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Combined warmup exerts an ergogenic effect on the speed of sprint swimmers: A systematic review with meta-analysis

El calentamiento combinado ejerce un efecto ergogénico sobre la velocidad de los nadadores velocistas: una revisión sistemática con metaanálisis

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Abstract. This study review and analyze studies that measured the effect of combined strength/power warmup (COMB) versus traditional (TRAD) on the post-activation performance enhancement (PAPE) of swimmers. For this, we performed a systematic review was carried out with meta-analysis based on descriptors related to PAPE in swimming. A total of 138 articles were identified, of which 15 were selected. Comparisons between the COMB condition and the TRAD warm-up were performed for the following set of variables: a) power in 50- and 100-meter events, b) start performance, c) test time of 50- and 100- meters, and d) instantaneous speed in 50-meters events. The data extracted from the studies showed acceptable homogeneity (I^2=0.000). When we observed the confidence intervals, it was verified that there were no differences between the COMB condition and the TRAD for power in 50 and 100 m events (Hedges g'=-0.12; 95%CI=-0.376; 0.136; p=0.357); time in 50- and 100-meter races (Hedges g'=-0.139; 95%CI=-0.314; 0.036; p=0.118); start performance (Hedges g'=-0.313; 95%CI =-0.643; 0.018; p=0.064). The COMB condition had an ergogenic effect on instantaneous speed in the 50 m event (Hedges g'=-0.282; 95%CI=-0.402; -0.162; p≤0.001). In conclusion, the present meta-analysis concluded that the COMB intervention does not exert an ergogenic effect on the performance of swimmers for the set of analyzed variables, except for instantaneous speed in 50 m events. Future studies may compare other forms of warmup versus the TRAD.
Keywords: Warm-up exercise; Musculoskeletal and Neural Physiological Phenomena; swimming; athletic performance.

Resumen. Este estudio revisa y analiza estudios que midieron el efecto del calentamiento combinado de fuerza/potencia (COMB) versus el tradicional (TRAD) en la mejora del rendimiento post-activación (PAPE) de los nadadores. Para ello se realizó una revisión sistemática con metaanálisis basado en descriptores relacionados con PAPE en natación. Se identificaron un total de 138 artículos, de los cuales se seleccionaron 15. Se realizaron comparaciones entre la condición COMB y el calentamiento TRAD para el siguiente conjunto de variables: a) potencia en eventos de 50 y 100 metros, b) rendimiento inicial, c) tiempo de prueba de 50 y 100 metros, y d) velocidad instantánea en pruebas de 50 metros. Los datos extraídos de los estudios mostraron una homogeneidad aceptable (I^2=0,000). Cuando observamos los intervalos de confianza, se verificó que no hubo diferencias entre la condición COMB y el TRAD para potencia en las pruebas de 50 y 100 m (Hedges g'=-0,12; IC95%=-0,376; 0,136; p=0,357); tiempo en carreras de 50 y 100 metros (Hedges g'=-0,139; IC95%=-0,314; 0,036; p=0,118); desempeño inicial (Hedges g'=-0.313; IC95%=-0.643; 0.018; p=0.064). La condición COMB tuvo un efecto ergogénico sobre la velocidad instantánea en la prueba de 50 m (Hedges g'=-0,282; IC95%=-0,402; -0,162; p≤0,001). En conclusión, el presente metaanálisis concluyó que la intervención COMB no ejerce un efecto ergogénico sobre el rendimiento de los nadadores para el conjunto de variables analizadas, excepto para la velocidad instantánea en pruebas de 50 m. Los estudios futuros pueden comparar otras formas de calentamiento versus TRAD.
Palabras clave: Ejercicio de calentamiento; Fenómenos fisiológicos musculoesqueléticos y neurales; natación; desempeño atlético.

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Introduction

Coaches prescribe warm-up exercises for their athletes before starting the training or competition session. This procedure aims at physiological and metabolic activation, preparing athletes to perform the task (Cuenca-Fernández, Batalha, et al., 2020; Cuenca-Fernández et al., 2022; Enríquez et al., 2023; Neiva et al., 2017). In this line, a study showed that adding aerobic stimuli can be an alternative that can improve the performance of male sprinters in 100m freestyle (Neiva et al., 2017). Compared to no warm-up, swimmers' performance in the 100-meter freestyle increased when they performed a 1000-meter warm-up in the pool (Neiva et al., 2014). West et al. (2013) suggested that international-level swimmers improve post-warm-up performance mainly due to increased muscle temperature, higher vascularization of tissues and muscles, and better neuromuscular activity. A meta-analysis on the topic (published in 2010) showed that performance could be improved if the warm-up is well planned. In turn, the authors of this review suggest that it is necessary to apply a specific warm-up for each sport, especially in sports that involve power and speed, which should include strength exercises during the warm-up (Fradkin, Zazryn, & Smoliga, 2010).

