Science & Sports 38 (2023) 217—231

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BASIC STUDY

Study of strength training on swimming performance. A systematic review

Étude de l'entraînement a la force en natation

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Reçu le 18 juillet 2022 ; accepté le 9 septembre 2022
Disponible sur Internet le 19 October 2022

KEYWORDS
Strength training ;
Swimming

Summary
Aims. — Strength training is not usually an important aspect of the training programme for swimmers. Instead, more emphasis is placed on traditional swimming training, which focuses mainly on endurance work.
News. — This is why in this study a systematic review is carried out with the aim of observing the effects that can be caused by a swimming training programme in which strength work is carried out, while maintaining traditional swimming training. Considering the PRISMA statement, the Web of Science (WOS) database was used to search for articles, taking those published between 2017 and 2022. A total of 387 articles were identified, from which, after passing all criteria, 19 were chosen as the study sample. After analysis, it was found that addressing strength enhancement work within programming can have a positive transfer on short-medium distance swimming performance, improving force transmission and stroke biomechanics.
Conclusion. — This indicates that it would be appropriate to plan the training microcycles with strength sessions separated from the swimming sessions, without increasing the training volume too much, so as not to cause greater fatigue in the swimmer.

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https://doi.org/10.1016/j.scispo.2022.09.002

MOTS CLÉS
Musculation ;
Nage

Résumé

Objectif. — La musculation ne constitue généralement pas un aspect important du programme d'entraînement des nageurs. Au contraire, l'accent est mis sur l'entraînement traditionnel de la natation, qui se concentre principalement sur le travail d'endurance. C'est pourquoi, dans cette étude, une revue systématique est réalisée dans le but d'observer les effets que peut avoir l'entraînement de la force sur la santé.

Actualités. — C'est pourquoi, dans cette étude, une revue systématique est réalisée dans le but d'observer les effets qui peuvent être causés par un programme d'entraînement de natation dans lequel le travail de force est effectué, tout en maintenant l'entraînement de natation traditionnel. En considérant la déclaration PRISMA, la base de données Web of Science (WOS) a été utilisée pour rechercher des articles, en prenant ceux publiés entre 2017 et 2022. Un total de 387 articles a été identifié, parmi lesquels, après avoir passé tous les critères, 19 ont été choisis comme échantillon de l'étude. Après analyse, il a été constaté que le fait d'aborder le travail d'amélioration de la force dans le cadre de la programmation peut avoir un transfert positif sur la performance de la natation de courte et moyenne distance courte et moyenne, en améliorant la transmission de la force et la biomécanique de la nage.

Conclusion. — Cela indique qu'il serait approprié de planifier les microcycles d'entraînement en séparant les sessions de force des sessions de natation, sans nage, sans trop augmenter le volume d'entraînement, afin de ne pas fatiguer davantage le nageur.

1. Introduction

Nowadays, the physical capacity that receives the most attention in swimming is endurance, to the detriment of other aspects. One aspect that is often overlooked in programming for this sport is strength work, a physical capacity that has numerous physiological and sporting benefits [1]. Some factors within swimming can be highly related to the level of strength, such as impulses in starts and turns [2], stroke biomechanics and swimming speed [3]. Another aspect to take into account in swimmers is that, being a low-impact sport, there is not a correct development of bone mass in these athletes, leading to an increased risk of bone fracture [4]. Strength training can increase the growth of bone mass, so it would be ideal to apply it in the training programming of swimmers [5].

The concept of training is about the guidelines imposed on an individual, in order to achieve a higher state of self, which can be of a different nature, that will allow him/her to face a future situation with greater ease [6]. In sports training, physical capacities are worked on in such a way that they are aimed at being assimilated to those that are used in greater proportion within the competition of the sporting discipline [7]. These capacities are: endurance, strength, speed and flexibility. All of them are interrelated, however, the one that influences all of them if worked on is strength [8].

From a biomechanical perspective, force is the ability of an object to cause an alteration in the state of mobility of another object [9]. At a physiological level, force is produced by the mechanical tension of muscle fibres in response to a nerve impulse, performing contractions in the muscle groups involved in the action to be performed. The objective of the individual is to generate a force greater than the resistance of the object, managing to move it in the desired direction [10].

Extrapolating strength to the field of swimming, it is observed that, in order to reduce the contact time with the pool wall during impulse starts and turns, coaches should prescribe training that improves this rapid leg extension, which focuses on moving a moderate load in the shortest possible time, working the peak power [11]. Benefits have been seen in turning performance and the underwater phase of the swim after a warm-up with resistance exercises (strength work) at high intensity, applying the practice of post-activation performance enhancement, which seeks to take advantage of the adaptation of the organism generated during that warm-up [12].

Likewise, when tackling the turn, body control is linked to abdominal stability, so training focused on working on abdominal stability, with exercises that activate the abdominal area, such as the barbell squat and isometric exercises, such as the front and side plank, can improve the swimmer's ability to maintain optimal aerodynamics, reducing resistance against the water and reducing the time of the turn [13—15]. Another factor that has been observed in the scientific literature is that continuous swimming induces accumulated fatigue in the shoulders, due to the repeated rotations that swimmers continuously perform [16], reducing their range of motion and stroke length, so a strength training programme to work this area would help prevent fatigue and improve performance, enabling the swimmer to maintain an optimal state for longer [17].

Finally, and taking into account all of the above, the aim of the present research is to show whether the work on this physical capacity can cause a positive transfer in swimming.

2. Material and method

Taking into account the main aspects of the problem, a review of the scientific literature was carried out using a systematic procedure. To select the articles to be reviewed, the PRISMA statement was taken into account in its Spanish version [18,19], with the aim of correctly structuring this systematic review.

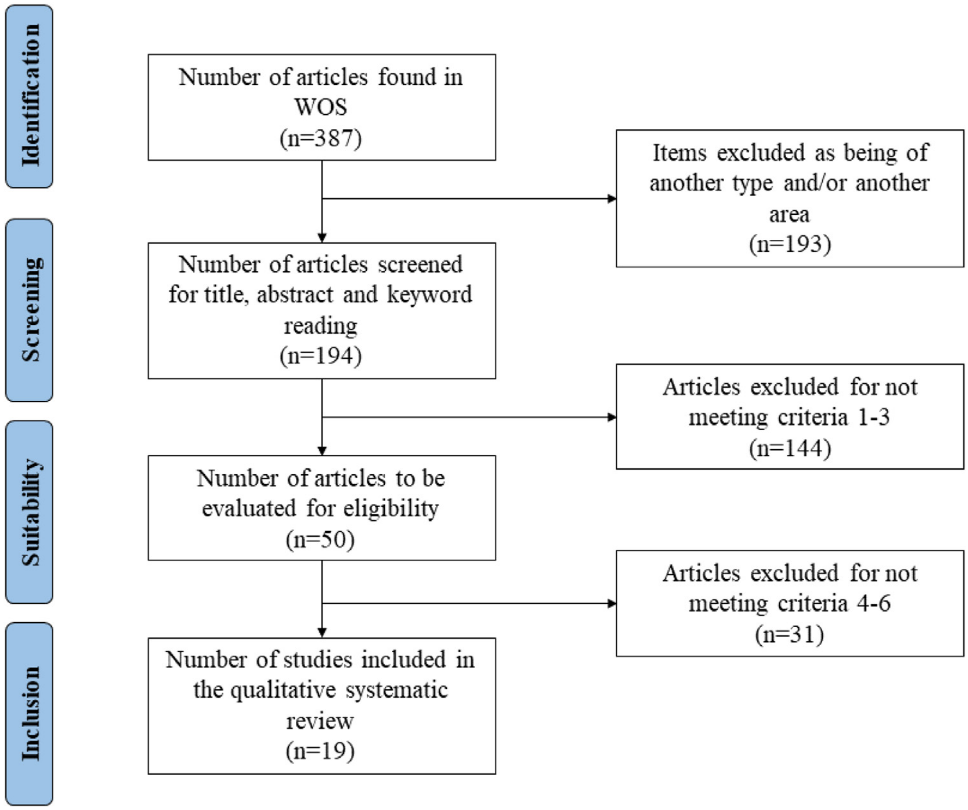

Figure 1 Representation of the process of selecting items to review.

