Review

Effects of a maximum strength training programme on competitive swimmers: a systematic review

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Summary

Introduction: Maximal strength training programs have been traditionally used in swimming planning, mainly as a complementary dry-land workout. Although there is evidence of the utility of this type of physical preparation, it is still unclear how a maximal strength training program affects different performance variables in swimmers.
Objective: The objective of this systematic review was to conduct a literature review on the effects of a maximal strength training program on the variables associated with swimming performance (swimming speed, stroke frequency, stroke length, turns and reaction time) in competitive swimmers.
Material and method: The primary search was performed until February 2022 in different databases (Web of Science, Pubmed and Scopus). Inclusion criteria: 1) studies analyzing swimming performance parameters; 2) interventions with maximal strength training programs (≥85% RM) of at least four weeks duration; 3) subjects with national competitive level or higher; 4) subjects with at least four years of competitive swimming experience and ten hours of training per week; and 5) investigations comparing the effects of maximal strength training on swimming performance.
Results: A total of eight studies met the inclusion criteria. Eight of the studies examined effects on swim speed, five effects on stroke frequency, five on stroke length, three on start reaction, and two on turns.
Conclusion: A maximal strength training program has a positive effect on swimming speed. Likewise, they significantly increase kinematic variables such as stroke length. However, no evidences of significant stroke frequency modification have been identified.

Key words:
Swimming. Resistance training. Strength training.

Efectos de un programa de entrenamiento de fuerza máxima en nadadores de competición: una revisión sistemática

Resumen

Introducción: Los programas de entrenamiento de fuerza máxima han sido utilizados tradicionalmente en la planificación en natación, principalmente como un trabajo complementario. Aunque existen pruebas de la utilidad que puede evidenciar este tipo de preparación física, aún no queda claro cómo un programa de entrenamiento de fuerza máxima afecta a las diferentes variables del rendimiento en nadadores.
Objetivo: El objetivo de esta revisión sistemática fue realizar una revisión de la literatura sobre los efectos de un programa entrenamiento de fuerza máxima sobre las variables asociadas al rendimiento en natación (velocidad de nado, frecuencia de brazada, longitud de brazada, virajes y tiempo de reacción) en nadadores de competición.
Material y método: La búsqueda fue realizada hasta febrero de 2022 en distintas bases de datos (Web of Science, Pubmed y Scopus). Criterios de inclusión: 1) Estudios que analizaran parámetros de rendimiento en natación; 2) intervenciones con programas de entrenamiento de fuerza máxima (≥85% RM) de al menos cuatro semanas de duración; 3) sujetos con nivel competitivo nacional o superior; 4) sujetos cuatro años de experiencia competitiva en natación y diez horas de entrenamiento semanales; y 5) artículos en los que se comparan los efectos del entrenamiento de fuerza máxima en el rendimiento en natación.
Resultados: Un total de 8 estudios cumplieron los criterios de inclusión. Ocho de los estudios analizaron efectos en la velocidad de nado, cinco efectos en la frecuencia de brazada, cinco en la longitud de brazada, tres en la reacción de salida y dos en los virajes.
Conclusión: Un programa de entrenamiento de fuerza máxima tiene un efecto positivo sobre la velocidad de nado. De igual manera puede afectar variables cinemáticas como la longitud de brazada, por otro lado, no se observan en la frecuencia de brazada.

Palabras clave:
Natación. Entrenamiento de fuerza. Entrenamiento de potencia.

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Introduction

Swimming is clearly different from other sports as movements are mainly made in a horizontal position[1] suspended in a liquid and the propelling actions are made using alternative or simultaneous arm and leg movements. In addition, water presents less resistance to the propelling actions compared to forces against the ground produced in other sports on land[2]. Swimming performance is also defined by physiological, psychological and anatomical components[3,4]. In the same way, a study published in 2013 by Barbosa *et al*.[5] showed that swimming performance depended on kinematic and kinetic energy, where the former is the relationship between the swimming speed, the stroke length and the stroke frequency and the latter is the work energy that is generated when being propelled through the water[5].

