Strength Training for Swimmers: Scientific Basics and Practical Applications

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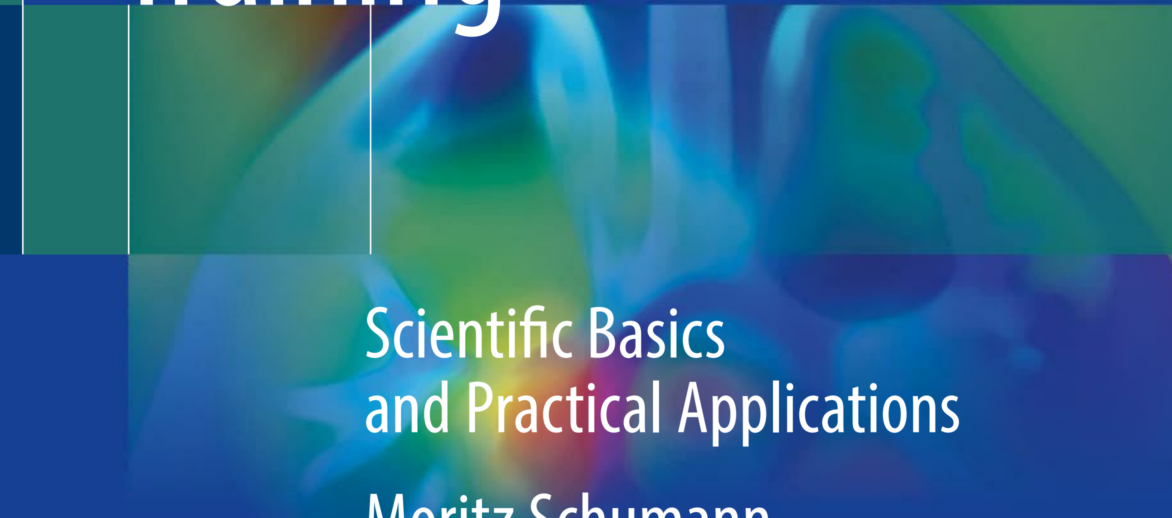
Concurrent Aerobic and Strength Training



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Strength Training for Swimmers

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Concurrent training is nowadays an integral part of most competitive swimmers' preparation process, as they often combine their long, mostly aerobic swimming sessions with some form of strength training, either on dry-land or in the water. Swimming events at World Championships range in duration between approximately 21 s in the men's 50 m freestyle and 5 h 15 min in the women's 25 km open water event. This huge range in distance and duration, along with the contribution to swimming performance of explosive actions such as starts and turns, makes the relative contribution of aerobic and anaerobic pathways to power production highly variable. Therefore, training to improve both muscle strength and aerobic endurance seems to be essential to enhance competitive swimming performance.

Interest of Strength Training for Swimmers

To achieve competitive success at national or international level, swimmers must include a year-round resistance training programme to either maintain or increase strength and power, improve movement patterns, and limit the risk of injury [1, 2]. The application of muscular force in swimming results in a horizontal displacement

