F(1, 17) = 38.126$, $p < 0.001$, $\eta^2 = 0.692$, large effect), indicating improvements in both groups likely due to practice effects from standard training. Post-hoc tests suggested a group difference at post-test ($p < 0.05$) (Table 1*).* Exploratory sex-specific analysis showed experimental males (206.52 ± 26.66 s) and females (218.59 ± 11.89 s) improved more than controls (males: 221.45 ± 9.34 s, females: 230.70 ± 6.97 s), but the group × sex interaction was not significant ($F(1, 15) = 0.030$, $p = 0.864$, $\eta^2 = 0.002$) (Table 2a, 2b, Fig. 2). These findings are hypothesis-generating due to the underpowered nature of the subgroup analyses.

# Discussion

This randomized controlled trial aimed to systematically assess the effects of a structured 10-week imagery and breathing exercise training intervention on swimming performance, mental toughness, and heart-mind coherence among competitive adolescent swimmers. Findings revealed statistically significant differences between experimental and control groups across all primary outcome measures, with notable implications for sport psychology practice and athletic training methodologies.

Although the overall statistical analysis did not detect a significant time × group interaction in 200-meter freestyle swimming performance ($F(1, 17) = 0.412$, $p = 0.529$, $\eta^2 = 0.024$; small effect), a detailed exploration via post-hoc analyses uncovered *moderate and sustained improvements with potential clinical relevance* within the experimental group. Specifically, swimmers engaging in combined mental training protocols exhibited a 3.8% improvement (210.54 ± 22.72 s), nearly double the rate of improvement observed in the control group, which underwent standard physical training only (1.8% improvement; 227.00 ± 8.88 s). Although the experimental group showed a 3.8% improvement in swim performance, this difference was not statistically significant ($p = 0.529$). These findings suggest that mental training strategies may hold promise for performance enhancement, although larger studies are needed to substantiate these effects. Coaches and practitioners can interpret these outcomes as evidence supporting the integration of systematic mental imagery and breathing techniques within training regimens to maximize competitive performance gains.

Regarding mental toughness, the results demonstrated a statistically significant and clinically important group × time interaction, underscoring the psychological benefits conferred by the intervention. Post-intervention, mental toughness significantly improved in the experimental group (54.22 ± 5.30) compared to a decline observed within the control group (44.80 ± 12.22). This outcome suggests that the imagery and breathing protocol may help preserve or enhance

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psychological resilience during intense training[23]. Such findings align with existing literature advocating structured psychological interventions to prevent burnout, sustain motivation, and enhance competitive resilience among youth athletes[12,26]. To expand on the mechanisms behind these improvements, qualitative feedback from participants indicated that imagery primarily drove enhancements in confidence and visualization of success, while breathing exercises contributed to relaxation and emotional regulation. However, the relative influence of each component remains unclear without component-specific analyses. Additionally, the unblinded, open-label design introduces the possibility that mental toughness improvements could reflect expectancy or placebo effects, as participants in the experimental group were aware of receiving the intervention. Therefore, mental training may be a valuable complement to physical training in youth sport contexts.

Heart-mind coherence data further validated the efficacy of combined imagery and breathing exercises, demonstrating a significant group × time interaction effect ($p = 0.008$). Coherence levels notably increased from baseline to post-test within the experimental group (2.26 ± 0.78 vs. control 1.28 ± 0.63), indicating improved autonomic nervous system regulation and enhanced psychophysiological synchronization. Given the link between coherence and cognitive-emotional functioning[18,22], the observed increase may offer benefits for managing competition-related stress and enhancing focus. This supports the inclusion of breathing techniques as a component of mental preparation protocols.

Contrary to initial hypotheses, maximum coherence values demonstrated a significant main effect for time but not for group interaction ($F(1,17)=0.309$, $p=0.585$), suggesting that while all participants improved their maximal coherence over time, the intervention itself did not confer a statistically superior benefit compared to physical training alone. Nonetheless, the significant within-group improvements over the intervention period emphasize the potential role of standard training alone in moderately enhancing autonomic regulation, with imagery and breathing exercises providing additional complementary effects, particularly evident in overall coherence rather than maximum peaks alone.

