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Meta-Analysis of the Effects of Core Stability Training on 50-Meter Freestyle Performance in Men and Women

Metanálisis de los efectos del entrenamiento de estabilidad del core en el rendimiento de 50 metros estilo libre en hombres y mujeres

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Abstract

Introduction. Core stability training (CST) has gained increasing relevance in sports due to its potential to enhance athletic performance and reduce injury risk, particularly in swimming. The 50-meter freestyle is a key performance test in swimming, and understanding the impact of CST on this specific event is essential for optimizing training programs.

Objective. This meta-analysis aimed to evaluate the effects of CST on the performance of male and female swimmers in the 50-meter freestyle.

Methods. A systematic search was conducted in PubMed, Bireme, Scopus, and Web of Science (WOS), adhering to the Cochrane Handbook guidelines. Risk of bias was evaluated using the ROB2 scale, while the quality of the studies was assessed with the SIGN and CONSORT checklists. Data were analyzed using a fixed-effects meta-analysis in RevMan-Web, and heterogeneity was assessed using the I^2 and x^2 tests.

Results. Out of 2,323 records identified, 7 studies met the inclusion criteria. The meta-analysis revealed that CST significantly improved 50-meter freestyle performance, with a time reduction of -1.06 seconds (95% CI = -1.52, -0.60) in male swimmers and -3.28 seconds (95% CI = -4.57, -1.99) in female swimmers.

Conclusion. CST was found to be effective in enhancing performance in the 50-meter freestyle, particularly in female swimmers. These findings support the use of CST as a valuable training strategy for sports scientists and coaches aiming to improve swimming performance.

Declaration of interests
The authors have declared that there is no conflict of interest.

Data availability
All relevant data is in the article. For futher information, contact the corresponding author.

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Keywords

Abdominal core; core stability; athletic performance; swimmers.

Resumen

Introducción. El entrenamiento de estabilidad del core (CST) ha ganado cada vez más relevancia en los deportes debido a su potencial para mejorar el rendimiento atlético y reducir el riesgo de lesiones, particularmente en natación. Los 50 metros estilo libre son una prueba de rendimiento clave en natación, y comprender el impacto del CST en esta prueba específica es esencial para optimizar los programas de entrenamiento.

Objetivo. Este metanálisis tuvo como objetivo evaluar los efectos del CST en el rendimiento de nadadores masculinos y femeninos en los 50 metros estilo libre.

Métodos. Se realizó una búsqueda sistemática en PubMed, Bireme, Scopus y Web of Science (WOS), siguiendo las pautas del Manual Cochrane. El riesgo de sesgo se evaluó utilizando la escala ROB2, mientras que la calidad de los estudios se evaluó con las listas de verificación SIGN y CONSORT. Los datos se analizaron utilizando un metanálisis de efectos fijos en RevMan-Web, y la heterogeneidad se evaluó utilizando las pruebas I^2 y x^2.

Resultados. De los 2.323 registros identificados, 7 estudios cumplieron con los criterios de inclusión. El metanálisis reveló que el CST mejoró significativamente el rendimiento en los 50 metros estilo libre, con una reducción de tiempo de -1,06 segundos (IC del 95 % = -1,52, -0,60) en nadadores masculinos y -3,28 segundos (IC del 95 % = -4,57, -1,99) en nadadoras femeninas.

Conclusión. Se descubrió que el CST era eficaz para mejorar el rendimiento en los 50 metros estilo libre, en particular en nadadoras femeninas. Estos hallazgos respaldan el uso del CST como una valiosa estrategia de entrenamiento para los científicos deportivos y los entrenadores que buscan mejorar el rendimiento en la natación.

Palabras clave

Núcleo abdominal; estabilidad del núcleo; rendimiento atlético; nadadores.

Introduction

Core stability training (CST) has gained great importance in sports due to its potential to optimize athletic performance and prevent injuries [1]. Core stability, defined as the ability to maintain postural control and trunk alignment during physical activities [2], is essential in disciplines that demand a high physical level, such as swimming [3]. In particular, the 50-meter freestyle event, one of the most rigorous speed competitions in this sport, requires precise synchronization of movements and efficient transfer of the force generated by the limbs for displacement in the water [4].

