Swim-Specific Resistance Training: A Systematic Review

Borja Muniz-Pardos,[1] Alejandro Gomez-Bruton,[1,2,3,4] Angel Matute-Llorente,[1,2,3,4] Alex Gonzalez-Aguero,[1,2,3,4] Alba Gomez-Cabello,[1,2,3,4,5] Oliver Gonzalo-Skok,[6] Jose A. Casajus,[1,2,3,7] and German Vicente-Rodriguez[1,2,3,4]

[1]GENUD (Growth, Exercise, NUtrition and Development) Research Group, Department of Physiatry and Nursing, University of Zaragoza, Zaragoza, Spain; [2]Physiopathology of Obesity and Nutrition Networking Biomedical Research Center (CIBERObn), Madrid, Spain; [3]Agro-alimentary Institute of Aragon -IA2- (CITA-University of Zaragoza), Zaragoza, Spain; [4]Department of Physiatry and Nursing, Faculty of Health and Sports Science (FCSD), University of Zaragoza, Zaragoza, Spain; [5]Defense University Center, Zaragoza, Spain; [6]Faculty of Health Sciences, San Jorge University, Zaragoza, Spain; and [7]Department of Physiatry and Nursing, Faculty of Health Sciences (FCS), University of Zaragoza, Zaragoza, Spain

Abstract

Muniz-Pardos, B, Gomez-Bruton, A, Matute-Llorente, A, Gonzalez-Aguero, A, Gomez-Cabello, A, Gonzalo-Skok, O, Casajus, JA, and Vicente-Rodriguez, G. Swim-specific resistance training: A systematic review. *J Strength Cond Res* 33(10): 2875–2881, 2019—The purpose of this systematic review was to determine which type of swim-specific training is most beneficial to enhance swimming performance and to determine which specific strength- or power-related tests better predict swimming performance. A search was conducted on PubMed, Cochrane Plus, and SPORTDiscus up to June 2018. Studies were distributed into 2 main categories: swim-specific dry land resistance training (SDLRT) and specific in-water swimming power training (SSWPT). From 1,844 citations, 25 met the inclusion criteria. It was determined that SSWPT was the most appropriate method to improve swimming performance, with tethered swimming protocols being the most studied and effective. In addition, SDLRT was a competent method to enhance swimming performance, and specifically, the inclusion of inertial training might evoke greater improvements in both strength/power capacities and swimming performance, than traditional resistance training. In conclusion, tether forces showed the greatest associations with swimming performance, although the efficacy of tethered swimming as an SSWPT method is yet to be confirmed. Further research should focus on the effects of SDLRT to verify the greater transfer of dry land resistance practices to swimming performance, with inertial training being potentially more beneficial than traditional resistance training.

Key Words: swimmers, specific training, performance, dry land power, swimming power

Introduction

Swimming is a popular sport in Europe and across other continents. The National Institute of Statistics and Economic Studies in France reported that swimming was ranked as the 11th most practiced sport with 300,900 federative licenses (42). Statistics from Denmark reported that swimming was the second most practiced sport among children (23), and similar patterns have been seen in children from Australia (5). After this increasing success, the number of publications concerning "swimming" and "training" has considerably risen in the past decade (105 studies were published in the year 2008, and 211 were published in 2018, as reported by PubMed). For this reason, it is relevant to provide coaches and swimming specialists with an up-to-date review related to optimal training practices to improve swimming performance.

A recent review identified inconsistencies among studies focusing on nonspecific resistance training interventions in swimmers (31), as some studies demonstrated positive effects, while others found that gains in strength were not transferred to the propulsive forces used during swimming. A positive transfer occurs when the resistance training improves the muscle activation patterns required in the execution of the sport skill (9). Consequently, the inclusion of sports-specific resistance practices in the swimmer's periodization is crucial. It is worth noting that all training adaptations are "specific" to the stimulus applied, and these adaptations are determined by different elements such as the muscle group trained, the range of motion, or the speed of movement (1). In swimming, the muscle strength from the upper limbs provides approximately 75% of the energy required for an efficient propulsive force during front crawl (40). The muscle strength from the lower body has been shown to contribute only modestly to the propulsive forces, with a greater influence during the start and turn phases (25).

There are previous systematic reviews (4,10,31) investigating different strength/power interventions on swimming performance, but none of them have focused on the effects of swim-specific resistance training (performed on either dry land or in-water) (45). These systematic reviews demonstrated the role of muscle strength in swimming, finding a wide variety of strength training protocols to maximize swimming performance (e.g., free-weight training, swimming, resistance training, or plyometric training). Nevertheless, 2 of these 3 reviews (4,31) highlighted that studies with high-quality methodologies are lacking, making

Address correspondence to Dr. German Vicente-Rodriguez, gervicen@unizar.es.

Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site (http://journals.lww.com/nsca-jscr).

Journal of Strength and Conditioning Research 33(10)/2875–2881

comparisons between them difficult. For the present systematic review, we perform a comprehensive study of the existing literature focusing on swim-specific resistance training methods. This would provide coaches with an accurate set of practical guidelines to enhance their strength coaching regimes. Thus, the aims of this systematic review were to determine which type of swim-specific interventions is more suitable for the enhancement of swimming performance and to define the swim-specific strength/power parameters that are better associated with swimming performance in adolescent and young adult swimmers.

