

Effect of Different Training Methods on the Swimming Performance of Adolescent Athletes: A Meta-analysis

INPLASY2025120038

doi: 10.37766/inplasy2025.12.0038

Received: 10 December 2025

Published: 10 December 2025

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ADMINISTRATIVE INFORMATION

Support - This study has received support from Ningxia Normal University Key Project.

Review Stage at time of this submission - Completed but not published.

Conflicts of interest - None declared.

INPLASY registration number: INPLASY2025120038

Amendments - This protocol was registered with the International Platform of Registered Systematic Review and Meta-Analysis Protocols (INPLASY) on 10 December 2025 and was last updated on 10 December 2025.

INTRODUCTION

Review question / Objective This meta-analysis aimed to evaluate the effectiveness of various training methods on swimming performance among adolescent athletes, with a particular emphasis on 50-metre freestyle outcomes. In addition, it examined a series of moderating factors, including training modality, weekly training frequency, intervention duration, and maturational stage, in order to inform and optimize performance enhancement strategies for youth swimmers.

Rationale Taken together, important research gaps remain. First, most prior reviews treat different training modalities—such as water-resistance exercises, land-based resistance training, respiratory muscle endurance training, and high-intensity conditioning—as broad categories of “physical” or “core” training, with limited direct head-to-head comparison. Second, multiple

strokes and race distances are often analyzed simultaneously, so that targeted conclusions for hallmark sprint events like the 50-m freestyle are still lacking. Third, although the majority of participants in existing work are adolescents, few studies have explicitly stratified training effects across developmental stages within youth populations. Fourth, while training dose variables (weekly frequency and total intervention duration) have been explored individually, they have not been systematically quantified under a unified, competition-specific outcome in adolescent competitive swimmers. Therefore, the present meta-analysis focuses exclusively on.

Condition being studied Swimming is one of the oldest Olympic sports and is globally recognized for its unique performance demands in an aquatic environment (Pyne & Sharp, 2014). Elite swimming performance relies on the coordinated interaction of muscular strength, technical proficiency, movement rhythm, and high-velocity power

generation(Ribeiro et al., 2017). Efficient whole-body propulsion and hydrodynamic positioning constitute the foundation of sprint racing performance(Gatta et al., 2018). From a theoretical perspective, the multidimensional model proposed by Lavoie suggests that swimming performance is jointly determined by physiological, biomechanical, and psychological factors(Barbosa et al., 2010). Strength and conditioning training enhances neuromuscular function and propulsive force, psychological skills training contributes to self-regulation and competition coping ability, and biomechanical optimization improves stroke efficiency and movement effectiveness(Barbosa et al., 2010; Cormie et al., 2011).

METHODS

Search strategy The literature search involved five Electronic databases: Google scholar, Reference list SCOPUS, PubMed, EBSCOhost (SPORTDiscus), CINAHL Plus, and China National Knowledge Infrastructure (CNKI). The online search included journal articles in both English and Chinese that were published up to July 1, 2024. The key terms used were: (“training” OR “exercise” OR intervention OR program*) AND (“adolescent” OR “juvenile” OR “teenager” OR “youth” OR “young” OR “junior” OR “children”) AND (“player*” OR “athlete*” OR “sportsman*” OR “sportswoman*” OR “sportsperson*” OR “Jock*”) AND (“Swimming”). Of note, age (children and adolescents of 6–16 years) was the search limiter. In addition, Google Scholar and reference lists from all identified articles were searched for publications not identified by the original computerized search.

Participant or population Adolescent athletes.

Intervention Various training interventions targeting performance enhancement (e.g., resistance training, power training, capacity training).

Comparator Normal training.

Study designs to be included RCT.

Eligibility criteria This review utilized the PICOS (Population, Intervention, Comparison, Outcome, Study Designs) criteria to develop the inclusion and exclusion criteria. Articles that satisfied all the conditions below were considered for inclusion: (a) participants were adolescent swimmer (6-16 years old), without any restrictions on sex, swimming experience, or competition level; (b) active control group; (c) one outcome indicator related to

swimming performance for both the experimental and control groups was the 50-meter freestyle time ; (d) the training program was conducted without restrictions on the specific type of exercise employed; and (e) the study design was randomized controlled trials (RCTs).

Studies were excluded if they (a) involved injured athletes (e.g., ankle sprain); (b) had interventions lasting ≤ 2 weeks; (b) tested the effects of training intervention without a control group; and (c) were conducted in languages other than English and Chinese.