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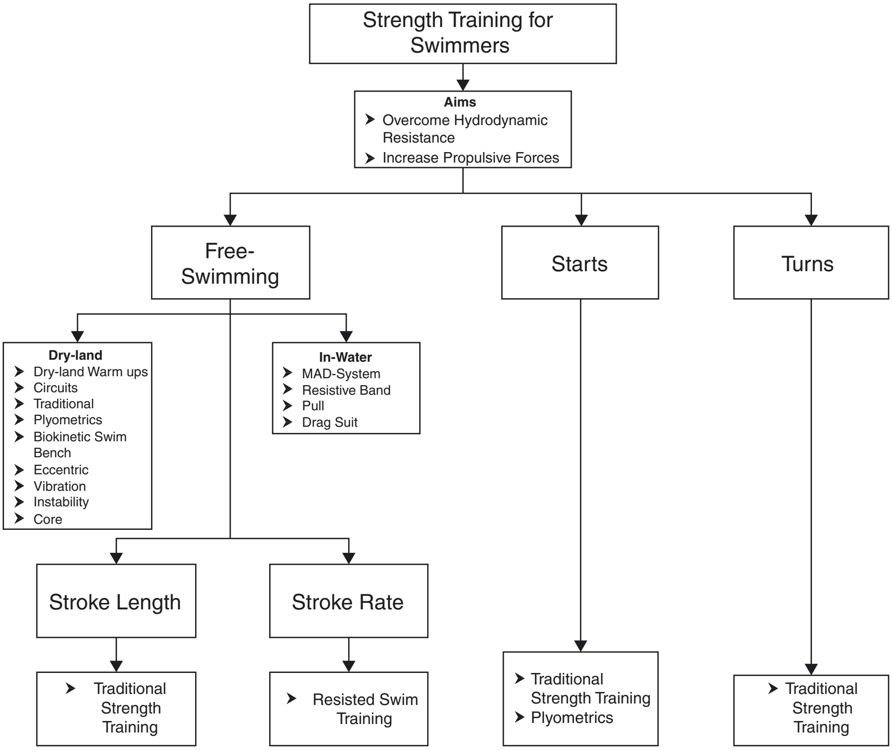

Fig. 25.1 Illustration of the strength training methods prescribed to improve swimming performance and results from the literature

of the athlete at a velocity proportional to the magnitude, direction, and duration of the resulting force. The main aim of the mechanical work performed by a swimmer is to overcome hydrodynamic resistance, which increases proportionally with the square of velocity, whereas the metabolic power required is proportional to the cube of the velocity. Therefore, any increase in swimming velocity demands a proportional increment of muscular force to overcome active drag and increase propulsive force, suggesting that muscular strength could be considered a performance determining factor in swimming [3].

Increments in muscular strength should theoretically translate into increased ability to generate propulsive force in the water, but technical aspects of swimming stroke mechanics will also determine the extent to which increased force transfers into faster swimming velocity [4–10] (Fig. 25.1). In this respect, it is important to keep in mind that strength training for swimmers should complement, not replace, sport-specific in-water training, and it should enhance, not hinder, the swimmer's in-water sessions by improving the quality of training, contributing to recovery and reducing the risk of overuse injury [2].

Impact of Strength and Power on Swimming Performance

Strength training is employed to manipulate the force-velocity curve and the ability to apply large amounts of muscular force under sport-specific conditions. A positive transfer to swimming performance should be achieved through improvements in both physiological and biomechanical parameters. Upper-body strength in particular is imperative in swimming, as most of the propulsive forces [11–13] and swimming velocity [11, 14–16] are generated by the upper-body musculature. Indeed, Carl et al. [17] reported a strong correlation between one repetition maximal lift (1RM) for the bench press, in-water force generation as measured during tethered swimming, and a timed 22.9 m swim. Such correlations were particularly relevant in male swimmers. Leg press 1RM, on the other hand, showed a weak correlation with swimming performance and did not correlate with tethered swimming force. Morouço et al. [18] assessed the mean power of the propulsive phase in three dry-land tests (squat, concentric phase of the bench press and latissimus pull down back), and analysed their associations with force production in water (mean force production during 30 s maximal effort tethered swimming in front crawl using whole body, arms only, and legs only) and swimming velocity in a maximal bout of 50 m front crawl. Mean propulsive power of bench press and latissimus pull down showed moderate–strong relationships with mean force production in whole body and arms only, whereas swimming performance was related with mean power of latissimus pull down back. The authors concluded that latissimus pull down back is the dry-land test most related with swimming performance, whereas bench press best related with force production in-water arms only, and work during counter-movement jump with tethered forces legs only. These and other similar findings [19] emphasized the need for separate evaluation of arms' and legs' force-velocity characteristics and the consideration of these measures in training design.

However, an increase in force generation capacities needs to be performed in a swimming-specific manner. Neuromuscular adaptations such as improved motor unit recruitment, synchronization, co-contraction, rate coding, intra- and inter-neuromuscular coordination, and neural inhibition have been thought to be responsible for an improvement in swimming performance. Whether a transfer-training method, based on a combination of dry-land weight training immediately followed by maximum velocity swimming could be a useful means to increase swimming power requires confirmation [20].