Methods

Experimental Approach to the Problem

This study was performed following the systematic review methodology proposed in the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement (27). Studies were identified by searching within the electronic databases (PubMed, SPORTDiscus, and Cochrane Plus), reference lists, and consultation with experts in the field. The search was conducted up to and including the June 1, 2018. The key words used in the search were "swimming," "muscle strength," and "athletic performance." The specific search strategy for PubMed was: ("Muscle Strength"[Mesh]) OR (("Athletic Performance"[Mesh]) AND "Swimming"[Mesh]) with the additional filter of "Humans." For SPORTDiscus, the search was ((DE "MUSCLE strength") OR (DE "PERFORMANCE")) AND (DE "SWIMMING"), and finally, the search strategy for Cochrane Plus was ((Muscle Strength) OR (Athletic Performance)) AND (Swimming).

Inclusion Criteria

The types of studies included in the present systematic review were longitudinal, randomized, or nonrandomized controlled trials, studying the effects of swim-specific resistance training programs on swimming performance. Cross-sectional studies evaluating the relationship between swim-specific strength/power parameters and swimming performance were also included. In addition, the types of subjects (following PubMed criteria) recruited were adolescents or young adults, all of which were competitive swimmers.

Exclusion Criteria

Studies in languages other than English, unpublished data, or studies involving triathletes, divers, or others who are not competitive swimmers were excluded from the present systematic review. Studies focusing on parameters other than swim-specific strength/power-related interventions or assessments (swimming technique, rehabilitation, physiological parameters, or respiratory muscle training) and studies of which power assessments or interventions used nonspecific ergometers (e.g., Wingate test) were also excluded. Cross-sectional studies evaluating strength values without considering any kind of swimming performance or vice versa and training interventions not related to either strength or power training were not included. Finally, training programs only assessing strength changes, without considering swimming performance enhancements, or vice versa, were excluded.

Quality Assessment

The articles included in this systematic review were assessed using 2 different tools. For cross-sectional studies, the Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies proposed by the National Heart, Lung, and Blood Institute (33) was used, grading articles on a scale of 14 points. For experimental studies, the Physiotherapy Evidence Database (PEDro) scale (26) was used, classifying articles on a checklist composed of 11 items. Two separate researchers evaluated the quality of the studies independently.

Type of Studies

The articles selected for this review were distributed into 2 categories: swim-specific dry land resistance training (SDLRT) and specific in-water swimming power training (SSWPT).

1. Swim-specific dry land resistance training: The studies included in this category were those including SDLRT through specific exercises, similar to the movement pattern used during swimming actions (e.g., training on the biokinetic swim bench or weight training from a swim-specific position).
2. Specific in-water swimming power training: The articles included in this category used tethered swimming, active drag swimming, or velocity through a perturbation method to improve swimming performance.

Results

Included Studies

Searches identified 1,844 potentially relevant articles. Following the review of titles and abstracts and excluding the duplicates, the total was reduced to 77 relevant manuscripts. Of these articles, 25 met the selection criteria and were included in this systematic review (Figure 1).

Regarding the 25 articles that met the inclusion criteria, 13 were cross-sectional studies evaluating the relationship between swimming performance and swim-specific dry land variables (strength/power during these actions) and SSWPT (tethered swimming, active drag, and passive drag) variables (Table 1).

Twelve of the 25 included articles were intervention studies assessing the effect (acute or chronic) of different swim-specific protocols on swimming performance (Table 2), such as swim-specific postactivation potentiation (PAP), training on the biokinetic bench, or swim-specific inertial training.

Quality Assessment

Scores of the Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies ranged from 3 to 5 of a maximum of 14 points (see Table 1, Supplemental Digital Content 1, http://links.lww.com/JSCR/A144), except 1 study that only reached 1 point (2). Some of the criteria assessed were not applicable due to the type of variables measured (exposures that cannot vary in amount or level, exposures measured only once over time or blinding subjects, therapists, or assessors). Furthermore, some points were not reported in most of the studies, such as the participation rate of eligible persons or loss to follow-up after baseline.

Scores of the PEDro scale ranged from 4 to 6 of a maximum of 11 points (see Table 2, Supplemental Digital Content 2, http://links.lww.com/JSCR/A145). These scores are relatively good, taking into account that some exercise protocols such as tethered swimming or biokinetic power training do not allow for blinding subjects or blinding therapists. Furthermore, blinding of the