2.1. Procedure and search strategy

The search for articles for this review was conducted through the Web of Science (WOS) database between February and March 2022, including only articles published between 2017 and 2022. The search terms used were ''swimming'', ''strength'' and ''training*'', using the Boolean operator ''AND''.

The first search returned 387 articles. Following this result, we applied the article-only format filter, which resulted in 318 articles. Seeing that some literature reviews appeared, the review articles were excluded, leaving a total of 287 articles. Subsequently, the refining process was applied in which only articles within the area of ''Sport Sciences'' were included, leaving 194 articles. With this collection, the title and abstract of each article were read, selecting only those with the following criteria:

- articles written in English or Spanish;
- swimming, training and strength included in the title, keywords or abstract;
- the sample is made up of amateur, semi-professional and/or professional swimmers;
- the methodology has a longitudinal or cross-sectional design;
- the intervention within the study is focused on improving swimming performance exclusively through strength training (resistance training), forming part of a programme that also addresses water training;
- the results help to expand knowledge on this topic.

After analysing whether the selected articles met the first three criteria, 144 were eliminated, leaving 50 articles, which, after checking, through their reading, whether they met the rest of the criteria, left only a sample of 19 of them. Fig. 1 shows a flow chart representing the entire selection process.

2.2. Data extraction procedure and description of the selected articles

For the extraction of the information, the units of analysis were considered, using this type of coding: (a) author(s); (b) year in which it was published; (c) nation; (d) study sample; (e) methodology/design; (f) study; (g) objective(s); (h) variable(s); (i) instruments; (j) results (Table 1).

3. Results

Fig. 2 represents the scientific articles found in WOS, categorised by year of publication (2017—2022), showing those that were selected for review because they met all the inclusion criteria. It can be seen that each year, the number of field research on this topic has been increasing, with fewer in 2022 due to the search being conducted between the months of February and March. Coincidentally, no articles from 2022 were selected for review, as they did not meet all the criteria.

For Table 2 the most representative data from the review articles were presented. Most of the studies looked at

Table 1 First sections of the items selected for review.

Author(s)	Year	Nation	Study sample
Lopes et al.	2021	Portugal	20 university swimmers (14 males and 6 females) (20.55 ± 1.76 years), weight: (68.86 ± 7.69 kg), height: (1.77 ± 0.06 m)
Sammoud et al.	2021	Tunisia	22 female swimmers. 12 from the experimental group (10.01 ± 0.57 years, 36.39 ± 6.32 kg, 143.6 ± 5.05 cm) and 10 from the control group (10.5 ± 0.28 years, 38.41 ± 9.42 kg, 143.6 ± 5.05 cm)
Batalha et al.	2018	Portugal	25 swimmers. 12 from the WG group (13.28 ± 0.96 years, 49.30 ± 7.90 kg, 159.61 ± 5.62 cm) and 13 from the LG group (13.52 ± 0.92 years, 48.59 ± 6.51 kg, 162.59 ± 9.46 cm)
Marques et al.	2020	Portugal	10 elite junior swimmers (5 men and 5 women) (16.6 ± 0.7 years, 62.2 ± 5.4 kg, 1.70 ± 0.07 m)
Sadowski et al.	2020	Poland	26 regional level swimmers (15.7 ± 0.5 years, 68.4 ± 8.2 kg, 174.6 ± 6.6 cm)
Morais et al.	2018	Portugal	27 swimmers (11 men and 16 women) at regional and national level (13.3 ± 0.85 years, 52.65 ± 7.42 kg, 162.11 ± 7.63 cm)
Amaro et al.	2017	Portugal	21 swimmers. Control group of 7 swimmers (12.6 ± 0.8 years, 47.8 ± 12.8 kg, 1.55 ± 0.07 m), experimental group 1 of 7 swimmers (12.7 ± 0.8 years, 47.9 ± 7.2 kg, 1.57 ± 0.07 m) and experimental group 2 of 7 swimmers (12.7 ± 0.8 years, 47.4 ± 10.0 kg, 1.58 ± 0.09 m)
Naczk et al.	2017	Poland	14 national level swimmers (10 males and 4 females) (15.8 ± 0.4 years, 69 ± 8 kg, 1.79 ± 0.07 m)
Cuenca-Fernández et al.	2020	Spain	20 national level swimmers (18.02 ± 1.39 years, 70.36 ± 8.97 kg, 1.80 ± 0.04 m)
Ji et al.	2020	South Korea	30 swimmers. CTG group of 15 swimmers (13.00 ± 0.88 years, 53.66 ± 5.85, 165.68 ± 7.35 cm) and WTG group of 15 swimmers (13.06 ± 0.88 years, 53.26 ± 6.94, 164.41 ± 4.92 cm)
Karpinski et al.	2020	Poland	16 national level swimmers. Control group of 8 swimmers (20.0 ± 1.9 years, 75.4 ± 6.27 kg, 182.1 ± 3.18 cm) and experimental group of 8 swimmers (20.2 ± 1.17 years, 74.9 ± 10.67 kg, 183.0 ± 6.57 cm)
Amara et al.	2021	Tunisia	22 swimmers. Control group of 11 swimmers (16.5 ± 0.30 years, 72.7 ± 5.30 kg, 174 ± 9.80 cm) and CRTG group of 11 swimmers (16.5 ± 0.30 years, 72.7 ± 5.30 kg, 174 ± 9.80 cm)
Amara et al.	2021	Tunisia	33 swimmers. HTVLG group of 11 swimmers (16.5 ± 0.30 years, 72.4 ± 5.3 kg, 175 ± 9.8 cm), MTVLG group of 11 swimmers (16.1 ± 0.32 years, 73.5 ± 5.4 kg, 177 ± 9.7 cm) and LTVLG group of 11 swimmers (15.9 ± 0.31 years, 74.6 ± 5.5 kg, 177 ± 9.4 cm)
Arsoniadis et al.	2019	Greece	12 regional and national level swimmers (19.0 ± 2.2 years, 74.4 ± 10.1 kg, 178.1 ± 7.9 cm)
Born et al.	2020	Switzerland	21 female swimmers at national and international level. Experimental group 1 of 10 swimmers (17.1 ± 2.6 years, 65.8 ± 10.1 kg, 1.75 ± 0.1 cm) and experimental group 2 (17.1 ± 2.7 years, 62.9 ± 9.1, 1.72 ± 0.07 m)
Thng et al.	2021	Australia	11 swimmers (6 males and 5 females). HF group of 6 swimmers (21.3 ± 1.7 years, 74.3 ± 10.5 kg, 1.73 ± 0.06 m) and VF group of 5 swimmers (21.0 ± 2.2 years, 70.0 ± 10.3 kg, 1.74 ± 0.08 m)
Sammoud et al.	2019	Tunisia	26 swimmers. Control group of 12 swimmers (10.5 ± 0.4 years, 38.2 ± 5.9 kg, 1.46 ± 0.07 m) and PJT group of 14 swimmers (10.3 ± 0.4 years, 36.2 ± 8.4 kg, 1.43 ± 0.08 m)
Schumann et al.	2020	Germany	17 national level swimmers. Control group of 7 swimmers (15.1 ± 1.1 years, 65.6 ± 7.7 kg, 180.6 ± 7.0 cm) and experimental group (14.8 ± 1.0 years, 65.0 ± 10.4 kg, 175.8 ± 9.1 cm)
Eskiyecek et al.	2020	Turkey	24 swimmers. Control group of 12 swimmers (10.42 ± 0.51 years; 45.56 ± 1.83 kg, 1.54 ± 0.03 cm) and experimental group of 12 swimmers (11.25 ± 0.75 years, 46.13 ± 2.11 kg, 1.55 ± 0.03 cm)