Despite the benefits of warm-up in the swimming performance (Cruz, 2023; Neiva et al., 2014). The competitive rules of swimming can compromise the performance of athletes (Cuenca-Fernández et al., 2022; West et al., 2013). The ideal situation is that the time between the warm-up and the test is between 5 and 15 min (Fradkin et al., 2010). However, this time can reach 45 minutes, according to reports issued by swimmers (Zochowski, Johnson, & Sleivert, 2007). This fact has led researchers to investigate the effect of different times between the warm-up and the competition on the performance of swimmers. In this line, studies observed that a 200-meter crawl performed 10 min (Zochowski et al., 2007) and 20 min (West et al., 2013) after warm-up results in better performance when compared to 45 minutes. This result is relevant because it shows the need to think of strategies that maintain the warm-up benefits for athletes who have events that happen late in the competitive program (Enríquez et al., 2023; West et al., 2013).

Regarding this subject, it may be interesting to use exercises that result in post-activation performance enhancement (PAPE) before the competition. Initially, the term post-activation potentiation (PAP) was proposed. PAP refers to an increase in electrically-evoked twitch force following a muscular contraction with a very short ergogenic effect (<5 min) (Cuenca-Fernández et al., 2017). However, the alternative term PAPE was proposed more recently, as it is adequate and comprehensive to explain the phenomenon. The PAPE occurs when there is voluntary improvement in athletic performance following muscular activity (Boullosa et al., 2020; Cuenca-Fernández et al., 2017). PAPE effect results from the sum of physiological factors that enhance performance, such as increased blood flow and muscle temperature (Boullosa et al., 2020; Crespo, Ruiz-Navarro, Cuenca-Fernández, & Arellano, 2021). Furthermore, it is noteworthy that the ergogenic effects observed in PAPE tend to be longer when compared to PAP (Boullosa et al., 2020; Cuenca-Fernández et al., 2017). A study suggests that a dryland power exercise circuit can improve the 50-meter sprint performance in male swimmers (Dalamitros et al., 2018).

Although the mechanisms responsible are not fully understood, neuromuscular mechanisms may contribute to PAPE. Examples include phosphorylation of the myosin regulatory chain, motoneuron excitability, increased recruitment of motor units, and short-term changes in the pennation angle of muscle fibers (Rassier & Macintosh, 2000). A study suggests that the factors that enhance performance must outweigh those that diminish it for the PAPE to occur. The activation and resolution of these factors may follow different time courses, which could create a window for enhanced performance in swimmers (Cuenca-Fernández, Batalha, et al., 2020; Pereira, Pesantez, Morales, & Vásquez, 2023).

Despite the ergogenic effects described above, the performance effects of combined strength/power exercises (COMB) in swimmers are unclear (Abbes et al., 2018; Barbosa, Barroso, & Andries Jr, 2016; Barbosa, Yam, Lum, Balasekaran, & Marinho, 2020; Cuenca-Fernández, Ruiz-Teba, López-Contreras, & Arellano, 2020; Hancock, Sparks, & Kullman, 2015; Thng, Pearson, & Keogh, 2019). In addition, some published studies have limitations (i.e.; analyze fragments of the sport as block start) that make it difficult to transpose the experimental protocol into the daily practice of swimming training and competition (Blanco, De la Fuente Caynzos, & Colomina, 2017; Hancock et al., 2015; Pereira et al., 2023). Based on the above, the present study aimed to review and analyze the effect of COMB versus TRAD warm-ups on swimmers' performance. To this end, a systematic review with meta-analysis was carried out in which performance variables performed after COMB or TRAD warm-ups were compared. To the best of our knowledge, only one systematic review compared the effect of COMB or TRAD warmups on swimmers' performance (Thng et al., 2019), but this study was limited to investigating the effect on start. The present systematic review with meta-analysis may help coaches and athletes choose the most effective warm-up protocols to improve performance.

Materials and methods

Procedures

A systematic review of the literature with meta-analysis was carried out to achieve the aims established for the present study. We included all relevant papers published from 1990 to August of 2022 that were analyzed, which measured the effect of COMB and other warm-up protocols on the performance of swimmers. We did the search strategy based on the population intervention comparison outcome (PICO) method (Frandsen, Nielsen, Lindhardt, & Eriksen, 2020). The search was performed in the following databases: PUBMED (2011-2022), SCOPUS (2015-2022), GOOGLE SCHOLAR (2016-2022), SPORTSDISCUS (2005-2022) and MEDLINE (2016-2022). The following keywords were used: "warmup" OR "post-activation potentiation" OR "post-activation enhancement performance" AND "swimming" OR "performance." In addition, the following filters were used: a) English language, b) humans, c) randomized controlled trials, and e) intervention. The inclusion criteria of the studies were: a) strength/power intervention protocols performed in humans; b) carrying out test protocols exclusively in swimming; and c) quantitative analysis of data by statistical tests. Exclusion criteria were: a) studies in which the investigated intervention was not strength/power intervention protocols (i.e., TRAD warm-up vs. no warm-up; comparison of different times of TRAD); b) studies which do not compare COMB versus TRAD warm-up; c) another sport; and; d) results not presented by mean and standard deviation.