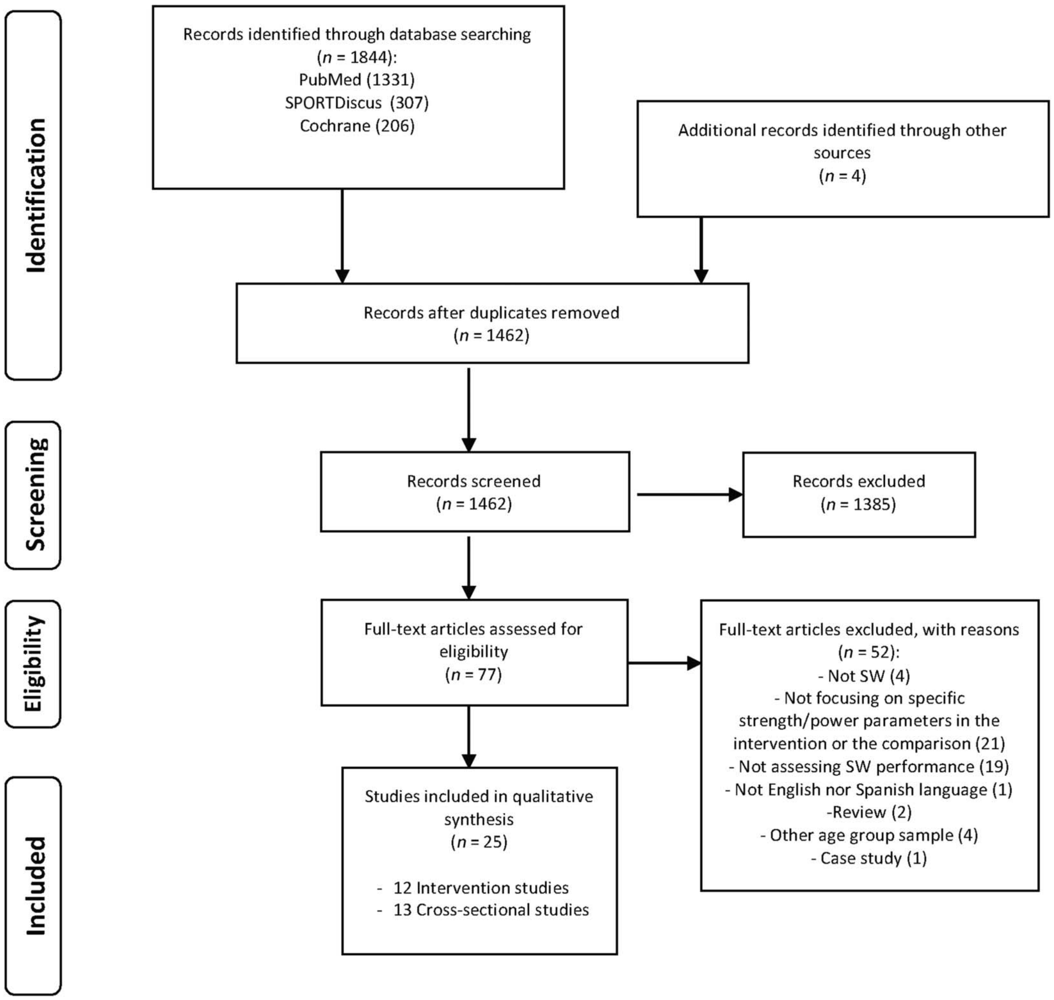

Figure 1. Flowchart. SW = swimmers or swimming.

assessors and concealed allocation were 2 variables that were poorly reported in most of the selected studies.

Discussion

The studies examining the association between SDLRT and swimming performance have changed their research orientations over time, with varying outcomes of interest and protocols across the past 30 years. Up to 2005, most of the studies approached the assessment of dry land power mainly through biokinetic ergometers, whereas SDLRT through swim-specific movement patterns has been a category of special interest in the past decade.

Concerning the training on biokinetic ergometers, the swimmer lies on a sliding bench with a small incline, arms extended over his/her head, and hands secured in hand paddles (10). This device was conceived to isolate and mimic the specific arm movement used during swimming (40). Roberts et al. (36) developed the first experiment using this device with male swimmers, finding no effects of 10 weeks of biokinetic resistance training on the swimming bench on 100-yard performance (91.44 m). This may be because the biokinetic training was applied during the competitive phase of the season, where the training intensity is notably increased. It is likely that this higher intensity would have attenuated the response to the additional biokinetic stimulus (36). Similarly, Sadowski et al. (37) found no effects of training with a similar ergometer on 25-m swimming performance. In this case, the lack of positive results might be related to the different stroke frequencies observed during swimming when compared with the frequencies on the ergometer (7).

These results are in agreement with previous cross-sectional findings (19), reporting that dry land power as measured on the swim bench was not associated with 25-yard swimming performance (22.86 m). Notably, the swimmers in this study were highly trained (with a power output above 400 W) which may account for some of the lack of association. As previously observed (39), the relationship between dry land power and swimming performance is not linear when a power output is very high (~500 W). In conclusion, factors other than power are more important in strong swimmers, such as more efficient biomechanics or a reduction of body drag. Although the swim bench can adopt similar movements to those performed while swimming, it might not reproduce the biomechanical requirements in the water (e.g., propulsive phase). Nevertheless, there are several researchers who have found a positive relationship between dry land power on the swim bench and swimming performance in cross-sectional studies (8,40,41). However, these studies were not prospective; they only describe an association and not a cause-effect relationship (4). Therefore, it can be concluded that swim bench training is an ineffective method to improve swimming