The displacement speed in any sport can be defined as a set of functional characteristics that allow motor performance in the least possible time[6]. In swimming, the movement patterns to generate the body's displacement mainly take place when the swimmers exercise propelling resistance forces against the direction of the body's movement. Increasing the stroke and kick frequency makes the force applied greater in a shorter time range, increasing the displacement speed[2]. Consequently, the components of a swimmer's physical condition play a determining role in the propelling actions when swimming. This is the case of strength, which must be developed to generate faster movements against the load represented by the water and thereby maintain the speed when moving for a longer time[7]. Increasing mechanical strength and muscular strength is a key factor in a swimmer's performance[8], the force generated by the body's upper limbs is vitally important for propulsion and speed in swimming[4]. The capacity to apply force in the water is therefore fundamental when competing[9]. Muscular strength is the capacity of a muscle or muscle group to perform reiterated contractions against a resistance which is less than the maximum for a determined period of time[10]. In swimming, it is essential to maintain or increase swimming speed during the effort required in each competitive race[11]. In addition, flexibility in swimming makes it possible to save and distribute strength better with better technical potential[12]. Wide-ranging mobility among swimmers can allow a greater period of action time for the propelling forces, a greater joint mobility arch to make sure that the movement to recover the arm and kick effort does not alter the body's alignment[2].

Consequently, several studies have shown the usefulness of strength programmes in competitive sporting disciplines[1,13,14], due to the growth of phosphagens, contractile proteins, development of anaerobic potential, muscular architecture, fibre feathering, protein synthesis and hypertrophy of fast-contracting muscular fibres[15,16], increase in the maximum strength and therefore developing strength at a greater rate[17]. As a consequence, trainers and fitness coaches run strength and physical conditioning programmes to develop swimmers' strength and improve their performance[5,18]. This is the case of kayaking where strength is a fundamental skill for optimum performance because the speed of the craft is due to the continuous application of force in the water using the paddle. Still-water kayaking comprises several competitions ranging from 40 seconds to several hours so the force applied will be different for a 200 m, 1,000 m or marathon race[19].

Some studies have analysed the effects of strength training and conditioning on swimming performance, although there is a lack of scientific evidence to explain the performance improvement parameters[9,13,18]. Some studies demonstrate a correlation between arm strength and swimming performance[9,20], and a link between the leg muscle strength and performance when leaving the starting blocks and turning in swimming[21]. In addition, weak and moderate correlation is found between strength and swimming speed[8,22]. It has been suggested that the possible reasons for a weak relationship between strength training outside the pool and performance in swimming might lie in transferring this strength gain to the pool because it is not as specific[5]. The review by Wirth *et al.*[23], concluded that maximum strength work is vitally important for swimmers, with intensities between 85 and 100% of the MR, allowing central and morphological adaptations that help muscular activation in a short time[23]. On the other hand, one study found that its traditional strength training group and its specific strength training group using strength bands got similar swimming performance results[24].

Although there have been prior systematic reviews to investigate various strength interventions on swimming performance[1,13,15,25], none of them has focused on the effects of a maximum strength training programme on swimmers' performance. These systematic reviews compiled information on the role of muscular strength in swimming and they found a wide variety of training protocols such as the concurrent[14], the plyometric[21] or focused on the lumbar-abdominal belt[25] among others. Therefore, the aim of this study was to analyse the effects of a maximum strength training programme on the variables associated with swimming performance (swimming speed, stroke frequency, stroke length, turns and reaction time) among competitive swimmers.

Material and method

Search strategy

This systematic review was carried out according to recommendations from the PRISMA standard (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)[26].

The studies were obtained from the following databases:

PubMed, Web of Science (WOS), and Scopus up to February 2022, using the PICO strategy method (Patient, Intervention, Control and Outcomes)[27], which requires the research question to be devised properly and a literature review using the following keywords: "swimming", "resistance training", "strength training", "weight training", "Power training" and "force". The references from relevant studies were also examined to find other potentially eligible studies.

The following Boolean search operators were used: (swim*[Title]) AND ("resistance training"[Title/Abstract] OR "Strength Training"[Title/

Abstract] OR "weight training" [Title/Abstract] OR "Power training" [Title/Abstract]) NOT ("water polo"[Title/Abstract]).

Due to the low number of articles found with the former strategy, a further search strategy was used to increase the chances of finding other studies: (swim*[Title]) AND ("performance"[Title/Abstract]) AND ("resistance training"[Title/Abstract] OR "Strength Training"[Title/Abstract] OR "weight training" [Title/Abstract] OR "Power training" [Title/Abstract] OR force [Title/Abstract]. Nevertheless, an intensive review of the outcomes of this search did not increase the number of articles that met the inclusion criteria.