Figure 1 shows the selection flowchart of studies analyzed using the PRISMA methodology [19]. The data collected in the studies were the following: a) characterization of the participants; b) intervention strategy; c) physical test protocol; d) data that evaluated performance; e) speed in the 50m and 100m events; f) start performance, and; g) time in the test. Figure 1 shows the selection flowchart of studies analyzed according to the PRISMA methodology (Page et al., 2021). For the study selection, two independent evaluators (CJB and EFS) separately assessed the eligibility, extracted data, and checked the quality of the included studies using the keywords described above. Any disagreements were resolved between these evaluators or with a third reviewer (BM) if disagreements persisted. One hundred thirty-eight articles were identified after an initial search; however, 88 remained after removing the duplicates. Then, 62 articles were excluded after reading the titles, abstracts, and methods because they were outside the study scope. As a result, 26 articles were initially selected to be read in full, but 12 were excluded for: a) presenting the results in Figures (we contacted the corresponding author via e-mail. Unfortunately, we did not get a response); b) did not use COMB protocol in swimming; c) for not evaluating power, speed or time measurements in the 50 meters and/or 100 meters. Next, a quality analysis was performed after registering the data using the Tool for the assessment of Study quality and reporting in Exercise scale (TESTEX). This scale addresses quality assessment criteria specifically for physical training studies and has a total score of 15 points. Internal validity evaluation criteria and presentation of the statistical analysis used are included. One point for each criterion defined in the scale is attributed to the presence of quality indicators of the evidence presented, and no point is attributed to the absence of these indicators (Smart et al., 2015). The higher the score, the better the methodological quality and statistical description of the study.

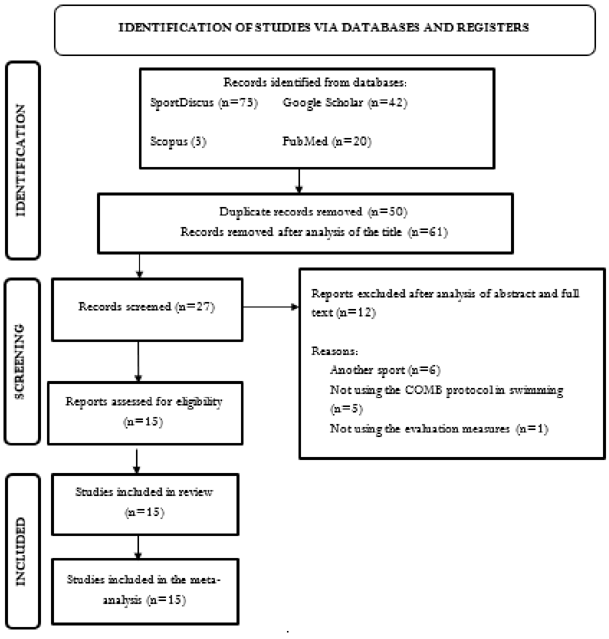

Figure 1. PRISMA flow diagram for study selection

Table 1.
Assessment of the TESTEX scale of the selected studies.

Study	1	2	3	4	5	6a	6b	6c	7	8a	8b	9	10	11	12	Total
Abbes et al. (2018)	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	14
Abbes et al. (2020)	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	14
Barbosa et al. (2020)	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	14
Cuenca-Fernández et al. (2015)	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	14
Cuenca-Fernández et al. (2019)	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	14
Cuenca-Fernández, Batalha, et al. (2020)	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	14
Cuenca-Fernández, Ruiz-Teba, et al. (2020)	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	14
Dalamitros et al. (2018)	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	14
Dalamitros et al. (2019)	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	14
de Arruda et al. (2020)	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	14
Đurović, Stojanović, Stojiljković, Karaula, and Okičić (2022)	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	14
Hancock et al. (2015)	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	14
Ng, Yam, Lum, and Barbosa (2020)	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	14
Sarramian et al. (2015)	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	13
Sirieiro, Rego, Terzi, Willardson, and Miranda (2022)	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	13

1. Specification of inclusion criteria; 2. Random allocation; 3. Secrecy in the allocation; 4. Similarity of groups in the initial or basal phase; 5. Evaluator masking; 6. Measure of at least one primary outcome in 85% of allocated subjects (6-a. Outcome measures assessed in 85% of subjects; 6-b. Reported adverse events; 6-c. Reported session attendance); 7. Intent-to-treat analysis; 8. Comparison between groups of at least one primary outcome (8-a. Reporting of statistical comparisons between groups (Primary Outcomes Report); 8-b. Reporting of statistical comparisons between groups (Reported Secondary Outcomes); 9. Reporting measures of variability for all reported outcome measures 10. Activity monitoring in control groups 11. Relative exercise intensity remained constant 12. Characteristics of exercise volume and energy expenditure.

After the quality analysis, the extraction of numerical data described in mean and standard deviation was performed. The study variables were defined according to the hypotheses presented. Thus, the present study evaluated the statistical data about whether the COMB warm-up condition could: a) improve power in 50- and 100-meter events; b) improve the start performance; c) improve performance in the 50- and 100-meter race time; and d) improve instantaneous speed in 50-meters events. Random effects analysis was used to pool the effect sizes of included studies. This model was used to consider differences between studies that may have affected the treatment effect. The effect size was calculated by the Hedges g' (Hedges, 1981) corrected to investigate the effectiveness of COMB when compared to TRAD warm-up, which can be categorized as small (0.20-0.49), medium (0.50-0.79) or large (0.80-1.29).