Journal of Strength and Conditioning Research™

Table 1
Cross-sectional studies included in the systematic review (*n* = 13).*

Article	Age (y)	Level	*N* (males)	Variables	Outcomes
Kalva-Filho et al. (21)	18.0 ± 2.0	Regional to National	9 (5)	*S(50)*, *S(100)*, *S(200)*, SWP (3 minutes all-out tethered SW)	Significant correlation between mean tether F and all distances' performance. Higher correlations with longer distances.
Santos et al. (38)	21.6 ± 4.8	Competitive SW	21 (NS)	*S(200) SWP* (tethered SW).	Positive relationship between PPO (tethered SW) and *S(200)*.
Loturco et al. (24)	17.0 ± 0.7	National	10 (10)	*S(50)*, *S(100)*, *S(200)*, SWP (tethered SW).	Positive relationship between tether F and *S(50), S(100).*
Morouço et al. (30)	17.2 ± 2.7	National and International	34 (34)	*S(50)*, SWP (tethered SW).	Positive relationship between SWP and *S(50).*
Papoti et al. (34)	Ms (12.5 ± 0.8) Fs (16.0 ± 1.0)	Trained SW	12 (9)	*S(100)*, *S(200)*, *S(400)*. SWP (tethered SW).	Positive relationship between tether F and *S(100)*, *S(200)*, *S(400)* (decreasing with distance).
Dominguez-Castells et al. (12)	22.1 ± 4.3	National	18 (18)	*S(25)*, SWP (Tethered SW).	Positive relationship between tether F and *S(25).*
Morouço et al. (28)	Ms (19.0 ± 2.8) Fs (15.3 ± 1.7)	International	32 (20)	*S(50)*, *S(100)*, *S(200)* in all 4 strokes. SWP (tethered SW).	Positive relationship between absolute values of tether F and *S(50)*, *S(100)*, *S(200)* in all strokes except for the breaststroke *S(200).*
Morouço et al. (29)	14.9 ± 0.7	National	10 (10)	*S(50)*, SWP (tethered SW: whole body, arms only, legs only).	Positive relationship between *S(50)* and F production (arms only).
Arellano et al. (2)	21.4 ± 2.2	National	11 (6)	*S(5)*, DLP (CMJ and simulated jump off the block).	Positive relationship between horizontal F off the block, *S(5)* time, and *S(5)* mean velocity.
Shimonagata et al. (41)	21.5 ± 1.0	Competitive SW	11 (5)	*S(100)*, *S(25)*, SWP (semitethered SW), DLP (biokinetic SW bench).	Positive relationship between both distance performance and both SWP and DLP.
Bradshaw and Hoyle (8)	NS	University students	7 (7)	*S(25)* full stroke, arms only, and legs only. DLP (biokinetic SW bench).	Positive relationship between arm power and *S(25)* (full stroke and arms only SW).
Johnson et al. (19)	18.0 ± 2.0	Collegiate and high school SW	29 (29)	*S(22.86)*, SWP (tethered SW), DLP (biokinetic SW bench).	Positive relationship between *S(22.86)* and PPO (tethered SW) and DLP (SW bench).
Sharp et al. (40)	15.2 ± 0.3	Competitive SW	40 (18)	*S(22.86)*[a], DLP (biokinetic SW bench).	Positive relationship between DLP and *S(22.86)*[a]

*CMJ = countermovement jump; DLP = dry land power; F = force; Fs = females; Ms = males; NS = not specified; PPO = peak power output; *S("number")* = sprint (meters); *S("number")*[a] = yards converted to meters; SW = swimmers or swimming; SWP = swimming power.

performance, given that none of the 2 interventions presented positive effects.

After this period of interest in the effects of biokinetic bench training, recent research has focused on the effects of dry land strength training using swim-specific resistance exercises. Aspenes et al. (3) observed that an 11-week upper-body strength training on a specific apparatus simulating the butterfly movement resulted in a 1.4% improvement in 400-m performance. This improvement was accompanied by a 6.9% enhancement in maximal swimming force (tethered swimming) and a 20.3% improvement in maximum dry land strength (bilateral shoulder extension in a cable cross-over apparatus), concluding there was a positive impact of this SDLRT in performance, swimming force, and dry land strength.

Cuenca-Fernandez et al. (11) were the first to compare the effects of a traditional strength PAP protocol (3 repetitions of lunge exercise) to a swim-specific PAP stimulus (3 repetitions in a Yo-Yo squat flywheel device, modeling the starting position on the block) on swimming block start performance, in comparison with a control condition (swimming block start after traditional swimming warm-up). The Yo-Yo squat flywheel device uses a wheel to generate a moment of inertia at the end of the concentric phase of the movement. When this point is reached, there is a strong eccentric contraction, which has been demonstrated to evoke greater improvements in muscle peak power than traditional weight training (32). The authors stated that the Yo-Yo squat protocol was the most effective PAP stimulus to enhance both 5- and 15-m swimming block start performance (5.7 and 2.4%, respectively) due to the similarity in the movement pattern.

Similarly, a recent study (32) examined the efficacy of an inertial training method in 14 national-level swimmers. The authors performed a 4-week upper-body inertial training using the Inertial Training Measurement System (ITMS; a novel device which allows for the performance of specific movements (32)). Both muscle force and power were determined using the ITMS. The authors reported positive effects in muscle force, power, and 100-m swimming performance (improvements of 12.8, 14.2, and 1.8%, respectively), in comparison with the control group (traditional swimming training). Subsequently, these authors concluded that specific inertial training may provide greater benefits than traditional strength training.