Study selection

Studies were included if they met the following criteria:

1) Studies that analyse swimming performance parameters;
2) interventions with maximum strength training programmes (≥85% of the MR) lasting at least four weeks;
3) subjects at national competition level or higher;
4) subjects with at least four years' experience of swimming competitively and ten hours of weekly training;
5) articles which compare the effects of maximum strength training on swimming performance.

Regarding the exclusion criteria, studies were rejected if: 1) Studies were not in English; 2) case reports, communications or congress and conference posters or systematic, literary or narrative reviews; 3) articles that correlate maximum force and swimming performance without strength training; and 4) swimmers with pathologies or some type of injury during the study.

Quality assessment

The PEDro[28] scale was used to assess the quality of the articles, mainly based on agreement of experts and not on empirical data. This instrument makes it possible to quickly recognise which of the random tests might have enough internal validity and statistical information for its results to be interpretable. The scale comprises 11 criteria, and one point is awarded for each criterion that is met. According to the scale, after using the inclusion and exclusion criteria, all selected studies achieved a score of 5 or more and were admitted in this review (Table 1).

Data extraction and synthesis

Once the studies had been read, the study objectives were consulted for data referring to the participants (number, age, gender). Type of intervention, duration of the intervention (weeks), variables analysed, procedure (series, repetitions, intensities), analysis method and results. To score each study, the degree of significance of the p value appeared in the results section to be checked, and also the size of the effect was facilitated to calculate from the average and the standard deviation.

Summary of the search

The PRISMA methodology was used, consisting of a list of 27 items (Figure 1) and a four-phase flow chart. At first, 348 studies were recognised using the database and an additional record was found in other sources (Google Scholar). Excluding duplicate articles left 191 articles. After reading the summaries carefully, 32 articles were chosen to read the complete text. 24 were excluded according to the inclusion and exclusion criteria. Finally, 8 studies were included in this systematic review.

Results

Characteristics of the included studies

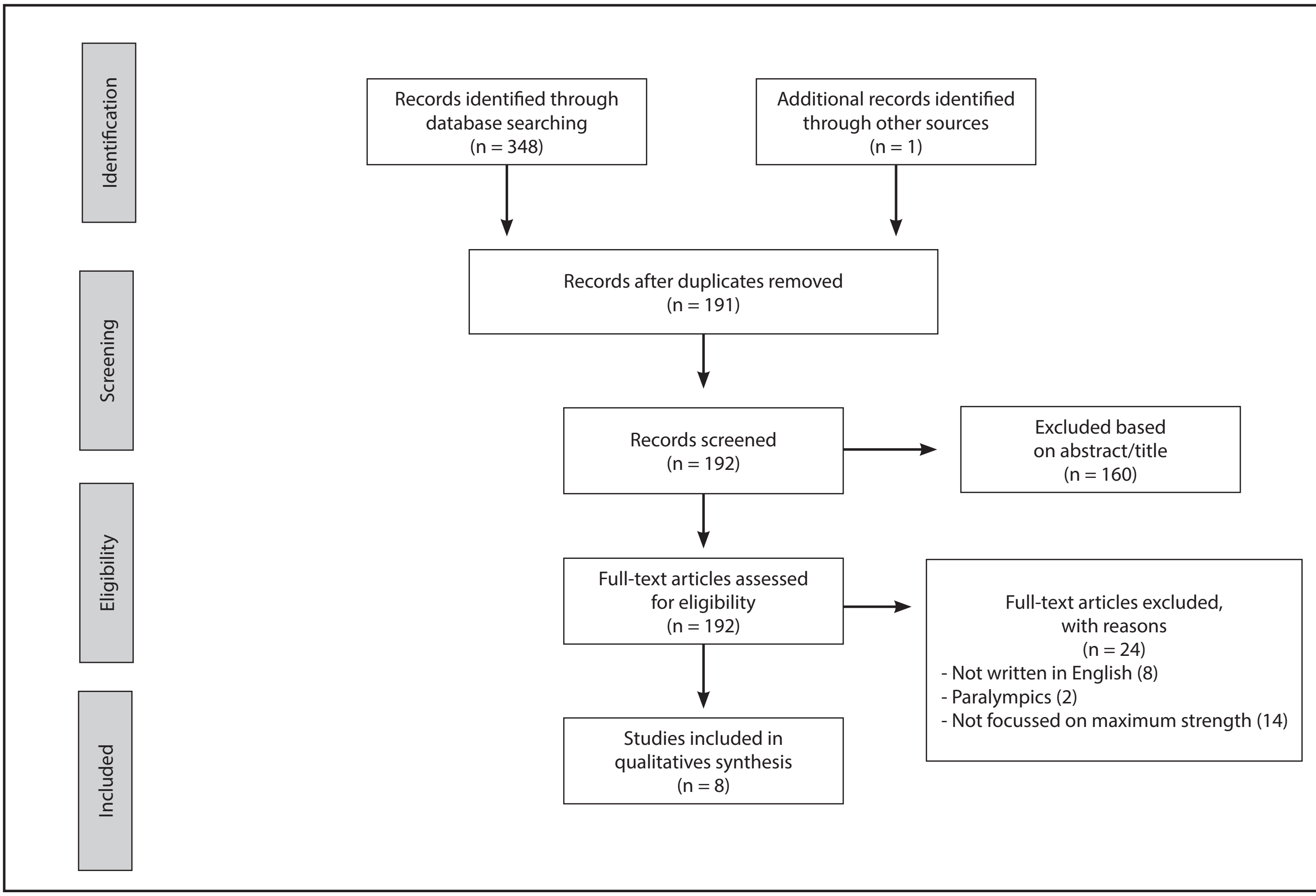
The classification of all the studies included a total of 166 athletes (109 men and 57 women), with ages ranging between 14 and 23 years