Table 2 Description of the most representative data of the items.

Study	Objective/s	Variables	Instruments	Results
Lopes et al.	To examine the effects of 8 weeks of strength training, combined with pool training, on upper and lower body strength, jumping ability and swimming performance	Stroke length, stroke frequency, stroke index. Performance in strength exercises and times in 50 and 100 metres crawl style	Finis 3 × 100 stopwatch, Kinovea v. 0.8.15, T-Force System Ergotech, Microgate Optojump Next	The experimental group improved sprint performance, stroke frequency and stroke rate. Both groups increased their strength, but the gains were greater in the experimental group
Sammoud et al.	To examine the effects of 8 weeks of plyometric training (PJT) programming on diving performance and specific swimming performance	Muscle power (CMJ and SJ), performance in 25 m and 50 m with underwater start in crawl style, 25 m without initial impulse on the crawl wall, and 25 m using only legs	Microgate Optojump photoelectric system, stopwatch	The experimental group improved performance in the CMJ and SJ, and in all pool tests
Batalha et al.	To evaluate and compare the effects of two 10-week rotator cuff strength, balance and muscular endurance training programmes	Level of strength, balance and muscular endurance in internal and external rotators	Biodex System 3 isokinetic dynamometer	The dry programme proved to be more effective in reducing muscle imbalance and fatigue
Marques et al.	To analyse the combined long-term effect of strength and plyometric training programming on strength, power and swimming performance levels during the competitive season (20 weeks)	1RM in squat and bench press, jumping height (CMJ), maximum number of repetitions in pull-ups and 50 m crawl time	Microgate Optojump photoelectric system, Finis stopwatch 3 × 100	Programming improved all parameters
Sadowski et al.	To compare the effects of a specific dry strength training programme on an ergometer with a traditional strength exercise programme, and to determine how much transfer there is to the specific swimming conditions	Isometric strength, 25 m crawl performance while moving arms only (stroke length and frequency) and strength during tethered swimming	Sony HDR-CX 130 video camera, Kinovea System Software, Belt with long cable StretchCordz	There was greater transfer in all variables with ergometer specific strength programming

Table 2 (*Continued*)

Study	Objective/s	Variables	Instruments	Results
Morais et al.	To analyse the interaction between dry strength training and stroke biomechanics during a 34-week training programme	100 m crawl performance, wingspan, throwing speed (medicine ball), stroke frequency and stroke length	Rosscraft tape measure, Swimsportec wired swimming speedometer, LabVIEW software, AcqKnowledge v.3.5 software	All the parameters improved, increasing the wingspan of the individuals
Amaro et al.	To investigate the effects of two strength training programmes (one focused on strength and the other on explosiveness) over 6 weeks	Average strength and mechanical impulse during tethered swimming, throwing distance (medicine ball), vertical jump height (CMJ) and 50 m crawl performance	Tape measure, belt with long cable and stopwatch SEIKO S120-4030	The strength training programming focused on explosiveness improved all parameters with greater results than the rest of the programming
Naczk et al.	To assess the influence of dry inertial training on muscle strength and power and swimming performance over 4 weeks	Muscle strength and power (measured on the inertial device), muscle mass, 100 m butterfly and 50 m crawl times	Monark 818 ergometer, Skintact electrodes, ME6000 Biomonitor and OMEGA electronic stopwatch	The experimental group performed better than the control group due to inertial training programming
Cuenca-Fernández et al.	To compare the effects of pull-over strength exercise and a swimming warm-up on the semi-tied swim	Kinetic variables (velocity, force, acceleration, momentum, rate of force development and intra-cycle velocity variation) and kinematic variables (distance, time, frequency and stroke length) of swimming	Pulley system on a Smith machine (Jim Sports Technology SL), WeiHeng electronic dynamometer, Ergotech isoinertial dynamometer, three Sony video cameras and SE-900 digital video switcher	The experimental group (strength exercise and swimming warm-up) increased the rate of strength development and swimming frequency compared to the control group, but decreased their speed, strength, acceleration, momentum and power
Ji et al.	To investigate the effects of a core training programme on fitness and swimming performance over 12 weeks compared to a traditional strength training programme	Maximum muscular strength, anaerobic power (Wingate test), core stability and power, muscular endurance and swimming performance	Excalibur Sport Cycloergometer	The group that did the core training programme improved in all parameters

Table 2 (*Continued*)

Study	Objective/s	Variables	Instruments	Results
Karpinski et al.	To evaluate the impact of a core training programme on swimming performance over 6 weeks	50 m crawl performance (entry distance and speed, reaction time, flight time after the jump, jump angle, time to reach 5 m after the turn, average speed to 5 m after the turn, swim speed, stroke length and frequency, and total time)	OMEGA electronic stopwatch, two JVC GC-PX100BE video cameras, one Sony FDR-X3000 camera	The experimental group performed better than the control group thanks to the core training programme
Amara et al.	To examine the effects of a 9-week concurrent training programme (dry strength and water strength-endurance training) on muscular strength, 25 m and 50 m crawl performance and kinematic variables compared to a traditional swimming training programme	1RM in bench press, times in 25 and 50 metres normal and arms-only crawl, swimming speed up to 10 metres, and stroke frequency, stroke length and stroke rate up to 10 metres	Stopwatch SEIKO S210-4030, video camera Sony SNC VB 603, software Kinovea v. 0.8.15	The group that did the concurrent training programme performed better than the control group
Amara et al.	To compare the effectiveness of three maximal strength training programmes (high, medium and low volume) on muscular strength and swimming performance over 9 weeks	Time in 25 and 50 metres crawl style; speed, time and start distance (from the start signal to the head contacting the water); turn time; 1 RM bench press and 1RM leg extension	Stopwatch SEIKO S210-4030 and two video cameras Sony SNC VB 603	All training programmes had similar results, with slightly better results in the high volume programme
Arsoniadis et al.	To examine the acute effect of dry strength training on physiological and biomechanical parameters in a subsequent swimming training session, in a 2.5-week intervention	Oxygen consumption, blood lactate concentration, heart rate, subjective perception of effort, stroke frequency, stroke length and efficiency	VO2000 portable gas analyser, Accutrend Plus analyser, Musclelab digital dynamometer and converter, FINIS tempo pro sound transmitter, CASIO HS-80 stopwatch, Polar Electro S610i heart rate monitor, Samsung HMX-Q10BP/EDC camcorder	The experimental group (dry strength training) expressed slightly more fatigue than the control group, varying stroke frequency and stroke length, without reducing swimming speed