Toussaint and Vervoorn (43) were the first researchers to study the effects of an SSWPT on freestyle swimming performance. They implemented a new training device derived from the MAD system (system to Measure Active Drag (18)), providing the swimmer with 16 submerged fixed push-off points along the length of a swimming pool. The force applied on these fixed points was measured through a force transducer placed at 1 end of the swimming pool, measuring maximal force, velocity, and power output. The authors evaluated the effects of a 10-week training program with this device on 50-, 100-, and 200-m swimming performance, in 30 competitive swimmers. The intervention group performed sprints using the aforementioned apparatus, with the control group performing traditional sprints. The results demonstrated a positive effect on force, power, and swimming velocity on the MAD system, with additional improvements in 50-

Table 2

Intervention studies included in the systematic review (n = 12).*

Article	Age (y)	Level	*N* (males)	CG [*M*]	EG [*M*]	Measurements	Outcomes	Effect
Kojima et al. (22)	13.6 ± 1.1	Regional	24 (12)	[12] SW T only (10 × 15 sprints)	[12] 10 weeks, 2 sess·w^{-1}. SWP program (tethered 10 × 10 sprints).	*S(50)*, SWP (tethered SW*).*	No differences between groups in the effects on *S(50)* nor tethered SWP.	Chronic
Papoti et al. (35)	16.0 ± 1.5	National	21 (12)	[11] SW T only	[10] 7 weeks, 5 sess·w^{-1}. SWP program (50% of the sets during each sess using tethered SW).	*S(50), S(100), S(400),* SWP (tethered SW).	No effects of the SWP program neither on SW times nor tethered SWP.	Chronic
Naczk et al. (32)	15.8 ± 0.4	National	14 (10)	[7] SW T only	[7] 4 weeks, 3 sess·w^{-1}. DLS program (inertial T using: 4 sets of 15 seconds)	*S(50), S(100-butterfly), DLP* (inertial training device: max power in a 10-second maximal test)	Positive effects on *S(50)*, *S(100-butterfly)*, and DLP test.	Chronic
Cuenca-Fernandez et al. (11)	17–23	National	14 (10)	Traditional SW WU	3RM lunge PAP WU. 4 reps Yo-Yo squat WU (position used in the block in an SW start).	*S(15)* and *S* (5) 8 minutes after each WU/PAP.	Positive effects of PAP on *S(5)* (for both PAP protocols) and *S(15)* (only for the Yo-Yo squat PAP).	Acute
Hancock et al. (16)	19–22	Collegiate SW	30 (15)	[30] Traditional SW WU	[30] PAP (4 × 10-m tethered SW).	*S(100)* 6-minute after WU/PAP.	Positive effects of PAP on *S(100).*	Acute
Sadowski et al. (37)	EG (14.0 ± 0.5) CG (14.1 ± 0.5)	Young SW	26 (26)	[12] SW T only	[14] 6 weeks, 3 sess·w^{-1}: DLP T (simulated SW on an ergometer; 6 × 50´) before SW T.	DLS (ISOM shoulder flexion), *S(25)* driven by upper extremities, F during tethered SW.	Positive effect of DLP T on tethered SW F.	Chronic
Dragunas et al. (13)	EG (19.3 ± 0.9) CG (19.0 ± 1.8)	Regional-National	18 (10)	[9] 5 weeks, 3 sess·w^{-1}. Interval T: 3 × 45.72 m[a] + 4× (4× 22.86 m[a] + 16 × 22.86 m[a]	[9] 5 weeks, 3 sess·w^{-1}. Same T than CG but wearing a drag suit.	*S(50)*, 6 × 50-m all-out times with and without drag suit on 2 separate days (*r* = 10 min).	No differences between groups in *S(50)* after the T period.	Chronic
Aspenes et al. (3)	EG (17.5 ± 2.9) CG (15.9 ± 1.1)	Collegiate	20 (8)	[9] SW T only	[11] 11 weeks, 2 sess·w^{-1}. 4 × 4 min SW intervals + 3 × 5RM (cable crossover device)	*S(50)*, *S(100)*, *S(400)*, SWP (tethered SW).	Positive effects of combined strength and interval SW T on *S(400)* and tethered SW F.	Chronic
Girold et al. (15)	16.5 ± 3.5	National	21 (10)	[7] 12 weeks, 6 sess·w^{-1}. SW T only	12 weeks, 6 sess·w^{-1}. [7] Dry land T with barbells. 1.5 h·w^{-1} extra. [7] RAS T with elastic tubes. 1.5 h·w^{-1} extra.	*S(50)* before, at week 6 and after intervention.	Positive effects of both dry land and RAS T on *S(50)* only at week 12.	Chronic
Girold et al. (14)	16.5 ± 3.0	Regional to national	37 (16)	[11] SW T only + 6 × 50-m sprints.	3 weeks, 3 sess·w^{-1}. [11] Assisted T with elastic tubes. [15] Resisted T with elastic tubes.	*S(100).*	Positive effects of both RAS T methods on *S(100)* (Greater in Resisted *G*).	Chronic
Roberts et al. (36)	19.1 ± 2.1	National	16 (16)	[NS] SW T only	[NS] 10 weeks, 3 sess·w^{-1}. Biokinetic resistance T on SW bench.	*S(91.44)*[a], PPO and fatigue test (biokinetic SW bench).	No positive effects of biokinetic resistance T on *S(91.44)*[a] nor PPO on the biokinetic swim bench.	Chronic
Toussaint and Vervoorn (43)	NS	National	22 (16)	[11] SW T only (8 sess·w^{-1}; 4,500 m·sess^{-1})	[11] 10 weeks, 3 sess·w^{-1} of sprints using POP system (16 POP, mounted below the water surface).	*S*(50), *S*(100), *S*(200). Max force, V and power from the POP system.	Positive effect of intervention on max power and velocity in the POP system, *S*(50), *S*(100) and *S*(200).	Chronic