Table 1. PEDro scale to classify studies.

Study	1	2	3	4	5	6	7	8	9	10	11	Score
Born *et al*., 2020	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	6
Aspenes *et al.,* 2009	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	6
Jones *et al.*, 2017	N	Y	N	Y	N	N	N	Y	Y	Y	Y	5
Girold, *et al.*, 2012	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	6
Girold *et al.,* 2007	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	6
Strass, 1988	Y	N	N	Y	N	N	N	Y	Y	Y	Y	5
Schumann *et al.*, 2019	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	6
Amara *et al.*, 2021	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	6

1. The selection criteria were listed; 2. The subjects were assigned to the groups at random (one cross-study, the subjects were distributed at random as the treatment was received); 3. Assigning was hidden; 4. The groups were similar at the beginning concerning the most important prognostic indicators; 5. The subjects were blinded; 6. The therapists who gave the treatment were blinded; 7. The evaluators that measured at least one key result were blinded; 8. The results were obtained from at least one key result. The measurements for at least one of the key results were obtained from more than 85% of the subjects; 9. They were initially assigned to the groups; the results were shown for all subjects who received the treatment or who were assigned to the control group, or when this could not happen, the data was analysed for at least one key result by "intention to treat"; 10. The results were informed from the statistical comparisons between groups at least for one key result; 11. The study provides specific measures and variability at least for one key outcome.

Figure 1. PRISMA flow chart.



old, admitted according to the review inclusion criteria. Due to the methodological variety of each study, a descriptive chart was provided featuring the general characteristics of the studies where maximum strength training was used in swimmers. Table 2 shows the general characteristics of the studies included in this systematic review. It includes a brief description of the subjects specifying the number of persons involved in each study, their respective gender, age, intervention time, competitive levels, the maximum strength programme carried out and the performance measure.

Type of study

Depending on the type of study, there were five Random Controlled Tests[9,24,29-31], one pilot study[32], one design with repeated measurements between groups[33], and one comparative study[34]. The size of the sample was also analysed, differentiating between the control group, experimental group, gender and average age of the subjects. Seven studies used a sample equal to or greater than 16 subjects[9,24,29-33]. Regarding measurement of the effects of maximum strength training on swimming performance variants, Tables 3 to 7 were devised to show the results from each of the respective variables measured.

The following studies presented in Table 3 show the results for swimming speed. Aspenes *et al.*[9] found a significant improvement in performance in the 400 metres freestyle (P <0.05) with a decrease in swimming time from 290.43 to 286.43 seconds in the experimental group and no change in the control group. Concerning performance in the 50 and 100 metres freestyle, no significant improvements were found in the experimental group, or in the control group (P = 0.11 and P = 0.12), respectively.