Pool swimming is comprised of three distinct phases: free swimming, starts, and turns (Fig. 25.1). The impact of strength training on free swimming performance has been widely researched. A recent review by Crowley et al. [21] reported that low volume, high velocity and/or force, and swim-specific strength training programmes showed a positive transfer to swimming performance, but the lack of high quality methodological studies using elite swimmers makes the literature hard to interpret. In addition, in spite of the similarities between the arm actions in dry-land swim simulations and sprint swimming, only the power measurements made in the water are specific to the propulsive forces of front crawl swimming. Besides, the power contribution from each limb [22, 23], as well as intra-cycle force production and power output vary during different propulsive phases of front crawl swimming [24, 25].

Starts

Swimming starts are comprised of the unique coordinative effort of reaction time, vertical forces, and horizontal forces. The key component of start performance is lower-body strength, which is strongly correlated to swimming start performance [26]. The peak velocity reached during jumps with external loads relative to body mass is a good indicator of swimming start performance [27], and swimmers that possess the capacity to generate high levels of force have the ability to swim faster to 10 m [28]. Indeed, elite swimmers generate higher horizontal and vertical impulses than non-elite counterparts [29]. Lower-body plyometric interventions have resulted in positive effects on swimming start performance [30–32], which also highlights the key role of lower-body strength and power for start performance.

Turns

Swimming turning literature is sparse and does not provide a clear insight into the benefits of strength training for turning performance. Reduced drag forces, high peak propulsive forces, and increased wall push-off time produce the fastest turn performance, i.e. 2.5 m on approach and push off [33]. Lyttle et al. [34] studied the net forces created when towing swimmers while gliding and kicking underwater to establish an appropriate speed for initiating underwater kicking, and the most effective gliding position and kicking technique to be applied after a turn (prone streamline glide, lateral streamline glide, prone freestyle kick, prone dolphin kick, lateral dolphin kick). The optimal range of speeds to begin underwater kicking to prevent energy loss from excessive active drag was 1.9–2.2 m/s, but no differences were found between the prone and lateral streamline glide positions or between the three underwater kicking techniques. Faster swimmers, however, show greater squat jump power, counter-movement jump height, vertical height, and velocity at push off [35]. Elite male and female swimmers also possess ~30–50% superior leg extensor strength/power characteristics during dry-land jumping (particularly unloaded squat jump peak velocity and power) and in-water turning tasks when compared to sub-elite counterparts [36]. Short-term ballistic training and maximal strength training can enhance leg extensor force characteristics and improve aspects of the push-off stage of the swim turn in elite swimmers [37]. A well-planned and executed strength and conditioning programme is therefore needed for emerging and elite swimmers to develop these qualities [36, 37].

Impact of Strength Training on Swimming Biomechanical Parameters

Swimming velocity is the product of stroke length and stroke rate and has an important role to play in improving swimming performance. Factors such as training, intensity, physiological capabilities, race distances, sex and swimming technique influence the relationship between stroke length and rate [38–40], and coaches often prescribe training to improve either of these technical parameters [41–43]. Unfortunately, no research to date has specifically looked at improving either stroke length or stroke rate through the application of strength training.

Stroke length maintains swimming propulsive forces in the horizontal direction, improves swimming efficiency, and determines swimming velocity [13, 44–50]. Although some studies suggest that low repetition and high force strength training induced an increase in stroke length [51, 52], others showed no significant increase [10, 53], so further investigation is warranted. Nevertheless, real-life examples show that swimmers achieving the fastest times in the world have the greatest stroke length, which requires high levels of strength. Stroke rate has a great impact on swimming velocity over shorter duration events, such as 50 m performance [10, 46, 49, 54]. A training intervention using resisted swims can improve 100 m swimming performance, as the swimmer has to produce sufficient propulsive forces to move forward by increasing stroke rate, rather than being pulled back by the resisted band. In addition, a faster second half of the 100 m swimming performance suggests that resisted swims improve muscular strength endurance [48].