The relationship between core stability and 50-meter freestyle performance has been the focus of numerous studies that have explored how the improvement in core stability could be translated into an increase in swimming speed and efficiency [5]. However, the results of these investigations have shown considerable variability, with some studies revealing significant benefits and others reporting non-existent effects [5-8]. This discrepancy in the findings highlights the need for a systematic and comprehensive analysis that integrates the available evidence to provide more robust conclusions.

It should be noted that the only meta-analysis performed on the effect of CST in swimmers also included athletes from other disciplines and healthy adults [9], which could have influenced the interpretation of the results. Furthermore, physiological differences between male and female swimmers, such as body composition, muscle mass distribution, and hormonal effects, suggest that of CST may have differentiated impacts by sex, as well as by the competitive level of the athletes. These variations not only affect how each group engages stabilizing muscles in the water but may also influence the adaptation and effectiveness of CST at different levels of athletic demand [10]. In this context, the present meta-analysis aims to evaluate, through a rigorous quantitative analysis of existing studies, the effects of CST on 50-meter freestyle performance in both male and female swimmers.

Methods

Study design

This meta-analysis was conducted to determine the effects of CST on 50-meter freestyle performance in male and female swimmers. The study was properly registered in the International Prospective Register of Ongoing Systematic Reviews (PROSPERO) under the identification number CRD42024579857. The research was based on the collection and analysis of randomized controlled trials and controlled clinical trials, following the guidelines of the Cochrane Handbook and the statements established by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [11,12].

Criteria for the evaluation of studies

Types of studies

Randomized controlled trials and controlled clinical trials, without language restriction, reporting on the effects of CST on 50-meter freestyle performance in male or female swimmers were included.

Type of target population

Studies conducted in swimmers of all ages and sexes who had participated in CST programs, either alone or in combination, were considered. Studies that included athletes from sports modalities other than competitive swimming, those in which the swimmers had underlying pathologies or disabilities, as well as studies that administered ergogenic aids that could influence swimming performance were excluded. Studies with an unclearly defined gender population were also excluded.

Types of intervention

Interventions could include strength, endurance or power exercises aimed at strengthening core musculature or training core stability. Programs could include a variety of exercises performed on stable or unstable surfaces, using body self-loading or external weights. Activities could be dynamic, static or a combination of both.

Types of comparators

Placebo, no training, or any other physical exercise program that did not include core stability exercises nor those aimed at strengthening core musculature with the objective of improving swimming performance, were considered as comparison groups.

Types of outcome measures

The primary outcome measure was 50-meter freestyle performance, evaluated in 25 or 50-meter pools, using handheld digital stopwatches or specialized stopwatches, such as photocells, among others.

Search strategy and procedure

A systematic search was conducted during August 2024, using databases such as PubMed, Scopus, Web of Science and Bireme. The search was optimized using MeSH, DeCS and free terms. Details of the search strategy and history for each of the databases are available in the supplementary material.

Identification of studies and data extraction

Two reviewers made the selection of articles through a preliminary reading of titles and abstracts to determine their relevance. Subsequently, the reviewers independently analyzed the full texts of the pre-selected articles to decide on their inclusion in the review. In case of discrepancies, a third reviewer intervened to resolve the disagreement. The collaborative application Rayyan was used for this process [13]. Data were extracted from each study including title, first author, year of publication, objective, population, methodology, training protocols, and measures or mean differences of the results in the 50-meter freestyle, along with their respective standard deviations. In case of missing data, authors were contacted through the correspondence author's email or through the scientific social network ResearchGate to obtain the missing information.

Quality of the studies

Quality of the included studies was assessed using the clinical trial checklist provided by the Scottish Intercollegiate Guidelines Network (SIGN) [14] and the Consolidated Standards of Reporting Trials (CONSORT) approach [15]. These tools provide predefined criteria for grading quality based on the presentation and reporting of studies. The assessment was performed by two investigators and, in case of disagreement, a third reviewer was involved.