We chose this method because it includes a correction factor in Cohen's d to avoid analysis bias in studies that were performed with small samples. The I^2 test was used to explore heterogeneity, which was classified as acceptable (<50%), moderate (50-75%) and high (>75%). The results are presented as weighted mean and 95% confidence interval (95%CI).

The threshold of significance was $p<0.05$ and the data were analyzed using the Comprehensive Meta-Analysis version 2.2 statistical software.

Results

Participants presented the following descriptive characteristics – age: 18.1±3.4 years, body mass: 71.3±7.6 kg, and height: 176.6±12.1 cm. Most parts of the participants were experienced athletes and competed at the national or international level with an experience time of 5.7±1.8 years. According to Table 1, the included studies showed high methodological quality (≥13). Table 2 presents the results of the studies included in the present meta-analysis.

Table 2.
Summary of included studies that evaluated the effect of warmup on post-activation performance enhancement.

Study; experimental fashion	Participants[1]	Participant characteristics	Protocols	Interval between protocols and tests	Measures	Results
Abbes et al. (2018); randomized counterbalanced	17 teenage male-trained athletes	Age:13.0±2.0 yrs. Weight: 52.5±9.5 kg Height: 161.1±12.4 cm ET: ≥4 yrs.	COMB 1: TRAD + Push-ups COMB 2: TRAD + Squat jump COMB 3: TRAD + Burpee (30" max. rep.) TRAD: 1200m freestyle	10 min 10 min 10 min 30 min	Power and time in 50- and 100-meters freestyle	↔ COMB X TRAD
Abbes et al. (2020); randomized counterbalanced	14 teenage male-trained athletes	Age:13.0±2.0 yrs. Weight: 52.5±9.5 kg Height: 161.1±12.4 cm TE: ≥4 yrs.	COMB: 1200m freestyle + tethered swimming (3x10s 1' int.) TRAD: 1200m freestyle + 200 m freestyle	8 min 8 min	Power and time in 50- and 100-Meters freestyle	↔ COMB X TRAD
Barbosa et al. (2020) Randomized	12 male trained athletes	Age:23.5±3.4 yrs. Weight: 71.0±7.9 kg Height: 176.0±4.0 cm ET: 8.1±4.6 yrs.	COMB: 700m [200m self-speed + 100 crawl (25m steady/25m fast) + 100m kick drill + 2x100m (1 crawl + 1 medley) + 50m easy + 50m (dive) + 2 x 5RM band pull TRAD: 1400 m [400m self-speed + 200 crawl (25m steady/25m fast) + 200m kick drill + 4x100m (2 crawl + 2 medley) + 100m easy + 2x50m (dive)	8 min 8 min	Speed Arm-pull kinetics	↔ COMB X TRAD for speed ↑ COMB X TRAD for speed thrust
Cuenca-Fernández et al. (2015); randomized	10 male highly trained athletes	Age: 20.5 yrs. Weight: 69.0 kg Height: 176.3 cm ET: ≥5 yrs.	COMB 1: Lunges (3 rep. 85% 1RM) COMB 2: eccentric flywheel[2] (4 max rep) TRAD: 400m [200m freestyle + 1x50m freestyle (12.5m fast/ 12.5m slow) + 1x50m fast + 100m freestyle]	8 min 8 min 8 min	Start performance	↑ COMB X TRAD
Cuenca-Fernández et al. (2019); Randomized	11 male trained athletes	Age: 19.0 yrs. Weight: 76.6 kg Height: 181 cm ET: not reported	COMB: eccentric flywheel[2] (5 max rep) TRAD: 400m freestyle + 2 starts	6 min 6 min	Start performance	↑ COMB X TRAD
Cuenca-Fernández, Ruiz-Teba, et al. (2020); Randomized	17 male highly trained athletes	Age: 18.4±1.4 yrs. Weight: 74.7±9.0 kg Height: 181.0±0.0 cm ET: not reported	COMB 1: TRAD + 3 lunges (85% 1MR) + 3 arm strokes[3] COMB 2: TRAD + 5 rep. max. in eccentric flywheel TRAD: 400m freestyle [200m freestyle + 1x50m freestyle (12.5m fast/ 12.5m slow) + 1x50m fast + 100m freestyle]	6 min 6 min 6 min	Race time and instantaneous speed in 50 meters	↔ COMB X TRAD (50 meters) ↑ COMB X TRAD (5 meters)
Cuenca-Fernández, Batalha, et al. (2020); Randomized	20 male highly trained athletes	Age: 18.0±1.4 yrs. Weight: 70.3±9.0 kg Height: 180.0±0.0 cm ET: not reported	COMB: Control + 3 arm strokes TRAD: 400m freestyle [200m freestyle + 1x50m freestyle (12.5m fast/ 12.5m slow) + 1x50m fast + 100m freestyle]	6 min 6 min	Time of 50- and 100-meter freestyle instantaneous speed and start performance	↑ COMB: RFD (Δ=9.4%), stroke speed (Δ=5.1%) ↓ COMB: speed, power, acceleration ↑ TRAD: speed (Δ=3,1%) and power (Δ=2.7%)
Dalamitros et al. (2018); Randomized	10 male highly trained athletes	Age: 19.3±2.2 yrs. Weight: 83.8± 10.7 kg Height: 183.2±7.4 cm ET: ≥9 and ≤12 yrs.	COMB 1: Control + 2x (3x medicine ball throw up (2kg), 3x medicine ball throw side, 3x box jump 40cm) TRAD: 1000m (300m freestyle, 6x50m, 8x25m, 2X50m)	15-10 min 30 min	Time in 50-meter freestyle	↑ COMB X TRAD
Dalamitros et al. (2019); Randomized	22 trained highly trained men 22 untrained	Age: 20.3±1.8 yrs. Weight: 77.6±6.6 kg Height: 179.7±6.9 cm ET: 14.4±2.4	COMB 1: 1,100 m (continuous swimming/arm and kick drills/short sprints/cool down) + 5 jumps with weight vest 10% BM (trained)	15 min 20 min	Time in 50-meter freestyle	↔ COMB X TRAD (trained)