Table 2 *(Continued)*

Study	Objective/s	Variables	Instruments	Results
Born et al.	To analyse sprint sprint swimming performance after a maximal strength training programme compared to a 6-week vertical jump training programme	Time over 5, 10, 15 and 25 metres crawl style, kinematic variables (time in the poyette, horizontal flight speed, flight angle, entry hole size, maximum swim depth, butterfly kick frequency, butterfly kick distance, underwater swim distance, crawl stroke frequency and stroke length) and kinetic variables (maximum power, maximum horizontal and vertical force, maximum horizontal force of the rear foot and maximum grip force)	Kistler PAS-S software, 6 video cameras and DISTO D2 laser meter	There was no major difference between the groups. The group with the maximal strength training programme slightly improved their swim times
Thng et al.	To provide insight into the effects of two strength training interventions (over 8 weeks): horizontal vs. vertical strength, on performance in the early phases of the swim	1RM in hip strike, SJ variables (jump height, concentric impulse, RSI, average power and rate of force development), exit variables from the pole (average power, average acceleration, work/kg, horizontal flight velocity, maximum force, maximum front and rear horizontal force, average rear force, maximum grip force) and times at 5 and 15 metres	FD4000 force platform, ForceDecks software and KiSwim Type 9691A1 Kistler output yoke	There was no major difference in results between the two groups
Sammoud et al.	To examine the effects of an 8-week plyometric training programme on muscle power and swimming performance	Height in CMJ and SJ, time in 25 metres crawl style with and without impulse, 15 and 50 metres crawl style	Microgate Optojump photoelectric system and timer	Although the results were lower in the PJT group, the parameters were more improved than in the control group
Schumann et al.	To analyse the effects of two strength training programmes (one focused on hypertrophy and the other on maximal and explosive strength) on swimming performance over 16 weeks	Performance in 4×400 m crawl, 1 RM in bench press and partial squat, blood lactate concentration and CMJ height	Biosen EKF lactate analyser, Kistler Instrumente GmbH force platform, OSB 11 OMEGA output stand, 4 Sony SNC VB 603 video cameras and Utilius Kiwano software	Both groups had similar results, with the experimental group (maximal and explosive strength) performing a shorter time in the swimming test
Eskiyecek et al.	To investigate the effects of a core training programme on 50 m crawl, backstroke, breaststroke and butterfly performance over 8 weeks	Time in 50 m crawl, backstroke, breaststroke and butterfly	FINIS 3X-300 M stopwatch	The experimental group improved all their times more than the control group

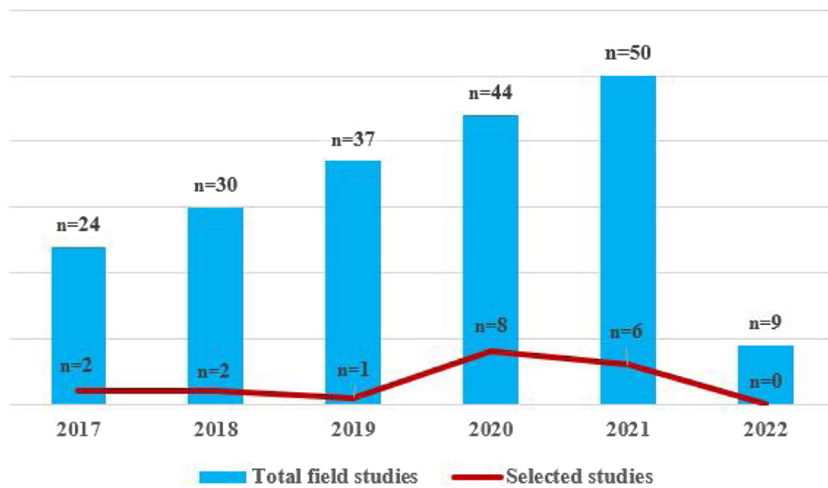

Figure 2 Evolution and selection of studies for the period 2017—2022.

whether there were effects of improved swimming performance, along with improved strength levels of the subjects. These were based on training programmes or interventions involving strength work. Similarly, the studies were dominated by the variables of stroke length and frequency, performance in strength exercises and power tests, and time variables for 50 and 100 m crawl. For the measurement of power levels, photoelectric systems and dynamometers are mostly used, and to a lesser extent, strength platforms and pool benches with built-in force detection systems. The Finis 3 × 100 stopwatch is generally used for time keeping. Video cameras were used to record the swimmers during the swim tests and video analysis software was used to record length and frequency. As a general rule, strength work increases swimming performance according to this review.

Table 3 lists the programmes and interventions carried out by the review studies. All the programmes were part of the swimmers' training programme along with traditional swimming pool training. The studies establish training based on traditional strength exercises (varying between strength, power, inertial work and hypertrophy), plyometrics and core work. In most of the studies, the workouts are based solely on traditional strength exercises, and in some few combined with plyometrics and/or core work, with practically all of them being very effective in improving performance.

4. Discussion

The purpose of this review was to analyse articles that showed the application of a training programme or intervention that worked on physical strength capacity, with the aim of improving performance in aspects of swimming. The systematic review by Hermosilla et al. [11] is similar to this one, except that it focused on interventions that mainly tried to improve performance in the turning phase. For the most part, the programmes and interventions produced an increase in swimmers' performance. It can be seen, according to the studies chosen, that swimmers who work on strength through a specific training programme develop better performance within their sport discipline, with a reduction in the marks recorded in swimming events after these programmes [20—22].

Such programmes usually focus on one or several of these aspects of training: traditional strength exercises, plyometric exercises and core exercises [14,22—24]. In some studies, these exercises are combined within the programming, and in others they are compared to see which is more effective [20,25]. In the studies by Amara et al. [23,24] the focus was on performance improvement mainly through strength exercises. The study compared 3 programmes with the same exercises and repetitions, but different number of sets, with one high volume programme, one moderate volume programme, and one low volume programme. The three programmes showed similar results, with the high volume programme achieving a slightly greater improvement than the other two.

The second study prescribed a concurrent training programme. In this, strength was worked in the dry (upper body strength exercises), similar to the programmes in the first study, and in water, with swimming with paddles and parachutes, to increase intensity. This programme improved performance more than the traditional swim training programme. Keiner et al. [26] note that upper body strength gains are highly correlated with increased sprint swim speed. In reference to the study by Gourgoulis et al. [27], an improvement in swim test performance can be seen with an 11-week parachute training programme, as with the review study. In contrast to these results, Barbosa et al. [28] showed that a 4-week programme with the use of swimming paddles did not cause a change in performance, which could be due to the duration of the programme or the training load.