Risk of study bias

Each study was individually assessed for risk of bias using the Risk of Bias 2 (ROB 2) tool of the Cochrane Handbook of Systematic Reviews [16]. The assessment was performed independently by two reviewers, with the intervention of a third reviewer to resolve discrepancies. Although it was considered to perform an analysis of the risk of publication bias using a funnel plot and Egger's test with the t statistic in STATA, it was decided not to carry it out due to the lack of at least 10 studies in each sex, which is the minimum number required to ensure the feasibility of these approaches [17-19].

Statistical analysis

The extracted data were analyzed following the guidelines of the Cochrane Handbook of Systematic Reviews [11]. For the global estimation of effect, means (M) and mean differences (MD) were used, as the measurement units and evaluation methods were consistent across studies. Therefore, it was not necessary to employ the standardized mean difference. Additionally, when needed, the pooled standard deviation (*pooled SD*) formula was applied to calculate the standard deviation of the mean difference effect. In cases where studies did not provide the standard deviation of the outcomes of interest, it was calculated from confidence intervals or standard errors, according to the guidelines of the Cochrane Handbook [11]. RevMan web software was used to assess statistical heterogeneity, applying statistical methods such as I^2 and x^2, along with their degrees of freedom and p values, in the fixed-effects model, assuming that all individual studies share a common true effect [20].

Results

Study selection

A total of 2,323 articles were identified through the database search. After eliminating duplicates, 1,000 manuscripts remained. Subsequently, they were submitted to a rigorous selection process, first by reviewing titles and abstracts, and then through full-text analysis. Finally, 7 studies were chosen for inclusion in the meta-analysis [21-27] (see Figure 1).

Characteristics of the included studies

The seven studies analyzed in this review were published between 2017 and 2023, and together included a sample of 142 swimmers, aged between 11 and 20 years. Of these, 71 swimmers were part of the intervention group and 71 of the control group, distributed in 48 females and 94 males. The studies used various dosages and training strategies: five implemented 8-week programs [22,24-27], while two opted for 6-week programs [21,23]. Most investigations established a training frequency of 3 sessions per week [21-23,25,26], although two studies increased the frequency to 4 and 5 sessions per week, respectively [24,27]. Table 1 presents a detailed summary of the most relevant aspects of each included study.

Quality of the studies

In the assessment of reporting quality using the CONSORT checklist, it was observed that items 2a, 2b, 5, 6a, 6b, 7b, 11b, 12a, 12b, 13a, 13b, 15, 16, 17a, 20, 21 and 22 were fulfilled in all the reviewed studies. Nevertheless, items 1a, 4a, 4b, 8a, 8b, 9, 10, 11a, 23 and 24 were not always adequately reported. The main deficiencies were concentrated in items 8a, 8b, 9, 10 and 11b, which are related to the sample size calculation, the randomization mechanism and the blinding of both participants and evaluators.

Regarding the specific quality of the studies, assessed using the clinical trial checklist proposed by SIGN, six studies were classified as acceptable quality [21-26] and one as low quality [27]. No study complied with item 1.4, referring to blinding of the subjects, investigators, and assessors. Still, it is recognized that given that the intervention in question is physical exercise, implementing the blinding of participants and of the investigators responsible for the training program represents a significant challenge.