*CG = control group; DLP = dry land power; EG = experimental group; F = force; G = group; ISOM = isometric; NS = not specified; PAP = postactivation potentiation; POP = push-off points; r = recovery; RAS = resisted and assisted sprint; RM = repetition maximum; *S*("number") = sprint (meters); *S*("number")[a] = yards converted to meters; sess = sessions; SW = swimming or swimmers; SWP = swimming power; T = training; V = velocity; WU = warm-up.

and 200-m performance in the intervention group. The high specificity of this method and the greater force applied on every push-off point in comparison with normal swimming seemed to favor a positive transfer to swimming performance (43).

After this pioneering study exploring the active drag training paradigm, others studied different active drag training techniques. Girold et al. (14) analyzed the effects of a 3-week tethered swimming intervention (swimming while being held by a flexible restraining device; e.g., tubes or ropes) on 100-m swimming performance in 37 competitive swimmers. They compared 3 different interventions: resisted tethered swimming with elastic bands (resistance against direction of motion; 6 × 30-second sprints), assisted tethered swimming with elastic bands (pull force in the direction of motion; 12 × 25-m sprints), and traditional swimming (control group: 6 × 50-m sprints without elastic bands). Although the authors witnessed swimming improvements in the resisted group, this improvement was not accompanied with strength enhancements but a higher stroke rate. These authors performed a longer and more rigorous research (15), examining the effects of a 12-week resisted and assisted sprint (RAS) training on 50-m performance in 21 adolescent swimmers. The subjects involved in the RAS group showed an improvement of 2.3% in swimming performance, whereas the control group only showed minimal changes (0.9%). This study showed that the stroke depth and the stroke rate were the best predictors of the 50-m performance in the RAS group, confirming their previous findings.

By contrast, a recent investigation (35) showed no effects of a 7-week tethered swimming program in 21 adolescent swimmers. The differences between the control and intervention group in 100-, 200-, and 400-m times and tethered swimming force did not differ after the training period. However, the intervention group increased their lactate production capacity, speculating that the inclusion of tethered swimming in the training routine may increase the anaerobic glycolysis contribution during exercise, despite the lack of improvement observed in swimming force. Kojima et al. (22) showed no significant differences between the intervention and the control group after a 10-week resisted training intervention on 50-m swimming performances in adolescent swimmers. These authors suggested that the level of maturation of the athletes might be a determinant confounding factor in the ability of an adolescent swimmer to respond to any specific training load.

Dragunas et al. (13) studied the effects of training with a drag suit on 50-m performance. Eighteen regional- and national-level young swimmers were equally divided into the control group and drag suit-trained (DST) group. For 5 weeks, the swimmers involved in the DST group performed the same training as the control group, but while wearing the drag suit (a total training volume of 950 $m \cdot wk^{-1}$). The authors showed no significant changes in swimming performance, although the DST group was more effective at maintaining technique than the traditional training method. The limitations of this study, however, make it difficult to interpret these results. For example, 30 swimmers were initially recruited, but the high dropout ($n = 18$) reduced the statistical power. Furthermore, the use of manual timing (44) and the lack of control over the training regimen may have biased the final results (13).

After these studies focusing on the chronic effect of different SSWPT interventions, Hancock et al. (16) investigated the acute effect of a PAP protocol on swimming performance, when compared with the control condition in 30 young swimmers. Their protocol consisted of 4 repetitions of 10-m all-out tethered swimming 6 minutes before a 100-m maximal effort. The PAP load was individually prescribed, taking into account the swimmers' best time in 100 m (t) and their lean body mass (LBM), using the formula: load = $0.2 \cdot LBM/(100 \cdot t^{-1})$. The results showed a significant improvement in 100-m performance for the PAP condition, compared with the control condition (0.86% enhancement). Although it is well known that PAP increases the rate of force development (17,20), further analyses through muscle biopsies would confirm the true effect of PAP on lower-body explosive power (i.e., confirming an increased phosphorylation of regulatory myosin light chains (16)).

Additional cross-sectional studies support the use of swimming power assessments through tethered swimming (12,19,21,24,28–30,34,38), semitethered swimming (41), and active drag (towing a perturbation buoy) (6) to predict swimming performance in distances ranging from 25 yards (22.86 m) to 400 m.

The association between swimming power and swimming performance seems evident since the 11 existing cross-sectional studies reported positive associations. However, further interventions would be necessary to confirm the effectiveness of this specific training, as 4 interventions improved swimming performance (14–16,43), whereas 3 studies reported no effects (13,22,35). Despite the effective MAD system tested by Toussaint and Vervoorn (43), no other studies have used this methodology neither in intervention nor in cross-sectional studies, probably due to the high cost of this specific equipment.