Concurrent Training in Swimming

Berryman et al. [55] recently assessed the net effects of strength training on middle- and long-distance performance through a meta-analysis of the available literature. Results indicated that the implementation of a strength training programme was associated with moderate performance improvements in running, cycling, cross-country skiing, and swimming. Such performance benefits were mainly due to improvements in the energy cost of locomotion, maximal force, and maximal power. Maximal force training (sets of 1–5 repetitions of isoinertial contractions at 80% of 1RM or more) and a combination of methods produced greater benefits than submaximal (sets of 6–25 repetitions of isoinertial contractions between 60 and 80% of 1RM) and maximal power (plyometric training, sprint training, and sets of 4–6 repetitions at the load that elicits maximal power during a specific isoinertial movement) training, and the beneficial effects on performance were consistent irrespective of the athletes' calibre. Strength training volume was associated with energy cost reductions, and concurrent programmes including more than 24 strength training sessions led to greater effects on energy cost than shorter programs. All sports included in the analyses, including swimming, seemed to benefit similarly from such a training strategy [55].

Dry-Land Strength Training

Improvements in a swimmer's strength and power are predominately generated during dry-land training (i.e. in the gym), but an adequate programme incorporating the right exercises can improve the in-water results attainable from strength and power training [1] (Fig. 25.1). Swimmers performing a combined intervention consisting of maximal strength and high-intensity interval endurance training twice per week over 11 weeks, in addition to their regular swimming training, improved dry-land strength, tethered swimming force and 400 m freestyle performance more than a control group that continued regular training within their teams. The improvement in 400 m performance correlated with the gain in tethered swimming force only in the female swimmers, and there were no changes in stroke rate and length, performance in 50 or 100 m freestyle, swimming economy or peak oxygen uptake. These results suggest that this type of strength training may be effective for improving middle-distance swimming performance [53].

Given the beneficial effects of strength training on anaerobic performance, a better understanding is needed of the relationship between strength training, anaerobic factors, and middle- and long-distance performance in endurance events in general and swimming events in particular. A better understanding is also needed regarding the influence of strength training duration. Berryman et al. [55] reported greater benefits on cost of locomotion after longer training protocols (>24 sessions), but the chronic effects of such a training regimen are less understood. More research is required to study the effects of different long-term periodization strategies to provide the athletes and coaches with detailed guidelines regarding, for example, the most appropriate timing for the implementation of strength development within the annual training plan [55].

In-Water Strength Training

Mujika et al. [56] reported on the training contents of a group of 18 elite 100 and 200 m swimmers over a 44-week season. Training volume in these swimmers ranged between 749 and 1475 km, 95% of which were swam at intensities below, at, or slightly above the onset of blood lactate accumulation. There was a huge variability in dry-land strength training, with some swimmers performing up to 40 h in the season, whereas some others performed no dry-land training at all. Interestingly, the amount of dry-land training bore no relationship with performance outcomes over the season. All swimmers, however, carried out large amounts of in-water submaximal strength training, such as arm pulling, kicking, and swim-specific strength training by swimming against an increased resistance to advance. Interestingly, swim-specific strength training seemed to have a negative impact on performance capacity in the short-run, but its medium- to long-term contribution to performance could not be determined [41].

Methods of Strength Training for Swimmers

Swimmers today include a wide variety of strength training practices in their preparation for competition. These include, but are not limited to, dry-land warm-ups, circuit training, traditional strength training, plyometrics, biokinetic swim bench training, measurement of active drag system (i.e. MAD-system), core training, resistive band training, pull training and drag suit training, eccentric overload training, vibration training, and instability training. A systematic review of the available controlled training intervention studies found indications that heavy strength training on dry-land (1–5 repetitions maximum with pull-downs for 3 sets with maximal effort in the concentric phase), or sprint swimming with resistance towards propulsion (maximal pushing with the arms against fixed points or pulling a perforated bowl) may be efficient for enhanced performance. Such strategies may also have positive effects on stroke mechanics, with largest effect size in 50 m freestyle after a dry-land strength training programme of 3 sets of 6 repetitions maximum in relevant muscle groups, and after resisted- and assisted-sprint training with elastic surgical tubes [57]. In the following section, we discuss the scientific evidence behind these training practices, where available, as well as their practical applications.