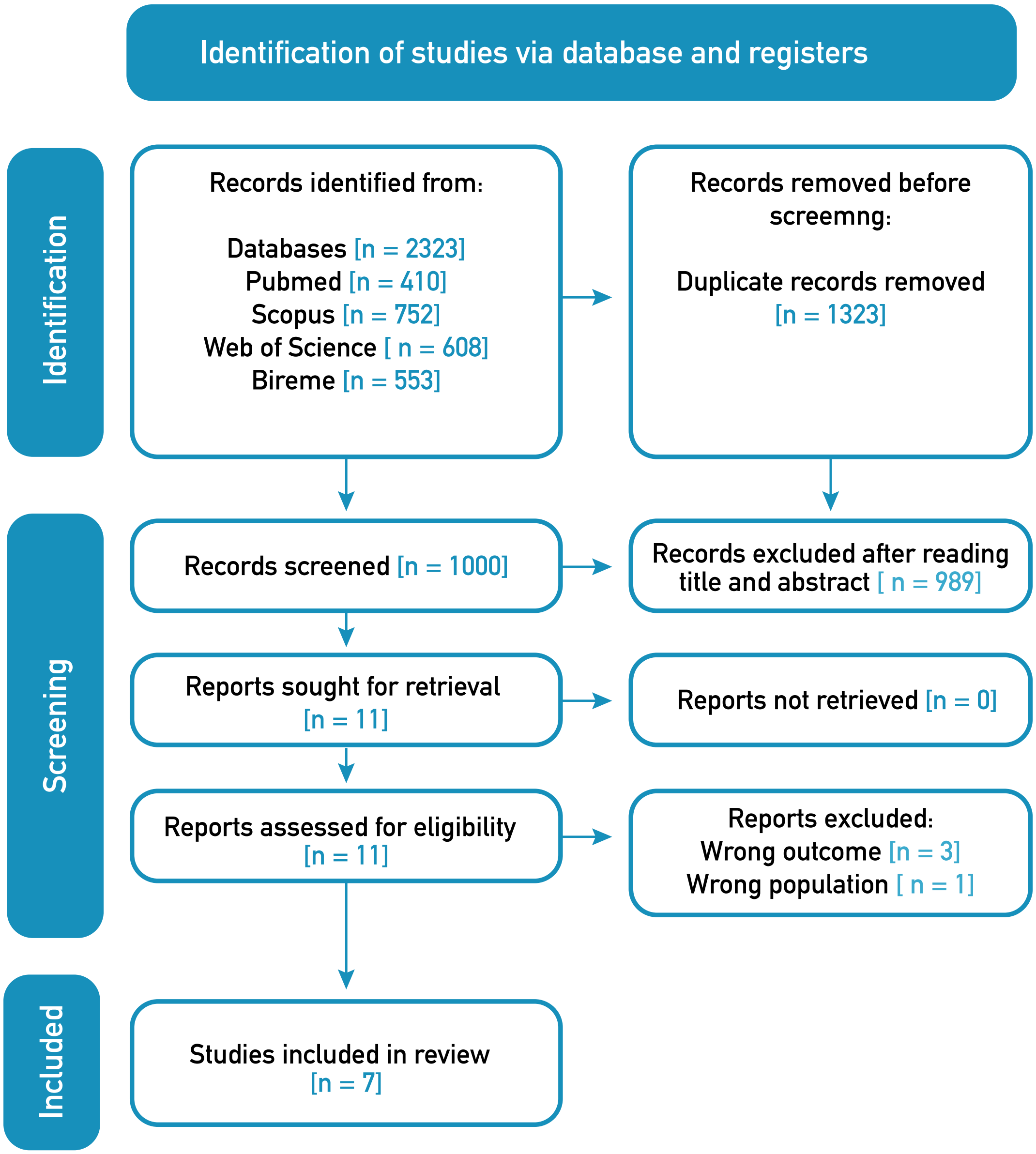


Figure 1. Summary of search and selection of studies.

Table 1. Characteristics of the included studies.