In conclusion, the inertial training method seems more beneficial than traditional resistance training to improve swimming performance, although more research is needed to verify this. Although several studies showed cross-sectional associations between the biokinetic bench values and swimming performance, no training interventions have found improvements in swimming performance after biokinetic bench training. However, training on the MAD system seems to be the most effective method to improve the propulsive forces used in water and swimming performance. However, only 1 study investigated this system. Finally, tethered swimming as an effective SSWPT method to improve performance remains under debate due to the contrasting results.

The present systematic review has identified limited research using female swimmers, as well as elite-level swimmers, finding important methodological limitations in the training protocols susceptible to bias the results (analyzing male swimmers and female swimmers as a whole, not adjusting by maturity status or level of performance, or the lack of a control group). Finally, the literature search performed in the present systematic review identified an important lack of studies using breaststrokers, backstrokers, and butterfly swimmers.

Practical Applications

Research indicates that swim-specific resistance training is an effective method to improve specific muscle strength and swimming performance. Since this practice allows for direct transfer to sports performance, coaches should design training protocols as specific as possible, especially with regard to movement pattern. Based on a critical evaluation of the existing evidence, coaches and practitioners should consider inertial training as a method that potentially offers greater benefits on both strength development and swimming performance, than traditional free-weight training. Regarding the different SSWPT methods examined, further high-quality studies are needed to confirm the efficacy of tethered swimming as a method to improve swimming performance. Tethered swimming forces have shown to elicit the greatest relationship with swimming performance. Finally, training on the MAD system seems highly effective, although the high cost of this equipment may reduce its availability to most swimmers.

Acknowledgments

The authors declare no conflict of interest and do not have any financial disclosures. The authors thank Mr. Shaun Sutehall for his assistance in revising the English throughout the article.