In another study by Girold *et al.*[24], the swimming speed performance in 50 metres freestyle improved significantly (P <0.05) both in week 6 and in week 12 (2.8 ± 2.5%) after a period of maximum strength training. No changes were observed in the control group's performance (P >0.05). Furthermore, Girold *et al.*[34] obtained significant changes in the average swimming speed over 50 metres freestyle (P <0.05) after a four-week period of strength training (+2 ± 1.3%); no changes were observed in the control group's performance throughout the study.

Table 2. General characteristics of the studies selected for the systematic review.

Studies	No. of participants	Gender	Age	Weeks	Competitive level	Strength training programme	Average performance
Born *et al.,* 2020	21	F = 12 M = 9	17.1 ± 2.6	6	National and international	Squat and dead weight 3x (6-8) rep - 4x y (2-4) rep +2.5 kg per finished series	5 m 10 m 15 m 25 m Starting reaction Stroke pace Stroke length
Aspenes *et al.,* 2009	20	F = 12 M = 8	16.5 ± 1.5	11	National	Cable cross over 3x5 rep + 1.5 kg per finished series 5 MR	50 m 100 m 400 m Stroke length Stroke pace
Jones *et al.*, 2017	12	F = 2 M = 10	19.4 ± 1.1	6	International	Bench Press, press, bench pull, shoulder press, chin-ups, and squat 4-5x (5-8) rep at 85-90% of MR	Turns 5 m
Girold *et al., 2012*	24	F = 12 M = 12	21.8 ± 3.9	4	National	Chin-ups and draws with pulleys 3x3 rep at 80-90% of the MR	50 m Stroke length Stroke pace
Girold *et al.*, 2007	21	F = 11 M = 10	16.5 ± 3.5	12	National	Bench press, chin-up, draw with barbells, squat and jumps 6 rep at 80-90% of MR	50 m Stroke length Stroke pace
Strass,1988	19	F = 2 M = 17	16.6 ± 1.2	6	National	Arm extensor muscles using weights 3x (3/90%MR-2/95% MR-1/100%MR)	25 m 50 m Stroke length Stroke pace
Schumann *et al.,* 2020	16	F = 6 M = 10	15.1 ± 1.1	7	International	Squat, dead weight, bench press and chin-ups 4x (3-4) rep at 85-90% of MR	5 m 10 m 15 m 400 m Starting reaction
Amara *et al.,* 2021	33	F = 0 M = 33	16.1 ± 1.2	9	National	Bench press and press 3-4-5 x (3-4-5) rep at 85-90% of the MR	25 m 50 m Time Starting reaction

F: female; Kg: kilogram; M: male; m: metres; Rep: repetitions; MR: maximum repetition.

The research carried out by Schumann *et al.*[35] did not demonstrate significant changes in the time over 400 metres freestyle during the intervention in either group. Regarding the speed over 5 metres and 15 metres, there were no significant changes in the experimental group, although the control group tended towards statistical significance ($P = 0.054$). Over 10 metres, performance improved (3.6%) in the experimental group ($P = 0.039$) but not in the control group. Similarly, after a maximum strength training intervention, Amara *et al.*[36] identified positive and significant effects on the 25 metres freestyle ($P < 0.001$) with a decrease in time from 13.52 ± 0.56 to 12.76 ± 0.54 seconds and in the 50 metres freestyle ($P < 0.001$) with a significant time improvement (Pretest 26.91 ± 1.29 and Post-test 25.20 ± 1.26 seconds) while no significant differences were found in the control group. Strass[37] also found positive effects of a maximum strength intervention using the arm extensor muscles, in average speed over 25 metres freestyle ($P < 0.001$) and at a distance of 50 metres freestyle ($P < 0.001$) with an average speed from 1.77 ± 0.08 to 1.81 ± 0.08 m/s. The control group did not demonstrate significant changes in the parameters for the swimming disciplines between pre and post measurements.

On the other hand, the study by Born *et al.*[38], did not find any significant differences between the pre and post split times over 5, 10, 15 and 25 metres ($P = 0.65$, 0.64, 0.53, and 0.74, respectively), but the peer comparison indicated an improvement over 5 metres ($P = 0.02$), 15 metres ($P = 0.03$) and 25 metres ($P = 0.01$). Similarly, Jones *et al.*[39], did not observe any effects in the time measured over the first 5 metres.