	men		COMB 2: 600 m (continuous swimming/arm and kick drills/short sprints/cool down) + 5 jumps with weight vest 10% BM (untrained) TRAD: 1,100 m or 600m (untrained)			↑ COMB X TRAD (untrained)
de Arruda et al. (2020); Randomized	13 male trained athletes	Age: 19.5±3.5 yrs. Weight: 72.0±7.6 kg Height: 177.9±5.4 cm ET: ≥3 yrs.	COMB 1: 15min freestyle + 3 rep. lunges (85% 1RM) COMB 2: 15min freestyle + 3 rep. max Pull-up + 5 box jump (40 cm and 60 cm) COMB 3: COMB 1 + COMB 2 TRAD: 30 min freestyle	10 min 10 min 10 min 10 min	Time of 50- and 100-meter freestyle and start performance	↔ COMB X TRAD (Peak force for knee extension and trial time) ↑ COMB X TRAD (Peak force for elbow extension and time of flight in start performance) ↓ COMB X TRAD (horizontal hip speed)
Đurović et al. (2022)	10 male highly trained athletes	Age: 16.2±2.0 yrs. Weight: 64.3±6.1 kg Height: 175.0±7.0 cm ET: ≥5 yrs.	COMB 1: 3x5 drop jumps (40m) 15s between jumps and 2" between sets COMB 2: COMB 1 + TRAD TRAD: 1600m [400m light (75m crawl + 25m backstroke + 2x100m medley + 200m crawl drills (25m fast + 25m easy) + 4x50m crawl + 4x50m crawl (start block) + 200m easy]	8 min 8 min 8 min	Start and 15m performance CMJ	↑ COMB 1 X TRAD for reactive and explosive strength and entry time ↑ COMB 2 X COMB 1 for reactive and explosive strength, eccentric force, 15m time and entry time
Hancock et al. (2015); Randomized	15 male college trained athletes	Age: 20.1±1.0 yrs. Weight: 78.1±6.0 kg Height: 180.0±4.6 cm ET: not reported	COMB: Control + 4x10m max. (Tethered Swimming) TRAD: 900m (800m freestyle + 4x25m max)	6 min 6 min	Time in 50- and 100-meters freestyle	↔ COMB X TRAD
Ng et al. (2020); Randomized	16 male athletes	Age: 22.1±3.8 yrs. Weight: 72.5±7.2 kg Height: 177.0±4.0 cm ET: 7.4±4.1 yrs.	COMB: 700m (200m freestyle self-selected pace + 100m crawl drills (25m light/25m fast) + 100 m flutter kick drills (15m fast/35m light) + 2 X 100m (2 crawl and 2 medleys) + 50m (easy) + 50m crawl drills (15m fast/35m easy) + 2 X CMJ TRAD: 1,400m (400m freestyle self-selected pace + 200m crawl drills (25m light/25m fast) + 200 m flutter kick drills (15m fast/35m light) + 4 X 100m (2 crawl and 2 medleys) + 100m (easy) + 2 X 50m crawl drills (15m fast/35m easy)	8 min 8 min	Speed with a flutter kick drills at 25 m	↑ COMB X TRAD for Peak Thrust, speed, speed fluctuation and kicking frequency
Sarramian et al. (2015)	10 male highly trained athletes	Age: 16.3±1.6 yrs. Weight: 64.1±8.0 kg Height: 169.0±0.06 cm ET: not reported	COMB 1: 15 min freestyle + 3 pull-ups + 3 throw-up medicine ball (4, 8 and 12 min) COMB 2: 15 min freestyle + 5 CMJ (10% BM) + CMJ (4, 8 and 12 min) COMB 3: COMB 1 + COMB 2 TRAD: 30 min freestyle (different speeds)	10 min 10 min 10 min 0 min	Time in 50-meters freestyle	↓ COMB X TRAD
Sirieiro et al. (2022)	21 male trained athletes	Age: 16.3±2.7 yrs. Weight: 65.0±9.5 kg Height: 171.3±6.0 cm ET: not reported	COMB: Control + 3 RM pullover TRAD: 1000m (20 min)	5 min 5min	Time in 50-meters freestyle	↔ COMB X TRAD

Legend: [1] Competitive level classification according to McKay et al. (2022). [2]Eccentric flywheel – equipment specifically developed to enhance block output; [3]Arm strokes – equipment developed to stimulate PAPE in the upper limbs, adapted from the Smith machine; COMB – strength/power warmup; ET – experience time; Rep – repetitions; MR – maximum repetition; Int – interval; BM – body mass; CMJ – countermovement jump.