Schumann et al. [29] show the comparison between a hypertrophy-focused programme and a strength-focused programme of equal duration. Improvements in swimming performance were obtained in both, with the strength-focused programme being slightly better. This indicates that a hypertrophy programme can be beneficial when using lower loads than the strength programme, achieving almost the same results, although this can only be applied in subjects who do not have a great deal of experience in strength training. Arsoniadis et al. [30] sought to analyse the effects

Table 3 Explanation of programmes and interventions.

Study	Intervention or programme
Lopes et al.	8-week strength training programme. Swimmers in the experimental group performed one strength session per week. The exercises were: full squat, countermovement jump (CMJ), medicine ball throw, pull-ups, lateral raises and triceps and shoulder exercises. Each exercise consisted of 3—5 sets with 6—12 repetitions at 60—80% of 1RM. The rest time between sets was 3 to 4 minutes
Sammoud et al.	8-week plyometric training programme (PJT). The swimmers in the PJT group performed 2 plyometric training sessions per week, lasting 25—30 minutes. The exercises were: countermovement jumping (CMJ) and bilateral ankle jumps. Between 4 and 6 sets were performed with 6—10 repetitions per exercise. There was a 90-second rest between sets
Batalha et al.	Two 10-week programmes of strength, balance and rotator cuff muscle endurance training. Each group performed one programme, with 3 sessions per week The first programme was dry. The exercises were performed with elastic bands. These were: shoulder abductions up to 50—60° between torso and arms, shoulder abductions up to 160° between torso and arms, and 90° external rotation of the shoulder with the arm flexed and abducted to 90°. Three series were performed with 30 seconds rest between them. The first two with 20 repetitions and the last one until exhaustion The second programme was in water. The exercises were: external rotation of the shoulder with the arms flexed at 90° and joined with an elastic band tied to the wrists, the same exercise but with swimming paddles placed on the back of the hand without using an elastic band, and the same exercise without material. They performed between 3 and 5 series with 30—45 seconds of repetitions. They had 10 seconds rest between sets and 2 minutes between exercises
Marques et al.	20-week programme of strength training and plyometrics. 2 cycles of 9 weeks with one week of recovery in between. 2 training sessions per week. Exercises were: squat, squat jump (SJ), countermovement jump (CMJ), bench press, pull-ups and shoulder press. The sessions lasted between 60 and 70 minutes. There were 3 to 4 sets with 3—10 repetitions
Sadowski et al.	Two 12-week strength training programmes of 3 sessions per week The first programme was carried out by the experimental group, and consisted of ergometer work. During the sessions, 10 sets of 30 seconds of effort were performed with 30 seconds of rest between each set The second programme was performed by the control group. This focused on traditional strength exercises
Morais et al.	34-week strength training programme, with 3 weeks of training per week In the first stage sessions (20 weeks) 6 exercises were performed, 2 sets of 20 seconds each per exercise. These were: sit-ups, push-ups, squats, vertical jumps, burpees and mountain climbers In the second stage (14 weeks) 2 sets of 30 seconds were performed for each exercise. The exercises of the first stage were performed together with push-ups with triceps focus and elastic band exercises (upper body)
Amaro et al.	Two 6-week strength training programmes, with two 30-minute sessions per week. Each experimental group performed one and the control group followed only traditional swimming training. Both programmes had the same exercises. These were: medicine ball throwing, CMJ to the box, dumbbell lunges, Russian twists and push-ups The first programme focused on strength. There were 3 sets per exercise, with 6—18 repetitions The second programme focused on explosiveness. There were 3 sets of each exercise, with 10—25 seconds of work
Naczk et al.	4 weeks dry inertial training programme with an inertial system working on triceps flexion. We worked with the inertial system for 3 sessions per week. Four sets of 15 seconds were performed, with a rest of 60 seconds between each one
Cuenca-Fernández et al.	Intervention in two groups. Both groups underwent two tests with pulley systems, the first in dry conditions, to determine the 1RM in pull-over, and the second in water, measuring the force-velocity profile, each in separate sessions. In the next session, one group performed dynamic stretching followed by 1 set of 3 repetitions of the pull-over exercise at 85% of 1RM. This was followed by a 15 m crawl swim, attached to a pulley system with a load within the swimmer's power range. The other group only performed the tethered swim. In the next session, the tables were turned

Table 3 (*Continued*)

Study	Intervention or programme
Ji et al.	Two 12-week strength training programmes, with 3 sessions per week, each lasting 80 minutes. Each session lasted 80 minutes and the first programme focused on core work. The first 4 weeks focused on stability (glute bridge, plank, push-ups and bird dog), the next 4 weeks on muscular power (deadlift, squat and rowing), and the last 4 weeks on power endurance (medicine ball kick, one-handed dumbbell pull-up and chops) The second programme focused on traditional strength training. The first two weeks focused on tissue adaptation, the next 4 weeks on maximal strength and the last 6 weeks on muscular power. The exercises were: chest pull-up, shoulder press, pull-over, pull-over, sit-up, lumbar extension, Russian twists, snatch, and barbell carry
Karpinski et al.	6-week core training programme, with 3 sessions per week. Each session lasted 25 minutes. Four exercises were performed: ''flutter kicks'', ''single leg V-ups'', trunk extension on ''physio ball'' and Russian twists. Each exercise was performed in 4 sets with 40 seconds of work and 20 seconds of rest between sets
Amara et al.	Concurrent training programme of 9 weeks, working strength in dry and in water. The dry strength work was performed in 2 sessions per week, performing bench press exercises with an intensity of 60—80% and medicine ball throwing. 3—6 sets with 6—12 repetitions were performed for each exercise. The strength work in water was performed in 4 sessions per week together with the traditional swimming training, and consisted of 2—3 sets of 4 repetitions of 15—25 metres with swimming paddles and parachute. There was 60—90 seconds rest between repetitions and 5 minutes between sets
Amara et al.	Three 9-week strength training programmes (high, moderate and low volume), 3 sessions per week of 60—70 minutes. The exercises were performed at 85—95% of 1RM and were: bench press and leg extension. In the high volume programme, 5—6 sets were performed, in the moderate programme 4—5 sets and in the low volume programme 3—4 sets. In all of them, 3—5 repetitions per set were performed
Arsoniadis et al.	Intervention of a dry strength training session (45 minutes). The exercises performed were: bench press (85% 1RM), rowing (85% 1RM), half squat (90° knee flexion) (85%), sit-up and lumbar extension. Three sets of 5 repetitions were performed with 4 minutes rest between sets in the first three exercises. In the last two exercises, 5 sets of 15 repetitions were performed with 30 seconds rest between sets
Born et al.	Two 6-week programmes, with 11 sessions in total. Each session lasted 1 hour. The first programme focused on maximal strength work. The exercises were: deadlift and barbell squat (90° knee flexion). There were 3—4 sets of 2—6 repetitions, with 5 minutes rest between sets. The second programme focused on vertical jump work. The exercises were: CMJ and SJ, both to the box. Seven sets of 6—7 repetitions were performed, with 2.5 minutes rest between sets
Thng et al.	Two 8-week strength training programmes, with 2 sessions per week. 2—3 sets of 3—8 repetitions were performed for each exercise. The first programme focused on horizontal strength work. The exercises were: hip thrust, horizontal jump with ''start from the bar'' position, sled push and ''vertical drop jump''. The second programme focused on vertical strength work. The exercises were: squat, SJ, Bulgarian squat and vertical drop jump
Sammoud et al.	8-week plyometric training programme, with 2 sessions of 25—30 minutes per week. 4—6 sets of 6—10 repetitions of bilateral ankle jumps were performed, with 90 seconds rest between sets.
Schumann et al.	Two 16-week strength training programmes, adapted for sprint swimmers and middle distance swimmers. The exercises were: full squat, deadlift, pull-ups, pull-ups, bench press, other exercises (lunges, femoral curl, rowing, shoulder rotation, arm adduction, dips, chin-ups, core stability), SJ, medicine ball strokes and 10 m sprint swim. The latter three were performed only by the maximal and explosive strength group. During the first 7 weeks, all subjects performed the hypertrophy programme. The rest of the weeks, they were divided into two groups, each performing one programme. The first programme focused on hypertrophy, with 3 sets of 6—10 repetitions for most of the exercises. The second programme focused on maximal and explosive strength, with 3 sets of 3—4 repetitions on most exercises
Eskiyecek et al.	8-week core training programme, with 3 sessions per week. The core exercises (10 in total) worked the abdominal and lumbar muscles. 3—4 sets of 15—20 repetitions were performed, with 1—3 minutes rest between sets