Author	Year	Type of study	Intervention group (CST + SWT)	Control group (SWT)	Core stability training program				
					# weeks	Frequency	Training surface	Type of exercises	# exercises
Gül [26]	2020	Randomized clinical trial	n: 7 male swimmers (11.57 ± 1.2 years)	n: 7 male swimmers (11.43 ± 1,2 years)	8	3 times x week	Stable	Does not report	6
Kurt [24]	2023	Randomized clinical trial	n: 11 male swimmers (12-15 years)	n: 11 male swimmers (12-15 years)	8	4 times x week	Stable	Dynamics	10
Eskiyecek [22]	2020	Randomized clinical trial	n: 12 male swimmers (11.25 ± 0.75 years)	n: 12 male swimmers (10.42 ± 0.51 years)	8	3 times x week	Stable	Dynamics	10
Karpiński [21]	2020	Randomized clinical trial	n: 8 male swimmers (20.2 ± 1.17 years)	n: 8 male swimmers (20.0 ± 1.9 years)	6	3 times x week	Stable and e unstable	Dynamics	4
Khiyami [23]	2022	Quasi-experimental clinical trial	n: 9 male swimmers (13 ± 2 years)	n: 9 male swimmers (13.11 ± 2,6 years)	6	3 times x week	Stable	Dynamics and statics	14
Gencer [27]	2018	Quasi-experimental clinical trial	n: 12 female swimmers (10.58 ± 1.31 years)	n: 12 female swimmers (10.75 ± 1.29 years)	8	5 times x week	Stable	Dynamics and statics	7
Zarei [25]	2017	Randomized clinical trial	n 12: female swimmers 12 (14 ±1.08 years)	n: 12 female swimmers (14 ± 1.27 years)	8	3 times X week	Stable	Dynamics	16

Note. Abbreviations = CST: Core stability training; SWT: Swimming training.

Risk of study bias

After applying the ROB 2 tool to assess the risk of bias in the included studies, all of the studies were found to have a low risk of bias in the domains "Deviations from intended interventions" and "Missing outcome data" (see Figure 2). However, concerns and a high risk of bias were identified in the domains "Randomization process" and "Selection of reported outcomes". Figure 3 presents the detailed individual risk of bias assessment for each of the 7 included studies.

Intervention effects on 50-meter freestyle performance

Effects in male swimmers

For the outcome measure in male athletes, five studies were included in the meta-analytic analysis [21-24,26]. The analysis showed low statistical heterogeneity (see Figure 3), with a I^2 value of 46% and a x^2 of 7.35, which does not exceed degrees of freedom. In addition, the p value of 0.12 suggests a possible absence of significant heterogeneity. A mean difference of -1.06 seconds was found in the 50-meter freestyle test (95% CI = -1.52, -0.60), indicating a statistically significant effect in favor of the intervention group (Figure 3).

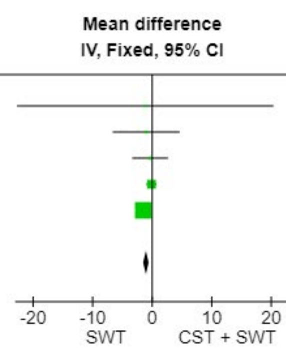
Studies	D1	D2	D3	D4	D5	Overall
Karpiński [21]	!	+	+	+	!	!
Eskiyecek [22]	!	+	+	+	!	!
Khiyami [23]	!	+	+	+	!	!
Kurt [24]	!	+	+	+	!	!
Zarei [25]	!	+	+	+	!	!
Gül [26]	!	+	+	+	!	!
Gencer [27]	-	+	+	!	!	-

Legent:

D1	Randomisation process
D2	Deviations from the intended interventions
D3	Missing outcome data
D4	Measurement of the outcome
D5	Selection of the reported result
+	Low risk
!	Some concerns
-	High risk

Figure 2. Risk of bias of included studies.

Study or Subgroup	CST + SWT Mean	CST + SWT SD	CST + SWT Total	SWT Mean	SWT SD	SWT Total	Weight	Mean difference IV, Fixed, 95% CI	Risk of Bias A	B	C	D	E	F
Gül 2020	-1.43	18.24	7	-0.27	22.63	7	0.0%	-1.16 [-22.69 , 20.37]	?	+	+	+	?	?
Kurt 2023	-1.5	7.62	11	-0.5	5.73	11	0.7%	-1.00 [-6.63 , 4.63]	?	+	+	+	?	?
Eskiyecek 2020	-0.43	1.84	12	-0.08	4.98	12	2.4%	-0.35 [-3.35 , 2.65]	?	+	+	+	?	?
Karpiński 2020	-0.3	0.42	8	-0.18	1.14	8	29.9%	-0.12 [-0.96 , 0.72]	?	+	+	+	?	?
Khiyami 2022	-1.6	0.84	9	-0.1	0.19	9	67.0%	-1.50 [-2.06 , -0.94]	?	+	+	+	?	?
Total (95% CI)			**47**			**47**	**100.0%**	**-1.06 [-1.52 , -0.60]**						