Dry-Land Warm-Ups

Dry-land warm-ups are an integral part of every elite swimming programme. They are prescribed for activation purposes as well as injury prevention. The inclusion of dry-land-based activation exercises before a race can improve freestyle sprint performance by 0.7–0.8% [58, 59]. The dry-land warm-up routine in these studies consisted of 3 × medicine ball (2 kg) throw downs, 3 × 10 s simulated underwater butterfly kick with an oscillation device above the swimmers head, and 3 × 0.4 m box jumps. The dynamic component of this warm-up routine would result in improved total body temperature, metabolic, neural, and psychological mechanisms [60]. This suggests that dry-land warm-ups are an important component of a swimmer's training schedule to compete at the highest level, and provide a great opportunity for both pre-habilitation and rehabilitation.

Circuit Training

Circuit training is included in many sports as an additional strength and aerobic stimulus. It encompasses a range of exercises and can be prescribed in various manners. The implementation of light loads (40–60% 1RM), brief rest intervals and repeated circuits, 3–5 sets, is a typical circuit training structure [61, 62]. Circuit training has been prescribed to improve body composition, muscular strength, muscular endurance, and cardiovascular fitness in recreational participants [63, 64].

Untrained individuals show large improvements in VO_{2max} as a result of this type of training, but trained athletes show no improvement [65]. Similar outcomes are seen for power and strength measures. Although circuit training does not seem to provide clear improvements for elite athletes, it does provide several practical benefits, such as early season conditioning (aerobic, body composition, buffering capacity, etc.), structure for novice strength training swimmers, and time efficiency. Therefore, circuit training should not be overseen and can be an effective training tool for swimming programmes at the beginning of the season or for swimmers that require additional aerobic conditioning.

Traditional Strength Training

Traditional strength training is most frequently prescribed in elite swimming programmes and encompasses the prescription of conventional gym-based strength training exercises such as bench press, latissimus pull-downs, triceps extensions, triceps dips, bent arm flies, pull ups, and squats. Low volume, high velocity/force resistance training programmes result in significant improvements in swimming performance [21]. Indeed, Girold et al. [52] found a 2% increase in 50 m performance after 4 weeks of strength training; Strass [51] reported a 2.1% improvement and Girold et al. [10] a 2.8% increase after a 12-week programme. Strass [51] prescribed a power programme, whereas Girold et al. [10, 52] and Aspenes et al. [53] prescribed traditional strength training. Aspenes et al. [53] found large improvements in strength (20.7%) and this is not uncommon across all strength training programmes for swimmers and other sports. The need for high velocities during the concentric phase should be emphasized, as this can elicit greater neuromuscular adaptations and a higher recruitment of type II muscle fibres [66–68].

The practical application of traditional strength training programmes should be sport specific (e.g. joint angular ranges, muscles recruited, contraction mode, strength quality required), but specific training for muscular endurance, which is a critical component of swimming performance, does not need to be part of a strength training programme for swimmers. The focus should be on getting swimmers stronger and more powerful, while leaving the development of muscular endurance for the in-water swim training [1].

Plyometrics

Plyometrics is a sport-specific training modality used across a wide variety of sports, especially those requiring sprint and jumping performance, that utilizes the stretch-shortening cycle to produce high levels of force and power [69]. Plyometrics can improve swimming start performance and may also improve turning performance. The underlining principles of plyometrics require an eccentric contraction followed rapidly by a concentric contraction, therefore improving muscle function, coordination, and the direction of the resultant force [32]. Research by Rebutini et al. [32] found that plyometric long jump training improved lower limb joint torque and improved swimming start performance. Bishop et al. [31] showed positive effects of an 8-week intervention period of plyometric training on swimming start performance through explosive power training. Potdevin et al. [30] found an increase in swimming velocity over 50 and 400 m swimming performance, but the influence of start performance is unknown. Adolescent swimmers' turning performance, on the other hand, did not seem to improve after a plyometric training programme [70].