of a strength session on the subsequent swimming session of one group compared to a group that did not perform the strength session. Both groups performed the swim test at similar speeds. In addition, the experimental (strength) group had higher stroke frequency, blood lactate concentrations and a feeling of greater effort, yet this was not enough to reduce speed. As in the study by Thomas et al. [31], after a strength session there is a higher stress against the same loads, which is useful for training under conditions of higher fatigue/intensity.

Batalha et al. [32] compared dry and wet strength programming, both focused on the glenohumeral joint. It was found that the dry training programme had a greater transfer to swimming performance, improving the balance between internal and external rotators. This may be due to the selection of exercises for water training, working only the external rotators. Performing compensatory work on both rotators may reduce the risk of shoulder injury, which is common in swimmers [33].

Sadowski et al. [34] present in their study a strength training programme using an ergometer, performing sets with 30 seconds of effort each, compared to a strength training programme with traditional exercises. Both groups improved their performance, but swimmers in the experimental group made greater gains. This may be due to greater specificity [35] in maintaining a similar repetition frequency to swimming, with ergometer work being more transferable to swimming. The studies by Naczk et al. [36] and Cuenca-Fernández et al. [4] apply strength training with an inertial, pulley-based work approach. In the first study, the programme lasted 4 weeks and consisted of performing an arm extension from a 90° flexion position, working the posterior arm musculature, while the subject was lying prone. In the second study, the intervention was similar, but only one session was performed prior to the swim assessment. Instead of an arm extension, the ''pull-over'' exercise was performed, which consists of a shoulder extension with the arms straight at all times.

The experimental group in the first study improved their swimming performance, while the experimental group in the second study presented a higher rate of strength development and stroke frequency, but worsened other variables such as speed, acceleration and impulse when performing a semi-tied swim with resistance, when compared to the control group. This may be because strength training affected stroke biomechanics to some extent [37], being ineffective for swimming performance. The first study was able to have such results due to the duration of the programming, with swimmers achieving improved performance over the weeks. The study by Thng et al. [38] compares the effects of programming focused on vertical vector strength exercises with programming focused on horizontal vector strength exercises, including traditional and plyometric exercises. The results appear to be similar, with no observable improvement in swimming performance. The cause may be due to an interference effect generated by the high volume of swimming training, which did not allow adaptations to be achieved from strength training [39].

Two studies in the review [22,40] present strength training programmes composed solely of plyometric exercises. Both programmes were very similar. They produced significant improvements in the swimming performance of the experimental group compared to the control group. This may be due to increases in muscle activation of the muscles worked. Other studies [41,42] also show an improvement in swimming performance following such a training programme, even when combined with traditional strength training. The combination of plyometrics and traditional exercises can also be seen in the training programmes of the studies by Lopes et al. [20] and Marques et al. [21]. The experimental groups achieved higher swimming performance compared to the control groups. In contrast, there are studies [43,44] that indicate that strength training does not improve swimming performance, with the explanation being the high level of training experience of these subjects as a difficulty in achieving adaptations.

Born et al. [25] compared the effects of a traditional strength training programme with a plyometric training programme. The results were similar between the two groups, being slightly better with the traditional strength programme. It is possible that the explosive strength adaptations may have interfered with the high volume of swimming training [45]. Regarding strength training focused on the core musculature, Karpinski et al. [14] and Eskiyecek et al. [46] conducted programmes focused on exercises exclusively for that work, compared to a traditional swimming programme. The core training programme group performed better than the control group. Ji et al. [47], in their study, contrasted the effects of a core workout programme with a traditional strength training programme in swimmers. Both programmes improved the performance of the swimmers, but the core training had a greater transfer than the traditional programme. Possibly, these gains achieved with core training programmes allowed for improved stability of the lower and upper limbs, transferring energy more efficiently [15,48,49].

In the study by Morais et al. [3], core exercises are combined with traditional strength exercises within a programme, resulting in increased performance in all swimming parameters compared to a traditional swimming programme, including stroke biomechanics and even the swimmers' wingspan, being a determinant of performance in young swimmers [50,51]. In the study by Amaro et al. [52], they work with two similar programmes. One focused on strength and the other on explosiveness. Both had the same exercises (traditional, core work and plyometrics) but the training variables changed. The explosiveness-focused training programme had a greater transfer to swimming performance. This may be due to the fact that the other programme did not give importance to speed, thus not improving power, which is a factor closely related to performance in short-distance swimming events [28].

5. Limitations and future prospects

This review has certain limitations. One of them is to only select studies published between 2017 and 2022, otherwise, by selecting earlier studies we could have a broader view on this topic. Also, when searching with the chosen keywords, the number of articles to be analysed is reduced, and there may have been some that would have been useful for this review. Another limitation is that most of the studies reviewed have a sample between childhood and adolescence, so that the effects produced by training may be influenced by the maturational development of children [53]. Additionally, the subjects were short-medium distance swimmers, so it was not observed what effect strength improvement may have on long-distance swimming performance. A future search could consider a larger number of articles without applying so many criteria and try to find studies with samples of older age, higher category and long distance events.

6. Conclusions

Based on the review, it was found that the implementation of a training programme focused on improving the strength of swimmers can increase swimming performance, increasing fitness, performing the swim with more efficient biomechanics and reducing test times. Traditional strength, plyometric and core-focused exercises are useful for working on swimmer fitness and transferring a positive effect on competitive events. Coaches should programme training by separating strength sessions from swimming sessions within microcycles, selecting exercises that work all muscle groups without applying a large volume of training, thus avoiding leading the athlete to a state of overtraining, worsening his performance instead of increasing it.

Disclosure of interest

The authors declare that they have no competing interest.

Funding

Funding for open access charge: Universidad de Granada/CBUA.

Références

[1] Suchomel TJ, Nimphius S, Bellon CR, Stone MH. The importance of muscular strength: training considerations. Sports Med (Auckland) 2018;48(4):765—85, http://dx.doi.org/10.1007/s40279-018-0862-z.