The studies related to stroke frequency in maximum strength training feature in Table 4. In the research by Aspenes *et al.*[14], there were no changes in the stroke frequency in the experimental group (0.953 vs 0.930 Hertz), or in the control group (0.885 vs 0.872 Hertz). Furthermore, in the study by Girold *et al.*[24], no significant differences were found in the stroke frequency in the experimental group for maximum strength, although they were found in the control group

Table 3. Effects of a maximum strength training programme on swimming speed.

Study	Measurement	Results
Aspenes, 2009	50 metres (s)	*P* = 0.11
Aspenes, 2009	100 metres (s)	*P* = 0.12
Aspenes, 2009	400 metres (s)	*P* <0.05*
Girold, 2007	50 metres (s)	*P* <0.05*
Girold, 2012	50 metres (s)	*P* <0.05*
Schumann, 2020	5 metres (s)	*P* = 0.054
Schumann, 2020	10 metres (s)	*P* = 0.039*
Schumann, 2020	15 metres (s)	*P* = 0.054
Schumann, 2020	400 metres (s)	*P* >0.05
Amara, 2021	25 metres (s)	*P* <0.001*
Amara, 2021	50 metres (s)	*P* <0.001*
Strass, 1988	25 metres (s)	*P* <0.001*
Strass, 1988	50 metres (s)	*P* <0.001*
Born, 2020	5 metres (s)	*P* = 0.65
Born, 2020	10 metres (s)	*P* = 0.64
Born, 2020	15 metres (s)	*P* = 0.53
Born, 2020	25 metres (s)	*P* = 0.74
Jones, 2017	5 metres (s)	*P* >0.05

p <0.05: significant; *:significant; s: seconds.

Table 4. Effects of a maximum strength training programme on stroke frequency in swimming.

Study	Measurement	Results
Aspenes *et al.,* 2009	Stroke frequency (Hz)	*P* >0.05
Girold *et al.,* 2007	Stroke frequency (c*m)	*P* >0.05
Girold *et al.,* 2012	Stroke frequency (c*m)	*P* >0.05
Strass, 1988	Stroke frequency (c*m)	*P* <0.05*↓
Born *et al.*, 2020	Stroke frequency (c*m)	*P* >0.05

p <0,05: significativo; *:significativo; ↓: Disminución; c*m: ciclo*min; Hz: Hertz.

(*P* <0.05) from week 0 (47.8±3.7 cycle*min) to week 12 (48.7±3.7 cycle*min). The same authors[29] did not find a significant result in the increase of stroke frequency after eight weeks of maximum strength training in the experimental group[30]. A significant result was demonstrated in the study by Strass[32], as the stroke frequency dropped from 55.0 ± 4.0 to 53.5 ± 3.4 cycle*min both in the 25 metres freestyle (*P* <0.05) and in 50 metres freestyle (*P* <0.05) in the experimental group (56.7 ± 3.2 to 54.7 ± 3.6 cycle*min). However, in the study by Born *et al.*[33], there were no significant changes in the stroke frequency in the experimental group.

Table 5 summarizes the studies related to the effects of maximum strength training on stroke length. In the study by Aspenes *et al.*[9], no significant changes were seen in the stroke length for the experimental group in men (pretest 1.68 and post-test 1.73 metres), although it was seen in women (1.61 vs 1.78 m in pretest and post-test, respectively).

Girold *et al.*[24] did not demonstrate significant effects on swimmers' stroke length after 6 weeks, nor after 12 weeks of maximum strength training. A subsequent paper by Girold *et al.*[29] found significant results (*P* <0.05) in the stroke length, which increased in the experimental group from 2.05 ± 0.01 to 2.11 ± 0.08 metres[25].

On the other hand, the study by Strass[32], identified increases in the average values for stroke length (*P* <0.01) both in the 25-metre distance (2.01 ± 0.24 to 2.16 ± 0.26 metres) and over 50 metres (1.88 ± 0.10 to 2.01 ± 0.24 metres). These values correspond to an average increase of 3.9% over 25 metres and 4.1% over 50 metres. Furthermore, the results from Born *et al.*[33] demonstrated a drop in stroke length, although not significant, from 2.04 ± 0.12 to 2.02 ± 0.14 metres after maximum strength training.