Taken together, the above data suggest that plyometric training has a significant role to play in increasing swimming performance in general and start performance in particular. The large eccentric contribution due to plyometric training may also aid in kicking performance. Greater eccentric strength allows the swimmer to maintain greater knee and hip extension resulting in the retention of more water. However, it is important to include gradual progressions when prescribing plyometric training and the exercises should be specific and progressive in both intensity and volume [32].

Biokinetic Swim Bench

The biokinetic swim bench is a training tool used in many swimming programmes to simulate swimming techniques on dry-land [5]. The swimmer lies prone on a sliding bench with a slight incline, arms outstretched over his/her head and hands secured in hand-paddles. The swimmer is then able to pull along the sliding bench and therefore mimic the kinematics of front crawl swimming. The maximal power output produced on the biokinetic swim bench has a strong relationship ($r = 0.92$) with swimming velocity in semi-tethered conditions [71]. There are, however, limitations to the biokinetic swim bench. Its lack of specificity has been highlighted several times. This is due to the longer pulling pathway and the distribution of pulling forces throughout a range of joint angles which are not similar to free swimming [72]. Roberts et al. [73] designed a 3-week intervention using the biokinetic swim bench three times weekly. Results showed no improvement in swimming performance. Tanaka et al. [8] used the biokinetic swim bench to monitor improvements in strength due to a traditional strength training programme, but even though there was a significant improvement in swimming performance, there was no improvement in power outputs on the biokinetic swim bench. These results show no beneficial outcomes of the biokinetic swim bench, but similar dry-land tools may be advantageous when it comes to improving swimmer's technical and strength deficiencies.

MAD-System

The Measurement of Active Drag system (MAD-system) directly measures the forces of the hand as it pushes off from a series of pads placed 1.35 m apart and attached to a 22-m long rigid aluminium rod mounted 0.8 m below the water surface. The rod is connected to a force transducer enabling direct measurement of push-off forces. Swimmers use their arms only for propulsion, and their legs are floated with a small buoy [74]. The MAD-system has previously been used to predict individual power requirements for swimming a world record in the 50-m freestyle [75], but also as a water-based strength training device. A study reported that swimmers sprinting on the MAD-system 3 times a week simultaneously improved power and free swimming 50, 100, and 200 m race time significantly more than a control group [76]. However, the MAD-system should be used with caution, as swimmers are known to adapt their high speed stroke and usual head position to carefully adapt to the spatial arrangements of the pads [77].

Core Training

Core training is a widely used training method across a variety of sports and should be considered part of any strength training programme. Swimming performance requires a unique balance and stability in order to overcome the unstable and dynamic nature of water. During each stroke cycle, propulsive forces are produced through the hand which creates a dynamic reaction of the rotational aspects of the vertebrae causing an increase in lateral movement and excessive kicking movements, which results in a decrease in propulsive efficiency. Overcoming this instability requires a high level of core strength and stability. It is important to note that the best swimmers accelerate themselves in the horizontal direction and minimize vertical and lateral deviations. Any excessive movement, vertically or laterally is counterproductive for the swimmer's overall performance. Weston et al. [78] incorporated a 12-week core training programme and found significant improvements in swimming performance, as well as an increase in electromyography data. Dingley et al. [79] who employed a similar programme on paraplegic swimmers also found a significant improvement in swimming performance. It can be presumed that this improvement must be largely associated to an improvement in overall core strength and stability. It would seem plausible, and Weston et al. [78] alluded to this, that core strength increases stability in the lumbar and thoracic regions through a variety of exercises which in turn result in greater control through the rotational axes.