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The value of Hedges g' for power in 50- and 100-meter crawl was: -0.12; 95%CI = -0.376; 0.136; p=0.357. The forest plot representing the individual standardized mean differences, associated 95%CI, and the random effect models for Power are shown in Figure 2.

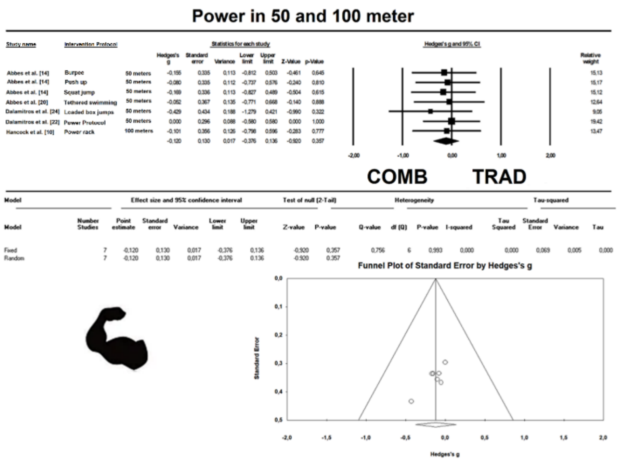

Figure 2. Comparison between performance in combined strength/power warmup (COMB) versus traditional (TRAD) for power in 50- and 100-meter freestyle events.

Regarding the time in the 50- and 100-meters, the COMB protocols used in the eight investigations did not represent an ergogenic or ergolytic effect (Hedges g'= -0.139; 95%CI= -0.314; 0.036; p= 0.118). The forest plot representing the individual standardized mean differences, associated 95% CI, and the random effect models for Time are shown in Figure 3.

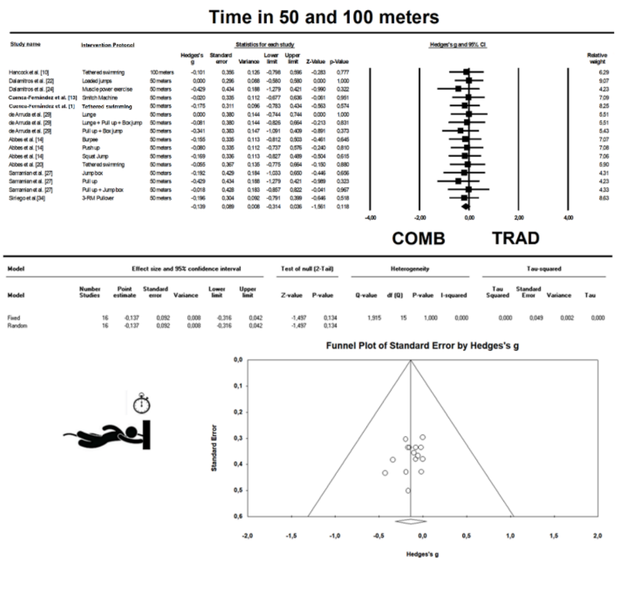

Figure 3. Comparison of performance in combined strength/power warmup (COMB) versus traditional (TRAD) for time in 50- and 100-meter freestyle events.

The included studies that evaluated the effect of the COMB intervention on the start performance showed that the proposed protocols were not efficient in generating an ergogenic effect on the reaction time of block both in the TRAD and in the COMB condition (Hedges g'= -0.313; 95%CI= -0.643; 0.018; p=0.064). The forest plot representing the individual standardized mean differences, associated 95% CI, and the random effect models for start performance are shown in Figure 4.

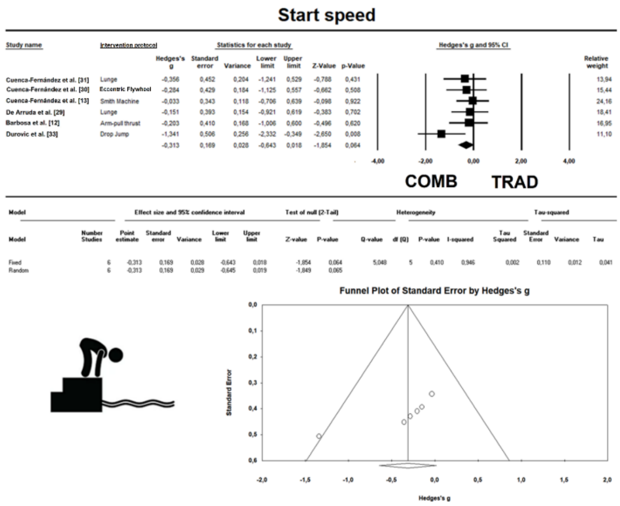

Figure 4. Comparison of performance in combined strength/power warmup (COMB) versus traditional (TRAD) for start performance.