The studies related to the effects of maximum strength training on the turn time and the starting reaction are shown in Table 6. Schumann *et al.*[30] found that there were no significant changes in the reaction time on the starting blocks in both groups (*P* >0.05), either experimental or control, while Amara *et al.*[31] revealed significant changes in the starting reaction (*P* <0.001) of the experimental group after 9 weeks of maximum strength training. On the contrary, Born *et al.*[33], did not find significant changes in the reaction time in the experimental group after 6 weeks of intervention. Table 7 shows studies related to the effects of maximum strength training on swimmers' turns.

According to Amara *et al.*[31], the swimmers' turn time dropped significantly (*P* <0.001) after the subjects followed a strength programme,

Table 5. Effects of a maximum strength training programme on stroke length in swimming.

Studies	Measurement	Results
Aspenes *et al.,* 2009	Stroke length (m)	*P* >0.05
Girold *et al.,* 2007	Stroke length (m)	*P* >0.05
Girold *et al.,* 2012	Stroke length (m)	*P* <0.05*↑
Strass, 1988	Stroke length (m)	*P* <0.01*↑
Born *et al.*, 2020	Stroke length (m)	*P* >0.05

P <0.05: significant; *:significant; ↑: Increase; m: metres.

Table 6. Effects of a maximum strength training programme on starting reaction and turning in swimming.

Studies	Measurement	Results
Schumann, 2020	Starting reaction (s)	*P* >0.05
Amara, 2021	Starting reaction (s)	*P* <0.001* ↓
Born, 2020	Starting reaction (s)	*P* >0.05
Amara, 2021	Turning time (s)	*P* <0.001*↓
Jones, 2017	Turning time (s)	*P* >0.05

P <0.05: significant; *:significant ↓: Decrease; s: seconds.

Table 7. Effects of a maximum strength training programme on turning in swimming.

Studies	Measurement	Results
Amara, 2021	Turning time (s)	$P<0.001$*↓
Jones, 2017	Turning time (s)	$P>0.05$

$P<0.05$: significant; *:significant; ↓: Decrease; s: seconds.

while the study by Jones *et al.*[34] found no significant changes in the turn time six weeks after the maximum strength training programme.

Discussion

This systematic review exhaustively examines the effects of a maximum strength training programme on variables associated with swimmers' performance such as average swimming speed, stroke frequency, stroke length, starting reaction and turn time. The results of this review revealed that maximum strength training has a significant effect on swimming performance, particularly on the average speed in short disciplines, such as 25 and 50 metres freestyle. Great variability was observed between the exercises and intensities proposed in the various study protocols, and their methodology. The results of this systematic review are considered important because many trainers use this strength training method in their planning to attain better performance in the water.

Swimming speed

Swimming speed is the product of stroke frequency and stroke length5. This variable was studied after a training programme to improve maximum strength by several authors over short distances from 5 metres to 100 metres[9,24,29-34] and also over middle distances of 400 metres[9,30]. The speed over these distances is related to an improvement in strength as shown by Amaro *et al.*[35], and Marques *et al.*[36], who also assessed short swimming distances on completion of their high intensity physical conditioning interventions. Similar findings can be seen in works by Lopes *et al.*[37] and Amara *et al.*[38], where they analyse the effects of concurrent training among swimmers and the distances used to measure swimming speed ranged from 25 to 100 metres. In the same way, freestyle was the stroke most used by these studies when measuring swimming performance.

The performance or increase in swimming speed is measured by a drop in the time taken to swim the different distances. This review provides different results depending on the distance and the author. Significant improvements were seen in the times over 50 m freestyle in four[24,29,31,32] out of the five studies compiled. Regarding the 25-metre freestyle distance, two studies demonstrated an improvement in performance[31,32], and one showed no change[33], while over short distances from 5 to 15 metres only Schumann *et al.*[30] identified significant improvements in swimming speeds over 10 m. The effects of this type of training in longer races, such as 400 m, have been researched to a lesser extent with inconclusive results[9]. These results are reflected in the systematic review by Muniz *et al.*[39], where they analysed the power and strength training, finding that strength training on the body's limbs and upper torso, as part of the swimmer's training programme, seems crucial to improve propelling forces used in the water.

Consequently, these results might indicate that a general increase in strength, in this case with maximum strength exercises, leads to improvements in swimming performance, particularly over the short distances of 25 and 50 metres freestyle. However, over much shorter distances no improvements were identified, perhaps because in shorter spaces, actions with a more neuromuscular and coordinative component, such as starting speed from the blocks or subaquatic waves play a more important role[40]. Distances over 50 metres have not been studied as much, so more articles are required to analyse the effects of maximum strength over these distances. In practical terms, it might therefore be necessary for the trainers to include weeks of mainly maximum strength training in their schedules for swimmers specialising in short distances.