Resistive Band Training

Resistive bands are often used by swimmers during training for assistive purposes, but can also be used as a resistive tool. The resistive band is attached around the swimmer's waist using a belt and then secured to the diving block. The athlete swims out against the resistance of the elastic band and then maintains his or her position in the pool. Girold et al. [48] showed a 1.9% improvement in performance over 100 m following resistive band training over a 3-week period and followed up this research with another study showing significant improvements in 50 m swimming performance [10]. Juárez Santos-García et al. [80] also showed that four rounds of resistive bands followed by a maximum sprint improve swimming performance. This training method implies that swim-specific resistance training [81, 82] is necessary to elicit improvements in swimming performance. Sport-specific resistance training has also been seen in water polo, and it was speculated that the reason for an improvement in performance was the development of specific performance skills, again emphasizing the necessity for specificity. It is important to note, however, that this type of training can lead to overuse injuries and needs to be monitored carefully.

Pull Training

The isolation of the arms during swimming training is a commonly used training technique, as the majority of the impulse in swimming comes from the upper-body. It is thought that the isolation of the arms will result in an increase in upper-body strength, and, therefore, an improvement in swimming performance. Unfortunately, this seems to be untrue as in comparison to whole-body swimming, arms-only swimming reduces maximal oxygen uptake [83, 84], which is assumed to occur due to the increased buoyancy provided by the pull-buoy. Konstantaki et al. [85] confirmed this as they replaced regular swimming training with arms-only training, three times weekly. The arms-only training consisted of breathing drills, one arm only, hand-paddles, pull-buoy, etc. The findings of this study showed that arms-only peak exercise intensity, ventilatory threshold, and movement economy improved, but no improvement was observed in swimming performance. This lack of transfer may be due to numerous reasons, including loss of coordination between the arms and legs, additional buoyancy and, therefore, a reduction in core strength and stability, and changes in torque due to the changes in body-roll and stability in the water. However, arms-only training can be advantageous for novice swimmers to improve upper-body strength, emphasizing technical constraints, or allowing swimmers to swim more without expending high levels of energy. In order to elicit greater results from arms-only swimming, the exclusion of the pull-buoy and the inclusion of an elastic band around the ankles may result in greater core activation in order to maintain an optimal body position [86]. It is important to note that many coaches prescribe hand-paddles within their swimming programmes, but unfortunately no study has investigated the effects of hand-paddle interventions on swimming performance. From an observational perspective, hand-paddles do provide a swim-specific strength stimulus for swimmers, but their overuse can result in poor propulsive mechanics and overuse of the shoulder joint. It is advised that hand-paddles are used in moderation and are carefully monitored.

Drag Suit Training

Training specificity is a key element in the enhancement of swimming performance, and drag suits provide swimmers with an additional training tool. The logic behind drag suits is that the mesh clothing retains water and therefore increases the resistive drag forces, resulting in the swimmer applying more propulsive forces to the water to achieve the same time for a specific distance. A study by Dragunas et al. [87] found no significant improvement in swimming performance when the drag suit stimulus was removed. Training under this condition can result in swimmers losing their "feel for the water" [88], which may result in altered body position and, therefore, slower swimming times. It must be documented that most elite swimmers today have moved away from using drag suits due to the aforementioned concerns. Another training tool used is parachutes, which have been shown to induce no alterations in kinematic characteristics of front crawl swimming [89]. Further investigation is needed in this area, but parachutes may be the optimal training tool to increase resistive drag forces, resulting in the swimmer having to apply more propulsive forces to the water to achieve the same time for a specific distance.

Eccentric Overload Training

Concentric-eccentric actions are the most common modalities of dry-land strength training, but eccentric overload training could also be used as an alternative training stimulus for competitive swimmers. Eccentric muscle actions occur when the load applied to the muscle exceeds the force produced, resulting in a lengthening action and high muscle forces. During traditional concentric-eccentric resistance training, load is prescribed on the basis of concentric strength, which leads to the eccentric phase of movement being insufficiently loaded. Eccentric training is a potent stimulus to enhance muscle mechanical function, and muscle-tendon unit morphological and architectural adaptations. Recent research suggests that eccentric overload training can be superior to traditional resistance training at improving variables associated with strength, power, and speed performance for several groups of athletes [90], and it could represent an interesting addition to strength training programmes for swimmers.