Heterogeneity: Chi² = 7.35, df = 4 (P = 0.12); I² = 46%
Test for overall effect: Z = 4.50 (P < 0.00001)
Test for subgroup differences: Not applicable

Risk of bias legend
(A) Randomization process
(B) Deviations from intended interventions
(C) Mising outcome data
(D) Measurement of the outcome
(E) Selection of the reported result
(F) Overall Bias

Figure 3. Effect of core stability combined with swimming training vs. swimming training on 50-meter freestyle performance (males).

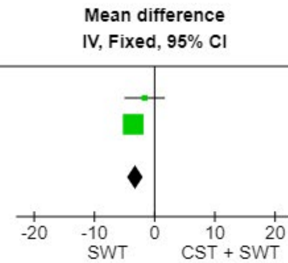
Note. Forest plot comparing the effect of core stability training combined with swimming training versus swimming training on specific performance in the 50-meter freestyle in male swimmers. Abbreviations= CST: Core stability training. SWT: Swimming training.

Effects in female swimmers

For the outcome measure in female athletes, only two studies were included in the meta-analytic analysis [25,27]. The analysis showed low statistical heterogeneity (see Figure 4), with a I^2 value of 5% and a x^2 of 1.05, which exceeds the degrees of freedom by 50%. Additionally, the *p* value of 0.31 suggests a possible absence of significant heterogeneity. A mean difference of -3.28 seconds was found in the 50-meter freestyle test (95% CI = -4.57, -1.99), indicating a statistically significant effect in favor of the intervention group (Figure 4).

Study or Subgroup	CST + SWT Mean	CST + SWT SD	CST + SWT Total	SWT Mean	SWT SD	SWT Total	Weight	Mean difference IV, Fixed, 95% CI	Risk of Bias A	B	C	D	E	F
Gencer 2018	-2.08	4.1	12	-0.42	4.29	12	14.8%	-1.66 [-5.02 , 1.70]	-	+	+	?	?	-
Zarei 2017	-3.8	1.79	12	-0.24	1.71	12	85.2%	-3.56 [-4.96 , -2.16]	?	+	+	+	?	?
Total (95% CI)			**24**			**24**	**100.0%**	**-3.28 [-4.57 , -1.99]**						

Heterogeneity: Chi² = 1.05, df = 1 (P = 0.31); I² = 5%
Test for overall effect: Z = 4.97 (P < 0.00001)
Test for subgroup differences: Not applicable



Risk of bias legend
(A) Randomization process
(B) Deviations from intended interventions
(C) Mising outcome data
(D) Measurement of the outcome
(E) Selection of the reported result
(F) Overall Bias

Figure 4. Effect of core stability combined with swimming training vs. swimming training on 50-meter freestyle performance (females).

Note. Forest plot comparing the effect of core stability training combined with swimming training versus swimming training on specific performance in the 50-meter freestyle in female swimmers. Abbreviations= CST: Core stability training. SWT: Swimming training.

Discussion

This systematic review with meta-analysis is presented as a pioneer in investigating the effects of core stability training (CST) on 50-meter freestyle performance, being to our knowledge the first of its kind. Previous reviews have focused on the effects of CST on general physical tests, such as jumping, running speed or CORE and limb strength [28,29]. However, specific performance in sport tests had been studied mainly in throwing sports such as baseball, although with a remarkable heterogeneity among studies, which could overestimate the real value of the results. Furthermore, in specific speed tests in various sports, the meta-analysis by Saeterbakken et al. [9] reported a significant improvement, with a reduction of 0.66 units in the standard deviation of the standardized mean difference (95% CI = 0.20, 1.12) in speed performance, including a study on swimming speed. In that meta-analysis, the standardized mean difference was used due to variations in measurements among the included studies, unlike the present meta-analysis, which used the mean difference. According to Cohen's criteria, this is a medium-sized effect [30]. Although the clinical relevance of these findings may seem modest, even small improvements can be crucial in the sports context.