Finally, a significant effect was observed in the COMB protocols used on the performance in instantaneous speed of the 50-meter event (Hedges g'=-0.282; 95%CI=-0.402; -0.162; p≤0.001). The forest plot representing the individual standardized mean differences, associated 95% CI, and the random effect models for the speed are shown in Figure 5.

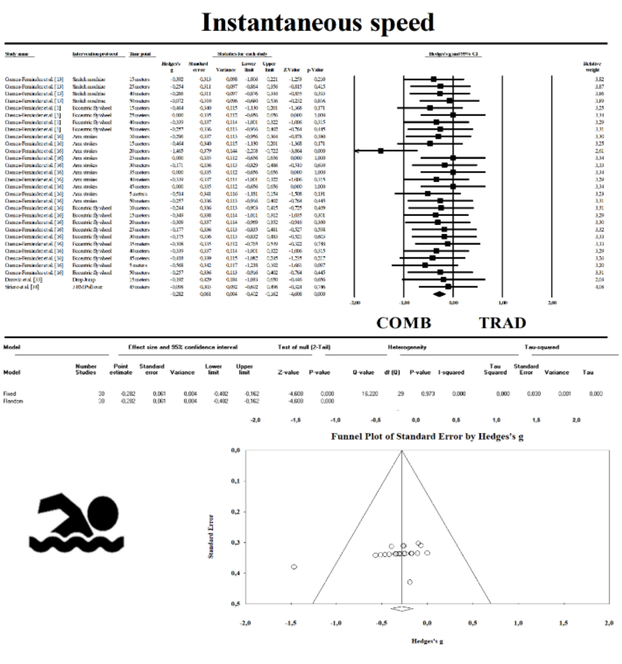

Figure 5. Comparison of performance in combined strength/power warmup (COMB) versus traditional (TRAD) for instantaneous speed in 50-meter freestyle events.

Despite the small number of studies that met the inclusion criteria, the studies did not show heterogeneity with I^2= 0.000.

Discussion

The present meta-analysis aimed to investigate the effect of COMB warm-up on the PAPE of sprint swimmers. The main results indicated that the COMB protocols applied so far do not exert a greater ergogenic effect than TRAD on start performance, power, and time but exert an effect on instantaneous speed over distances up to 50 meters, which makes it promising for use in sprint swimmers. In fact, inserting activation exercises into the warm-up seems to be an interesting method to be included in swimmer training routines (Abbes et al., 2020; Crespo et al., 2021; Cuenca-Fernández, Batalha, et al., 2020; Dalamitros, Mavridis, Semaltianou, Loupos, & Manou, 2019; Pereira et al., 2023; Thng et al., 2019). performance-based exercises have been shown to improve muscle contraction, strength, and speed through maximal or submaximal loads applied to the muscle (Cuenca-Fernández, Ruiz-Teba, et al., 2020; Pereira et al., 2023; Seitz & Haff, 2016; Thng et al., 2019). In addition, COMB protocols require less execution time compared to TRAD warm-ups, which can be advantageous (Dalamitros et al., 2018; Thng et al., 2019). In previous studies, ergogenic effects of COMB were observed in isolated tests, jumps, and sprints (de Oliveira et al., 2017; Fradkin et al., 2010; Gouvêa, Fernandes, César, Silva, & Gomes, 2013; Pereira et al., 2023). However, a swimming competition requires athletes to adequately express themselves in technical, physical, and psychological characteristics so that the projected performance is achieved (Abbes et al., 2018; Abbes et al., 2020). This is perhaps a factor that explains the absence of positive results from the COMB simulation of 50 and 100 meters, even if having an effect on speed.

Regarding the funnel plots, Fig. 5 presents an ideal distribution, while Fig 2, 3 and 4 showed asymmetries. Each point on the Funnel Plot graphs represents a study and its entirety constituting the set of studies for each meta-analysis (Fig. 2, 3 4 and 5). The X-axis of each funnel plot represents the effect size, while the Y-axis corresponds to the inverse of the standard error (SE), which in turn is related to the sample size (Egger, Smith, Schneider, & Minder, 1997). The dotted line corresponds to the proper effect size for a given intervention. Based on the analysis of the biases presented in the funnel plot, we can verify that there was a sample size bias for Figures 2, 3, and 4. While, in Fig. 5, we observed that the studies are distributed symmetrically, with the dotted line as the center, with the more prominent studies closer to the actual measure of association and the smaller ones being distributed on both sides of the line, with a greater dispersion of the smaller the SE they are. These results suggest that future studies may increase the sample size to obtain results with a lower standard error.

Swimmers' performance is determined by variables that directly imply swimming efficiency, including muscle strength and power (Sarramian, Turner, & Greenhalgh, 2015). In fact, higher power levels have a positive correlation with speed in the water (Schreven, Smeets, & Beek, 2022). However, when analyzed together, the studies included in the present meta-analysis did not show an effect of COMB regarding the best performance in these variables in a 50-meter crawl. In this line, some studies applied to swimming have shown a positive effect of COMB in physical tests (Cuenca-Fernández, Ruiz-Teba, et al., 2020; de Arruda et al., 2020); however, the protocols failed in studies of competition simulation (Abbes et al., 2018; Abbes et al., 2020) or in water resistance tests (Hancock et al., 2015). Thus, there seems to be a breaking point not yet understood by researchers and coaches where test results and athletic performance are dissociated.