[2] Jones J, Pyne D, Haff G, Newton R. Comparison between elite and subelite swimmers on dry land and tumble turn leg extensor force-time characteristics. J Strength Cond Res 2018;32(6):1762—9, http://dx.doi.org/10.1519/JSC.0000000000002041.

[3] Morais JE, Silva AJ, Garrido ND, Marinho DA, Barbosa TM. The transfer of strength and power into the stroke biomechanics of young swimmers over a 34-week period. Eur J Sport Sci 2018;18(6):787—95, http://dx.doi.org/10.1080/17461391.2018.1453869.

[4] Cuenca-Fernández F, Batalha NM, Ruiz-Navarro JJ, Morales-Ortiz E, López-Contreras G, Arellano R. Post high intensity pull-over semi-tethered swimming potentiation in national competitive swimmers. J Sports Med Phys Fitness 2020;60(12):1526—35, http://dx.doi.org/10.23736/S0022-4707.20.11136-8.

[5] Roelofs EJ, Smith-Ryan AE, Trexler ET, Hirsch KR. Seasonal effects on body composition, muscle characteristics, and performance of collegiate swimmers and divers. J Athl Train 2017;52(1):45—50, http://dx.doi.org/10.4085/1062-6050-51.12.26.

[6] Buckner SL, Jessee MB, Mouser JG, Dankel SJ, Mattocks KT, Bell ZW, et al. The basics of training for muscle size and strength: a brief review on the theory. Med Sci Sports Exerc 2020;52(3):645—53, http://dx.doi.org/10.1249/MSS.0000000000002171.

[7] Brearley S, Bishop C. Transfer of training: how specific should we be? Strength Cond J 2019;41(3):97—109, http://dx.doi.org/10.1519/SSC.0000000000000450.

[8] Zatsiorsky VM, Kraemer WJ, Fry AC. Science and practice of strength training. 3ª ed. Human Kinetics; 2020.

[9] Gutiérrez-Dávila M. Fundamentos de Biomecánica deportiva. Editorial Síntesis; 2015.

[10] Soares-Leite WS. Biomecánica aplicada al deporte: contribuciones, perspectivas y desafíos. Lect Educ Física Deportes 2012;(170).

[11] Hermosilla F, Sanders R, González-Mohíno F, Yustres I, González-Rave JM. Effects of dry-land training programs on swimming turn performance: a systematic review. Int J Environ Res Public Health 2021;18(17):9340, http://dx.doi.org/10.3390/ijerph18179340.

[12] Crespo E, Ruiz-Navarro JJ, Cuenca-Fernández F, Arellano R. Post-eccentric flywheel underwater undulatory swimming potentiation in competitive swimmers. J Hum Kinet 2021;79(1):145—54, http://dx.doi.org/10.2478/hukin-2021-0068.

[13] Cortesi M, Gatta G, Michielon G, Di Michele R, Bartolomei S, Scurati R. Passive drag in young swimmers: effects of body composition, morphology and gliding position. Int J Environ Res Public Health 2020;17(6):2002, http://dx.doi.org/10.3390/ijerph17062002.

[14] Karpinski J, Rejdych W, Brzozowska D, Golas A, Sadowski W, Swinarew AS, et al. The effects of a 6-week core exercises on swimming performance of national level swimmers. PloS One 2020;15(8):e0227394, http://dx.doi.org/10.1371/journal.pone.0227394.

[15] Weston M, Hibbs AE, Thompson KG, Spears I. Isolated core training improves sprint performance in national-level junior swimmers; 2014 [10.1123/ijspp.2013-0488].

[16] Heinlein SA, Cosgarea AJ. Biomechanical considerations in the competitive swimmer's shoulder. SAGE Publications; 2010.

[17] Matthews MJ, Green D, Matthews H, Swanwick E. The effects of swimming fatigue on shoulder strength, range of motion, joint control, and performance in swimmers. Phys Ther Sport 2016;23:118—22, http://dx.doi.org/10.1016/j.ptsp.2016.08.011.

[18] Hutton B, Salanti G, Caldwell DM, Chaimani A, Schmid CH, Cameron C, et al. The PRISMA extension statement for reporting of systematic reviews incorporating network meta-analyses of health care interventions: checklist and explanations. Ann Intern Med 2015;162:777—84.

[19] Hutton B, Catalá-López F, Moher D. La extensión de la declaración PRISMA para revisiones sistemáticas que incorporan metaanálisis en red: PRISMA-NMA. Med Clin 2016;147(6):262—6, http://dx.doi.org/10.1016/j.medcli.2016.02.025.

[20] Lopes TJ, Neiva HP, Gonçalves CA, Nunes C, Marinho DA. The effects of dry-land strength training on competitive sprinter swimmers. J Exerc Sci Fitness 2021;19(1):32—9, http://dx.doi.org/10.1016/j.jesf.2020.06.005.

[21] Marques MC, Yáñez-García JM, Marinho DA, González-Badillo JJ, Rodríguez-Rosell D. In-season strength training in elite junior swimmers: the role of the low-volume, high-velocity training on swimming performance. J Hum Kinet 2020;74(1):71—84, http://dx.doi.org/10.2478/hukin-2020-0015.

[22] Sammoud S, Negra Y, Chaabene H, Bouguezzi R, Moran J, Granacher U. The effects of plyometric jump training on jumping and swimming performances in prepubertal