From a theoretical perspective, these findings can be understood from different approaches. Core strength and stability are key to ensuring adequate force transmission from the large structures of the body, such as the trunk to the limbs. Even if the limbs possess great strength, if the core is not stable, that force transfer is impaired, leading to less force production in the peripheral segments and less efficient movement patterns [31]. Besides, according to the kinetic chain theory, any interruption in this muscle sequence can lead to energy losses, which has a negative impact on the execution of complex movements that require high physical performance [32]. These losses can originate both from a lack of stability and from muscle fatigue, which prevents the establishment of a solid base for a correct transmission of force.

This approach is supported by the study of Rosemeyer et al. [33], which evidenced how fatigue in the core musculature decreases the ability to generate force in the limbs, affecting their performance in all planes of motion. Moreover, it has been shown that a well-conditioned core musculature is closely linked to better performance in activities such as running and force or power generation [34].

Strengths and limitations of the study

This study represents the first systematic review with meta-analysis investigating the effects of CST on the specific performance of swimmers, positioning itself as a pioneering work in this field. Among the main strengths of the study, the methodical approach used in the search and selection of the studies, as well as in the data extraction and evaluation of the risk of bias, quality of the reports and quality of the included studies stand out. No studies were excluded by language or year of publication, which ensured the inclusion of all available evidence. In addition, the fact that at least two reviewers were involved in the initial phases of the search, selection, extraction and evaluation of the studies helped to reduce bias and improve the quality of the process.

Nevertheless, there are some important limitations, particularly related to the risk of bias in the considered studies. One of the studies showed a high risk of bias [27], while the others presented some concerns [21-26], mainly due to the lack of trial registration and lack of clarity in the report on the concealment of the randomization sequence, which generates some uncertainties. On the other hand, it is important to note that six out of the seven included studies analyzed a population of athletes aged 10 to 13 years [21-27]. This age range corresponds to a critical stage of biological and hormonal maturation, which can significantly impact physical performance [35,36], potentially leading to an over- or underestimation of the intervention's true effect. Additionally, the studied population consisted exclusively of semi-professional level swimmers. This suggests that the findings may not be generalizable to other groups of swimmers, such as amateurs, who might benefit more substantially from this type of training, or elite-level swimmers, whose highly developed physical characteristics could result in a more modest response.

Another relevant limitation is the underrepresentation of female swimmers in the sample; only two studies included female participants [25,27]. This imbalance could result in an overestimation of the effect observed in this group. The limited data on female athletes weakens the robustness of conclusions regarding their response to the intervention, highlighting the need for greater inclusion of female samples in future studies. Given these limitations, we recommend that future researchers conduct additional primary studies involving both amateur and professional swimmers, as well as address the significant gap in data on female populations. This approach will allow for more accurate conclusions and a more balanced representation of responses to the intervention across diverse populations. Finally, although meta-analysis allows combining studies and increasing statistical power by including a larger number of subjects, which would not be possible in individual studies, the total population in this meta-analysis remains relatively small. Still, without this synthesis, the number of participants would be even more limited.

Conclusion

In the first place, these findings highlight the importance of future studies registering their protocols in advance on platforms such as ClinicalTrials [37], ensuring a more rigorous approach. In addition, it is crucial that investigators ensure and report in detail the randomization sequence and to the extent possible, attempt to blind evaluators, recognizing that due to the nature of the training, blinding the participants and trainers can be complicated.

In the second place, these results have practical implications for swimming coaches, who can integrate core stability training (CST) not only as a tool in physical therapy for injury prevention and rehabilitation of low back problems [38], but also as an effective strategy to optimize the physical performance of the athletes.

Finally, it is concluded that CST was shown to be effective in improving performance in the 50-meter freestyle test, reducing the time by -1.06 seconds (95% CI = -1.52, -0.60) in male swimmers and by -3.28 seconds (95% CI = -4.57, -1.99) in female swimmers. These results suggest that sport scientists working with swimmers might consider this type of training as a valuable tool to improve performance and help the athletes to achieve their sporting goals.

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