Information sources

Records identified through database search(n=1812)

CINAHL Plus(n=82)

Scopus(n=199)

CNKL(n=178)

Web of science(n=281)

SPORT Discus(n=1072)

Additional records identified through other sources(n=6)

Google scholar similar to the literature(n=4)

Reference(n=2).

Main outcome(s) Overall, combined training interventions produced a significant improvement in 50-m freestyle performance compared with conventional swim training alone (MD = -1.47 s, 95% CI: -2.02 to -0.92 ; $p < 0.00001$; $I^2 = 55\%$). Swimming-specific resisted training induced the greatest enhancement (MD = -1.62 s), followed by dry-land resistance and power training (MD = -1.49 s), while supplemental capacity training showed nonsignificant effects. Greater gains were observed with ≤ 3 weekly sessions and interventions > 8 weeks in length, indicating the importance of optimal training dose and sustained exposure. Age-related trends revealed declining responsiveness with increasing maturation, with athletes < 13 years demonstrating the largest improvements. Sensitivity analyses supported the stability of the results, and no publication bias was detected (Egger's $p = 0.2124$).

Additional outcome(s) Resistance-based and power-oriented training methods effectively enhance sprint swimming performance in adolescent athletes, with superior transfer observed in swimming-specific resisted modalities. Training effectiveness is moderated by dose and developmental stage, emphasizing the necessity for well-periodized and maturation-aligned strength programming within youth aquatics. These findings provide a refined evidence base to guide performance-focused training prescriptions in adolescent competitive swimming.

Data management The literature screening was conducted through a structured, sequential procedure. First, all retrieved bibliographic records were imported into the NoteExpress reference management system to remove duplicates. The primary author initiated the screening process by reviewing the titles, abstracts, and full texts of the identified publications. Subsequently, a second author independently evaluated the shortlisted articles to verify their compliance with the predefined inclusion criteria. In cases of disagreement, a third author was consulted, or the research team engaged in joint discussions to reach a consensus.

Quality assessment / Risk of bias analysis All included studies were evaluated using the Physiotherapy Evidence Database (PEDro) scale, with scores ranging from 6 to 8, indicating moderate to high methodological quality across the body of evidence. Most studies clearly reported the use of random allocation, ensuring a sound foundation for experimental design; however, only a few simultaneously met the criteria for both randomization and allocation concealment. Although the remaining studies adopted random allocation procedures, insufficient reporting regarding allocation concealment may introduce a potential risk of selection bias. All studies demonstrated good baseline comparability between intervention and control groups, thereby strengthening the validity of causal interpretations. Due to the inherent characteristics of exercise-based interventions, blinding of participants and therapists was largely infeasible, resulting in consistently low scores on these items; nevertheless, a small number of studies implemented therapist or assessor blinding.

Strategy of data synthesis Sixteen studies involving 311 adolescent swimmers were systematically analyzed using Review Manager 5.3 and Stata 17.0, in accordance with PRISMA guidelines. The primary outcome was 50-m freestyle time (mean difference, MD). Random-effects models were applied to estimate pooled effects and heterogeneity. Subgroup analyses were performed based on training modality (swimming-specific resisted training, dry-land resistance and power training, supplemental capacity training), weekly frequency (≤ 3 vs ≥ 4 sessions/week), intervention duration (≤ 8 vs > 8 weeks), and age group (< 13 , 13–15, ≥ 16 years). Egger's regression test and sensitivity analyses assessed publication bias and result robustness.

Subgroup analysis Subgroup analyses were performed based on training modality (swimming-

specific resisted training, dry-land resistance and power training, supplemental capacity training), weekly frequency (≤ 3 vs ≥ 4 sessions/week), intervention duration (≤ 8 vs > 8 weeks), and age group (< 13 , 13–15, ≥ 16 years). Egger's regression test and sensitivity analyses assessed publication bias and result robustness.

Sensitivity analysis A leave-one-out sensitivity analysis was conducted to evaluate the robustness of the pooled effect estimates. The results demonstrated that sequential removal of each individual study did not cause substantial fluctuations in the overall mean difference or its corresponding 95% confidence interval. No single study excessively influenced the direction or magnitude of the combined effect, and all recalculated estimates consistently favored improvements in 50-m freestyle performance. These findings confirm that the meta-analysis results are stable and reliable, and that the conclusions are not driven by any single study (Figure 3).

Country(ies) involved China.

Keywords Adolescent Athlete,; Swimming; Training; Performance; Intervention; Meta-analysis.

Contributions of each author

Author 1 - wei Guo - WG conceptualized the study, designed the methodology, and led the data analysis and interpretation.

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