male swimmers. J Sports Sci Med 2019;18(4):805—11 [https://www.ncbi.nlm.nih.gov/pubmed/31827366].
[23] Amara S, Barbosa TM, Negra Y, Hammami R, Khalifa R, Chortane SG. The effect of concurrent resistance training on upper body strength, sprint swimming performance and kinematics in competitive adolescent swimmers. A randomized controlled trial. Int J Environ Res Public Health 2021;18(19):10261, http://dx.doi.org/10.3390/ijerph181910261.
[24] Amara S, Crowley E, Sammoud S, Negra Y, Hammami R, Chortane OG, et al. What is the optimal strength training load to improve swimming performance? A randomized trial of male competitive swimmers. Int J Environ Res Public Health 2021;18(22):11770, http://dx.doi.org/10.3390/ijerph182211770.
[25] Born D, Stöggl T, Petrov A, Burkhardt D, Lüthy F, Romann M. Analysis of freestyle swimming sprint start performance after maximal strength or vertical jump training in competitive female and male junior swimmers. J Strength Cond Res 2020;34(2):323—31, http://dx.doi.org/10.1519/JSC.0000000000003390.
[26] Keiner M, Wirth K, Fuhrmann S, Kunz M, Hartmann H, Haff G. The influence of upper- and lower-body maximum strength on swim block start, turn, and overall swim performance in sprint swimming. J Strength Cond Res 2019;35(10):2839—45, http://dx.doi.org/10.1519/JSC.0000000000003229.
[27] Gourgoulis V, Valkoumas I, Boli A, Aggeloussis N, Antoniou P. Effect of an 11-week in-water training program with increased resistance on the swimming performance and the basic kinematic characteristics of the front crawl stroke. J Strength Cond Res 2019;33(1):95—103, http://dx.doi.org/10.1519/JSC.0000000000001879.
[28] Barbosa AC, Ferreira TH, Leis LV, Gourgoulis V, Barroso R. Does a 4-week training period with hand paddles affect front-crawl swimming performance? J Sports Sci 2020;38(5):511—7, http://dx.doi.org/10.1080/02640414.2019.1710382.
[29] Schumann M, Notbohm H, Bäcker S, Klocke J, Fuhrmann S, Clephas C. Strength-training periodization: no effect on swimming performance in well-trained adolescent swimmers. Int J Sports Physiol Perform 2020;15(9):1—9, http://dx.doi.org/10.1123/ijspp.2019-0715.
[30] Arsoniadis GG, Bogdanis GC, Terzis G, Toubekis AG. Acute resistance exercise: physiological and biomechanical alterations during a subsequent swim-training session. Int J Sports Physiol Perform 2019;15(1):1—112, http://dx.doi.org/10.1123/ijspp.2018-0897.
[31] Thomas K, Brownstein CG, Dent J, Parker P, Goodall S, Howatson G. Neuromuscular fatigue and recovery after heavy resistance, jump, and sprint training. Med Sci Sports Exerc 2018;50(12):2526—35, http://dx.doi.org/10.1249/MSS.0000000000001733.
[32] Batalha N, Dias S, Marinho DA, Parraca JA. The effectiveness of land and water based resistance training on shoulder rotator cuff strength and balance of youth swimmers. J Hum Kinet 2018;62(1):91—102, http://dx.doi.org/10.1515/hukin-2017-0161.
[33] Beach ML, Whitney SL, Dickoff-Hoffman SA. Relationship of shoulder flexibility, strength, and endurance to shoulder pain in competitive swimmers. J Orthop Sports Phys Ther 1992;16(6):262, http://dx.doi.org/10.2519/jospt.1992.16.6.262.
[34] Sadowski J, Mastalerz A, Gromisz W. Transfer of dry-land resistance training modalities to swimming performance. J Hum Kinet 2020;74(1):195—203, http://dx.doi.org/10.2478/hukin-2020-0025.
[35] Fone L, van den Tillaar R. Effect of different types of strength training on swimming performance in competitive swimmers: a systematic review. Sports Med Open 2022;8(1):19, http://dx.doi.org/10.1186/s40798-022-00410-5.
[36] Naczk M, Lopacinski A, Brzenczek-Owczarzak W, Arlet J, Naczk A, Adach Z. Influence of short-term inertial training on swimming performance in young swimmers. Eur J Sport Sci 2017;17(4):369—77, http://dx.doi.org/10.1080/17461391.2016.1241304.
[37] Dominguez-Castells R, Izquierdo M, Arellano R. An updated protocol to assess arm swimming power in front crawl. Int J Sports Med 2013;34(4):324—9, http://dx.doi.org/10.1055/s-0032-1323721.
[38] Thng S, Pearson S, Keogh JWL. Pushing up or pushing out-an initial investigation into horizontal- versus vertical-force training on swimming start performance: a pilot study. PeerJ (San Francisco, CA) 2021;9:e10937, http://dx.doi.org/10.7717/peerj.10937.
[39] García-Pallarés J, Sánchez-Medina L, Carrasco L, Díaz A, Izquierdo M. Endurance and neuromuscular changes in world-class level kayakers during a periodized training cycle. Eur J Appl Physiol 2009;106(4):629—38, http://dx.doi.org/10.1007/s00421-009-1061-2.
[40] Sammoud S, Negra Y, Bouguezzi R, Hachana Y, Granacher U, Chaabene H. The effects of plyometric jump training on jump and sport-specific performances in prepubertal female swimmers. J Exerc Sci Fitness 2021;19(1):25—31, http://dx.doi.org/10.1016/j.jesf.2020.07.003.
[41] Potdevin F, Alberty M, Chevutschi A, Pelayo P, Sidney M. Effects of a 6-week plyometric training program on performances in pubescent swimmers. J Strength Cond Res 2011;25(1):80—6, http://dx.doi.org/10.1519/JSC.0b013e3181fef720.
[42] Veliz R, Suarez-Arrones L, Requena B, Haff G, Feito J, Sáez de Villarreal E. Effects of in-competitive season power-oriented and heavy resistance lower-body training on performance of elite female water polo players. J Strength Cond Res 2015;29(2):458—65, http://dx.doi.org/10.1519/JSC.0000000000000643.
[43] Morouço P, Neiva H, González-Badillo J, Garrido N, Marinho D, Marques M. Associations between dry land strength and power measurements with swimming performance in elite athletes: a pilot study. J Hum Kinet 2011;29A(Special Issue):105—12, http://dx.doi.org/10.2478/v10078-011-0065-2.
[44] Sadowski J, Mastalerz A, Gromisz W, Jówko E, Buszta M. The effects of swimming and dry-land resistance training programme on non-swimmers. Pol J Sport Tourism 2015;22(1):35—40, http://dx.doi.org/10.1515/pjst-2015-0011.
[45] Häkkinen K, Alen M, Kraemer WJ, Gorostiaga E, Izquierdo M, Rusko H, et al. Neuromuscular adaptations during concurrent strength and endurance training versus strength training. Eur J Appl Physiol 2003;89(1):42—52, http://dx.doi.org/10.1007/s00421-002-0751-9.
[46] Eskiyecek CG, Gül M, Uludağ B, Gül GK. The effect of 8-week core exercises applied to 10—12 age male swimmers on swimming performance. Int J Appl Exerc Physiol 2020;9(3):213—20, http://dx.doi.org/10.26655/IJAEP.2020.3.22.
[47] Ji M, Yoon J, Song K, Oh J. Effect of dry-land core training on physical fitness and swimming performance in adolescent elite swimmers. Iran J Public Health 2021;50(3):540—9, http://dx.doi.org/10.18502/ijph.v50i3.5595.
[48] Kibler WB, Press J, Sciascia A. The role of core stability in athletic function. Sports Med (Auckland) 2006;36(3):189—98, http://dx.doi.org/10.2165/00007256-200636030-00001.
[49] Willardson JM. Core stability training: applications to sports conditioning programs. J Strength Cond Res 2007;21(3):979—85, http://dx.doi.org/10.1519/00124278-200708000-00054.

[50] Jürimäe J, Haljaste K, Cicchella A, Lätt E, Purge P, Leppik A, et al. Analysis of swimming performance from physical, physiological, and biomechanical parameters in young swimmers. Pediatr Exerc Sci 2007;19(1):70—81, http://dx.doi.org/10.1123/pes.19.1.70.
[51] Nasirzade A, Sadeghi H, Sobhkhiz A, Mohammadian K, Nikouei A, Baghaiyan M, et al. Multivariate analysis of 200-m front crawl swimming performance in young male swimmers. Acta Bioeng Biomech 2015;17(3):137—43, http://dx.doi.org/10.5277/abb-00160-2014-03.
[52] Amaro NM, Marinho DA, Marques MC, Batalha NP, Morouço PG. Effects of dry-land strength and conditioning programs in age group swimmers. J Strength Cond Res 2017;31(9):2447—54, http://dx.doi.org/10.1519/JSC.0000000000001709.
[53] Arede J, Ferreira AP, Gonzalo-Skok O, Leite N. Maturational development as a key aspect in physiological performance and national-team selection in elite male basketball players. Int J Sports Physiol Perform 2019;14(7):902—10, http://dx.doi.org/10.1123/ijspp.2018-0681.