One of the variables that influence the start performance is the reaction time off the block, especially for sprinters (Cuenca-Fernández, Batalha, et al., 2020; Cuenca-Fernández et al., 2019; Cuenca-Fernández, Ruiz-Teba, et al., 2020; Pereira et al., 2023). Reaction time refers to the start signal time and the swimmer's loss of contact with the block (Cuenca-Fernández et al., 2019). In this line, a study carried out with exercises in the specific block position indicated the importance of performing specific task-specific strength exercises (Eccentric flywheel) to improve the reaction time of athletes (Cuenca-Fernández, López-Contreras, & Arellano, 2015). However, when analyzed together, the studies included in the present meta-analysis did not indicate a superior effect of COMB compared to TRAD warm-up. It should be noted that this was the variable that had the lowest number of studies included in the analysis (n=3). According to Cuenca-Fernández et al. (2019), swimmers demonstrated a higher vertical impulse from exercises performed outside the pool in which movements were simulated to leave the block. These results are similar to those observed for power, where the performances obtained in the tests were not repeated in test simulations. It is therefore suggested that further studies be carried out exploring the use of COMB and the exit speed from the block since every centesimal is important for competitive results in swimming speed tests.

Despite the absence of a positive effect on swim performance when compared to TRAD warm-up, Cuenca-Fernández, Batalha, et al. (2020) suggest that COMB has the potential to be an effective tool for sprinters because it increases the rate of force development. Along these lines, studies published so far have shown that COMB can increase swimmers' speed when compared to TRAD warm-up. Crespo et al. (2021) observed a positive effect of COMB on speed measured in 10 and 15-meter sprints (Crespo et al., 2021; Cuenca-Fernández, Batalha, et al., 2020; Cuenca-Fernández, Ruiz-Teba, et al., 2020); however, another study by the same group of authors did not observe an ergogenic effect in a 15-meter sprint (Ruiz-Navarro et al., 2022). It is noted that despite the small heterogeneity in the present review, there are different protocols, and despite the positive effect on speed, a COMB protocol that provides more significant ergogenic effect than TRAD in swimming events has not yet been developed. Such findings indicate that the results of our meta-analysis suggest that it will be difficult to improve upon existing warm-up strategies in swimming.

It is also important to emphasize that the lack of standardization of the interval between the warm up and the test can affect PAPE efficiency (Dalamitros et al., 2019; Gouvêa et al., 2013). The intervals between the warm up and the tests in the present review varied between 6 and 15 minutes (Table 2). A meta-analysis that aimed to examine the effect of the wait period on jump height performance concluded that there is an ergolytic effect from 0-3 minutes, and there is an ergogenic effect from 8-12 minutes (Gouvêa et al., 2013). Thus, further studies are needed to investigate the ideal interval between the warm up and sprint swimmers' performance. Considering that there may be an ergogenic effect for approximately 8 minutes, it seems promising to investigate the additional effect of COMB in conjunction with TRAD warm-up. This is because the time between warm-up and the first race in official competitions tends to be over 30 minutes (Zochowski et al., 2007).

This meta-analysis showed some limitations that must be addressed, such as the number of studies that present good quality, small sample size, limited analysis of male athletes, and crawl style. We know that the volume, intensity, load, specificity of the exercise, sport level, and interval between the warm up and the test can affect the sport performance (Dalamitros et al., 2019; Fradkin et al., 2010; Gouvêa et al., 2013). In addition, it is important to consider the technical quality of the swimmers and the maintenance of the skills necessary to sprint swim. All of this can be interesting for coaches and athletes looking for a more efficient way to add strength and power exercises to their training programs. It is important because swimmers can lose the efficiency of their warm-up during the time before an official event due to factors that can directly interfere with performance, such as delays in competition times and long periods between the warm-up and the race (West et al., 2013; Zochowski et al., 2007). In fact, data from studies show that the time between warm-up and race can be as long as 45 minutes (Zochowski et al., 2007); however the ideal is that this time is not less than 5 minutes and greater than 20 minutes (West et al., 2013). Finally, studies in the present meta-analysis which evaluated experienced athletes in crawl swimming were included. More studies should be conducted with female samples and other swimming styles. Few protocols measure untrained athletes. Only one study in our analysis compared trained vs. untrained, and the results suggest that the untrained athletes performed better 50-meter sprint when using the COMB warm-up compared to the TRAD (Dalamitros et al., 2019).

Conclusion

Warm-ups based on COMB protocols can influence performance in specific or general tests performed by sprint swimmers, such as jumping, first meters of the race, and speed. However, based on the results of the present meta-analysis, the COMB intervention does not exert an ergogenic effect on performance in race simulation (50 and 100 meters), muscle power and start speed. Considering the small number of qualified papers on this subject, comparing other warm-up strategies with the TRAD is suggested. Future studies should carry out more robust protocols and also evaluate female athletes.

Availability of Data and Materials

Not applicable.

Competing interests

The authors declare no competing interests.

Fundings

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Ethical Approval

Not applicable

Conflict of interest

The authors declare no conflict of interests.

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