An important applied implication of these findings is the feasibility of integrating mental training into regular routines. Research emphasizes that the success of imagery-based interventions depends on consistent, structured application[27,28]. The present study's structured 10-week program, featuring consistent daily practice reinforced by digital reminders and feedback via WhatsApp, ensured systematic adherence and may explain the pronounced positive findings observed here. Regular use of imagery and breathing practices—especially before sleep—may contribute positively to both psychological and performance outcomes.

Furthermore, the use of wearable technology and biofeedback in this study offered objective monitoring of psychophysiological changes, which is an innovative methodological contribution. While biofeedback and wearable technology use are expanding in sport sciences[19,20], their utilization in youth swimmer populations remains relatively unexplored. Clinically, wearable technology can serve as a practical tool for coaches and psychologists to provide real-time feedback,

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objectively monitor physiological stress responses, and facilitate individualized training adjustments, promoting athlete adherence and long-term improvement in both psychological well-being and physical performance.

Although an a priori power analysis was conducted to determine the appropriate sample size, the final number of participants (n = 19) limits the statistical power, especially for detecting interaction effects. This small sample size also restricts the generalizability of our findings. Therefore, future studies with larger and more diverse cohorts are recommended to confirm and expand upon these results. Additionally, due to the nature of the intervention, blinding of participants and researchers was not feasible. This open-label design introduces a potential risk of bias, including expectancy and placebo effects. Although validated tools were used for outcome assessment, the influence of participants' awareness of group allocation cannot be entirely excluded. Additionally, the inclusion of both male and female participants within a relatively wide adolescent age range (13–18 years) may have introduced variability. While the sample size limited stratified subgroup analyses, future studies should consider controlling for age- and gender-specific effects, as these factors are known to influence sport performance. The SMTQ was used appropriately, but alternative or supplementary measures of psychological resilience could be valuable in future studies (e.g., MTQ48 or CSAI-2).

# Conclusions

From an applied sport science perspective, these findings provide preliminary support for integrating structured imagery and breathing exercises alongside standard physical training, particularly in youth competitive swimming programs. Coaches, sport psychologists, and trainers may consider incorporating such psychological training strategies to enhance athletes' readiness, improve stress regulation, and support long-term development. The observed improvements in coherence and mental toughness highlight the potential value of mental training, particularly in sports requiring sustained focus, emotional control, and adaptive coping. Incorporating these techniques during key training phases or preparatory periods may offer benefits for both psychological resilience and performance capacity.

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# Author contributions

Conceptualization, F.G.G., H.K.B., S.S., C.S., M.J., and G.A.; methodology, F.G.G., H.K.B., S.S., C.S., M.J., and G.A.; software, F.G.G., H.K.B., S.S., C.S., M.J., and G.A.; validation, F.G.G., H.K.B., S.S., C.S., M.J., and G.A.; formal analysis, F.G.G., H.K.B., S.S., C.S., M.J., and G.A.; investigation, F.G.G., H.K.B., S.S., C.S., M.J., and G.A.; resources, F.G.G., H.K.B., S.S., C.S., M.J., and G.A.; data curation, F.G.G., H.K.B., S.S., C.S., M.J., and G.A.; writing—original draft preparation, F.G.G., H.K.B., S.S., C.S., M.J., and G.A.; writing—review and editing, F.G.G., H.K.B., S.S., C.S., M.J., and G.A.; visualization, F.G.G., H.K.B., S.S., C.S., M.J., and G.A.; supervision, F.G.G., H.K.B., S.S., C.S., M.J., and G.A.; project administration, F.G.G., H.K.B., S.S., C.S., M.J., and G.A.; funding acquisition, F.G.G., H.K.B., S.S., C.S., M.J., and G.A. All authors have read and agreed to the published version of the manuscript.

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# Data sharing

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

# Competing interests

The authors declare no competing interests.

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