To this aim, the use of flywheel inertial resistance is an effective way to induce an eccentric overload. Flywheel inertial devices generate resistance as a function of the mass, distribution of mass, and angular acceleration of the flywheel, and they require a mechanical demand most suited for exercises involving dynamic lower and upper extremity muscle actions [91].

Vibration and Instability Training

Whole-body and upper-body vibration training has recently become a popular alternative and/or complementary method to resistance training because of its potential beneficial effects on the neuromuscular, endocrine, cardiovascular, sensory, circulatory, and bone systems [92, 93]. Similarly, resistance training involving base or platform instability by standing, sitting, kneeling or lying on balls, discs, wobble and rocker boards, foam rollers, low-density mats, and similar devices inducing varying degrees of instability has become a popular training method in recent times. Because swimmers perform their activity in an unstable fluid environment, this training modality could be particularly suitable for them, as it forces the athlete to stress and coordinate synergistic, stabilizing, and antagonistic muscle groups [94, 95]. The impact of such training methods on power production during swimming, however, has not been assessed.

Periodization of Strength Training for Swimming Performance

A well-planned and periodized strength training programme should allow proper long-term athlete development, limit the risk of injury and maximize competition performance [4]. Both dry-land and in-water strength training may have a direct impact on a swimmer's ability to apply force and move through the water, therefore strength training plans should adequately complement swim training throughout a season.

Hellard et al. [96] recently carried out a systematic examination of the relationships between periodized training loads and performance in a large cohort of elite swimmers over the final 11 weeks of training prior to a major competition. Although dry-land strength loads during the taper phase were shown to be detrimental to performance, relatively higher loads in the medium- (6–8 weeks before competition) and long-term (9–11 weeks before competition) meso-cycles were typically associated with faster competition performance. Differences were also observed among various distance specialists. Sprinters' priority was maximal strength and power in the long-term meso-cycle (weeks 9, 10, and 11 before competition). This was followed by a period of low-to-medium intensity training in the medium-term meso-cycle (weeks 6, 7, and 8). The peak high-intensity load was periodized in the medium-term and in the short-term meso-cycles (3–8 weeks before the main competition). For the middle-distance swimmers, the maximum concentration of strength training occurred typically in the long-term cycle, whereas low-to-medium intensity training was most effective in the medium- and long-term cycles, and the high-intensity load exerted the greatest positive effects 3–5 weeks before the final competition of the season. Taken as a whole, these data indicated that swimmers' strength and power capacities should be developed progressively in the medium- and long-term training meso-cycles, maintained in the short-term meso-cycle, and loads finally reduced to avoid detrimental effects during the taper period [96].

Newton et al. [1] suggested that in a periodized progression, the training programme should change before competition to emphasize neural activation and help swimmers in the taper process to be more coordinated and be able to deliver forces where they need to. Taper periods leading to major competitions are known to induce gains in swimming force and power [97–99], even in the absence of dry-land strength and power training stimuli. All of the above is consistent with the practices of leading international swimmers and indicates that periodization plans should be adapted to the distance specialty of swimmers.

Summary

Current evidence indicates that concurrent strength and endurance training could be a beneficial strategy for a majority of competitive swimmers. Increments in upper-body muscular strength and power should translate into increased ability to generate propulsive force in the water, improved stroke length and/or stroke rate, and increased free swimming speed. Lower-body strength and power can translate into faster start and turns. The ability of a swimmer to execute these performance components with high levels of technique, skill, and power will result in a greater overall performance. Both dry-land and in-water strength training can be beneficial to swimming performance. Swimmers today include a wide variety of strength training practices in their preparation for competition, including dry-land warm-ups, circuit training, traditional strength, plyometrics, biokinetic swim bench, MAD-system, core training, resistive band, pull and drag suit training, eccentric overload, vibration, and instability training. A well-planned and periodized strength training programme should adequately complement swim training throughout a season, allow proper long-term athlete development, limit the risk of injury, and eventually maximize competition performance.

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