Stroke frequency

We can understand stroke frequency as the number of stroke cycles that the swimmer makes every minute (cycles/min) or the time that they require to complete one stroke cycle (time/cycle)[2]. In freestyle and backstroke, a stroke cycle is composed of two strokes. This variable is very important in speed competitions in swimming as a higher stroke frequency is related to better performance when competing[13], as the swimming speed is the result of the stroke frequency and the stroke length[5]. Four studies compiled in this review show that stroke frequency is not affected[9,24,29,33] and only one shows[32] a drop. This variable seems not to be affected by maximum strength training, maybe because these are regularly unspecific traditional movements in swimming, or perhaps because stroke frequency is a variable that changes very little during growth and does not vary much between amateur and professional swimmers[41].

Stroke length

The stroke length is the distance covered during each stroke cycle. It is calculated as the swimmer's displacement (in metres) during a stroke cycle[5]. Some prior studies observed significant increases in the stroke length[29,32] while other investigations did not find any changes in this variable[9,24,33]. In a similar way, the review carried out by Crowley *et al.*[14] identified improvements in performance related to increased stroke length on the one hand and improvements in swimming speed with no changes to the stroke length, on the other. In the same way, significant differences have been seen between amateur and professional swimmers' stroke length, where the latter cover a greater distance per stroke cycle[41]. In light of the results, it is not really clear if a maximum strength training programme affects the stroke length, but it does seem as though it might because some studies do not achieve significance, despite improvements, so more articles are required to analyse the effects of maximum strength on this variable.

Reaction time

The reaction time is the time between the starting signal and the swimmer's first movement on the blocks. Only three studies analysed this variable after a maximum strength intervention[30,31,33], and only one of them found an improvement in the starting reaction[31]. Thng *et al.*[40] stated that it is difficult to determine whether traditional or combined training might be more useful to improve the starting reaction. Therefore, the effects of a maximum strength training programme on the starting reaction are not clear, but it is possible that other more specific factors such as explosiveness and reaction have a more important role to play than maximum strength.

Turns

This systematic review only found two studies[31,34] which related maximum strength training to performance in turns and only one revealed significant outcomes showing an improvement in turning performance[31]. Hermosilla *et al.*[42] performed a review where they analysed the effects of various strength programmes on turns. They discovered that high intensities between 85-100% of the MR have a positive effect on the power and force generated during the contact phase with the wall. They thereby concluded that training with maximum and sub-maximum loads might be more efficient to improve the performance on the propulsion. This leads us to consider that maximum strength exercises might help to improve turn performance. However, because very few studies which only measure contact time with the wall and not the distance covered after the propulsion were found and analysed in this review, the real impact of maximum strength on turns remains unknown.

Limitations

Some limitations can be identified within this study. Firstly, the methodological differences between some studies[32-34] and the low methodological quality of others[32] might affect the results. Secondly, the proposed maximum strength programmes use different intensities, volumes and exercises, which leads to a different magnitude of training load[14,24,29-33]. On the other hand, gender differences were not considered either and might affect the results. Furthermore, some studies use elite swimmers[31,33,34] who were experienced in strength training and might be doing concurrent training, which would possibly affect the physical response to these maximum strength stimuli.

Practical applications

Knowing how maximum strength training affects the various performance variables among swimmers makes it possible for trainers to produce more accurate schedules during the season and so better control adaptations to physical training and thereby improve performance in the water. In the same way, depending on the swimmer's profile (sprinter - semi endurance - endurance), the trainers might develop more specific sessions for these swimmers' goals and so improve their performance in competition.

Conclusions

The maximum strength training reveals positive effects on swimming speed over short distances as several studies show improvements in the performance of these disciplines. This type of strength programme could be beneficial for swimmers focused on speed, particularly over 50 m. On the other hand, as far as other kinematic variables are concerned, it seems that improving maximum strength might modify the stroke length, increasing its values without interfering with the stroke frequency. Finally, there is not enough evidence to state that performance in acyclic actions, such as turns and starts, improve significantly after a maximum strength training programme.

Conflicts of interest

The authors declare that there is no conflict of interest.

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