References

1. American College of Sports Medicine. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Med Sci Sport Exerc* 41: 687–708, 2009.
2. Arellano R, Llana S, Tella V, Morales E, Mercade J. A comparison CMJ, simulated and swimming grab-start force recordings and their relationships with the start performance. In: *ISBS-Conference Proceedings Archive* (Vol. 1). Beijing, China: International Society of Biomechanics in Sports, 2005. pp. 923–926.
3. Aspenes S, Kjendlie PL, Hoff J, Helgerud J. Combined strength and endurance training in competitive swimmers. *J Sport Sci Med* 8: 357–365, 2009.
4. Aspenes ST, Karlsen T. Exercise-training intervention studies in competitive swimming. *Sport Med* 42: 527–543, 2012.
5. Australian Bureau of Statistics. *Sports and Physical Recreation: A Statistical Overview: Australia*. 2010. Available at: http://www.ausstats.abs.gov.au. Accessed June 6, 2018.
6. Barbosa TM, Morais JE, Marques MC, Costa MJ, Marinho DA. The power output and sprinting performance of young swimmers. *J Strength Cond Res* 29: 440–450, 2015.
7. Bollens E, Annemans L, Vaes W, Clarys JP. Peripheral EMG comparison between fully tethered and free front crawl swimming. In: *Swimming Science V* (Vol. 18). Ungerechts B, Wilke K and Reischle K, eds. Leipzig, Germany: Human Kinetics, 1988. pp. 173–182.
8. Bradshaw A, Hoyle J. Correlation between sprinting and dry land power. *J Swim Res* 9: 15–18, 1993.
9. Carroll TJ, Riek S, Carson RG. Neural adaptations to resistance training. *Sport Med* 31: 829–840, 2001.
10. Crowley E, Harrison AJ, Lyons M. The impact of resistance training on swimming performance: A systematic review. *Sport Med* 11: 2285–2307, 2017.
11. Cuenca-Fernandez F, Lopez-Contreras G, Arellano R. Effect on swimming start performance of two types of activation protocols: Lunge and YoYo squat. *J Strength Cond Res* 29: 647–655, 2015.
12. Dominguez-Castells R, Izquierdo M, Arellano R. An updated protocol to assess arm swimming power in front crawl. *Int J Sport Med* 34: 324–329, 2013.
13. Dragunas AJ, Dickey JP, Nolte VW. The effect of drag suit training on 50-m freestyle performance. *J Strength Cond Res* 26: 989–994, 2012.
14. Girold S, Calmels P, Maurin D, Milhau N, Chatard JC. Assisted and resisted sprint training in swimming. *J Strength Cond Res* 20: 547–554, 2006.
15. Girold S, Maurin D, Dugué B, Chatard JC, Millet G. Effects of dry-land vs. resisted- and assisted-sprint exercises on swimming sprint performances. *J Strength Cond Res* 21: 599–605, 2007.
16. Hancock AP, Sparks KE, Kullman EL. Postactivation potentiation enhances swim performance in collegiate swimmers. *J Strength Cond Res* 29: 912–917, 2015.
17. Hanson ED, Leigh S, Mynark RG. Acute effects of heavy- and light-load squat exercise on the kinetic measures of vertical jumping. *J Strength Cond Res* 21: 1012–1017, 2007.
18. Hollander AP, De Groot G, van Ingen Schenau GJ, et al. Measurement of active drag during crawl arm stroke swimming. *J Sport Sci* 4: 21–30, 1986.
19. Johnson RE, Sharp RL, Hedrick CE. Relationship of swimming power and dryland power to sprint freestyle performance: A multiple regression approach. *J Swim Res* 9: 10–14, 1993.
20. Jubeau M, Gondin J, Martin A, Van Hoecke J, Maffiuletti NA. Differences in twitch potentiation between voluntary and stimulated quadriceps contractions of equal intensity. *Scand J Med Sci Sport* 20: e56–62, 2010.
21. Kalva-Filho CA, Zagatto AM, da Silva ASR, et al. Relationships among the tethered 3-min all-out test, MAOD and swimming performance. *Int J Sport Med* 38: 353–358, 2017.
22. Kojima K, Brammer CL, Sossong TD, Abe T, Stager JM. In-water resisted swim training for age-group swimmers: An evaluation of training effects. *Pediatr Exerc Sci* 20: 1–8, 2017.
23. Laub TB, Pilgaard M. *Sports Participation in Denmark 2011*. Available at: https://www.kenniscentrumsport.nl/publicatie/?sports-participation-in-denmark-2011&kb_id=12031. Accessed March 21, 2018.
24. Loturco I, Barbosa AC, Nocentini RK, et al. A correlational analysis of tethered swimming, swim sprint performance and dry-land power assessments. *Int J Sport Med* 37: 211–218, 2016.
25. Lyttle A, Benjanuvatra N. Start right? A biomechanical review of dive start performance. Available at: http://www.coachesinfo.com/category/swimming/321/. Accessed December 18, 2017.
26. Maher CG, Sherrington C, Herbert RD, Moseley AM, Elkins M. Reliability of the PEDro scale for rating quality of randomized controlled trials. *Phys Ther* 83: 713–721, 2003.
27. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *Int J Surg* 8: 336–341, 2010.
28. Morouço P, Keskinen KL, Vilas-Boas JP, Fernandes RJ. Relationship between tethered forces and the four swimming techniques performance. *J Appl Biomech* 27: 161–169, 2011.
29. Morouço P, Neiva H, González-Badillo JJ, Garrido N, Marinho DA, Marques MC. Associations between dry land strength and power measurements with swimming performance in elite athletes: A pilot study. *J Hum Kinet* 29A: 105–112, 2011.
30. Morouço PG, Marinho DA, Keskinen KL, Badillo JJ, Marques MC. Tethered swimming can be used to evaluate force contribution for short-distance swimming performance. *J Strength Cond Res* 28: 3093–3099, 2014.
31. Muniz-Pardos B, Gomez-Bruton A, Matute-Llorente A, et al. Non-specific resistance training and swimming performance: Strength or power? A systematic review. *J Strength Cond Res*, 2019. Epub ahead of print.
32. 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* 17: 369–377, 2017.
33. National Heart, Lung, and Blood Institute. *Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies*. Bethesda, MD: National Institutes of Health, Department of Health and Human Services, 2014.
34. Papoti M, da Silva AS, Araujo GG, et al. Aerobic and anaerobic performances in tethered swimming. *Int J Sport Med* 34: 712–719, 2013.
35. Papoti M, da Silva AS, Kalva-Filho CA, et al. Tethered swimming for the evaluation and prescription of resistance training in young swimmers. *Int J Sport Med* 38: 125–133, 2017.
36. Roberts AJ, Termin B, Reilly MF, Pendergast DR. Effectiveness of biokinetic training on swimming performance in collegiate swimmers. *J Swim Res* 7: 5–11, 1991.
37. Sadowski J, Mastalerz A, Gromisz W, Niynikowski T. Effectiveness of the power dry-land training programmes in youth swimmers. *J Hum Kinet* 32: 77–86, 2012.
38. Santos KB, Bento PC, Pereira G, Rodacki AL. The relationship between propulsive force in tethered swimming and 200-m front crawl performance. *J Strength Cond Res* 30: 2500–2507, 2016.
39. Sharp RL. Muscle strength and power as related to competitive swimming. *J Swim Res* 2: 5–10, 1986.
40. Sharp RL, Troup JP, Costill DL. Relationship between power and sprint freestyle swimming. *Med Sci Sport Exerc* 14: 53–56, 1982.
41. Shimonagata S, Taguchi M, Miura M. Effect of swimming power, swimming power endurance and dry-land power on 100 m freestyle performance. In: Chatard JC, ed. Saint-Etienne, France: University of Saint-Etienne, 2003. pp. 391–396.
42. The National Institute of Statistics and Economic Studies. Licenses sports and other equity securities by federation approved in 2015. 2015. Available at: https://www.insee.fr. Accessed June 12, 2018.
43. Toussaint HM, Vervoorn K. Effects of specific high resistance training in the water on competitive swimmers. *Int J Sport Med* 11: 228–233, 1990.
44. Vicente-Rodriguez G, Rey-Lopez JP, Ruiz JR, et al. Interrater reliability and time measurement validity of speed-agility field tests in adolescents. *J Strength Cond Res* 25: 2059–2063, 2011.
45. Young WB. Transfer of strength and power training to sports performance. *Int J Sport Physiol Perform* 1: 74–83, 2006.