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The Effects of Concurrent Aerobic Training and Maximal Strength, Power and Swim-Specific Dry-land Training Methods on Swim Performance:
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Review of the Literature

THE EFFECTS OF CONCURRENT AEROBIC TRAINING AND MAXIMAL STRENGTH, POWER AND SWIM-SPECIFIC DRY-LAND TRAINING METHODS ON SWIM PERFORMANCE: A REVIEW

Jade Haycraft[1] & Sam Robertson, PhD[2]

[1] Doncaster Templestowe Swim Club, Templestowe, Victoria
[2] Institute of Sport, Exercise and Active Living (ISEAL), College of Sport and Exercise Sciences, Victoria University, Melbourne Victoria

BLUF

Research is inconclusive in determining whether concurrent aerobic and resistance training, general hypertrophy, and power training improves swim performance in competitive swimmers. Dry-land maximal strength training may improve swim performance in middle distance and sprint swimmers when periodised correctly.

ABSTRACT

Competitive swimming is a sport that requires high levels of muscular strength and aerobic endurance, particularly at the elite level. Dry-land is considered to be any training that swimmers undertake on land. Therefore the purpose of this article was to outline the mechanisms behind concurrent training (undertaking both resistance training and aerobic training in the same periodisation cycle), and to give a summary of dry-land training protocols that facilitate the transfer of strength to swim performance. This review shows that the combination of dry-land strength and in-water aerobic training is a common practice at elite and junior levels of the sport. However, evidence was inconclusive in determining whether concurrent aerobic and resistance, general hypertrophy, swim-specific cable pulley resistance, and power training improves swim performance in competitive swimmers. One explanation for this may be the inappropriate periodisation of strength and power training as decreases in neurological function during peak training phases (~8,300 metres per day) may not allow for optimal performance gains. It was found however that swim-specific strength training that targets push/pull shoulder movements and lower body triple extension whilst working to near maximal effort (80-90% 1RM) did allow for improvements in swim performance of sprint and middle distance swimmers. It was recommended that highly trained swimmers follow maximal strength prescriptions (3 sets x 5-6 reps, with 2-5min recovery) when the dry-land training goal is to improve swim performance. To optimise strength gains, it should also be noted that overall swim load should be reduced to no more than 5,000 metres per day to minimise the effects of neuromuscular fatigue.

Key Words - Resistance training**,** power, strength, sprint.

INTRODUCTION

Competitive swim performance requires high levels of muscular strength and aerobic power, particularly at the elite level. The combination of both strength and in-water aerobic training is of common practice in swim training, however research into the effectiveness of concurrent strength and aerobic training on swim performance is inconclusive (1, 2, 16, 20, 35, 47, 51). This is despite the positive findings relating to concurrent training in other sports. For example, the effects of concurrent maximal strength training and endurance training have been found to improve time to exhaustion, exercise economy, and aerobic power in distance running (46), basketball (4) and cross country skiing (25, 38). Competitive swimming and swim training involve significant amounts of aerobic work, therefore the effects of concurrent aerobic and resistance training may be a valid method for eliciting swim performance gains (2, 4, 7, 25, 38, 46). Dry-land training is a term commonly used to define any training that a swimmer conducts on land (6, 20, 47). In this review, the focus specifically is on strength, power and swim-specific resistance training. Sprint swimming is classified as a power based sport and therefore power specific dry-land training protocols have been reported in the literature to determine if the power gains obtained during dry-land training are directly transferrable to swim performance (2, 6, 8, 13, 16, 17, 23, 35, 45). Specifically, the swim stroke relies on optimal hand placement and pull, whilst maintaining body positioning to reduce drag (36, 44). As such, the transferability of swim specific dry-land training protocols need to be assessed to determine whether specificity of training is more easily transferred to swim performance. Therefore, the aim of this review was to outline the mechanism behind concurrent training, determine its effect on swim performance, and summarise the most effective dry-land training protocols to improve swim performance.

METHODS

A search of relevant literature was undertaken between January 2012 and January 2014 by the first author (JH) using the following databases; PubMED Central, SportDISCUS with full text, and Scopus. The keywords used in the search using multiple combinations and/or phrases included ‘Swimming’, ‘Swim’, ‘Strength’, ‘Power’, and ‘Dry-land’. Further articles were collected following analysis of citations listed within collected publications.

The inclusion criteria required a) articles to be peer-reviewed and b) published between 1980 and December 2013. Further, articles were required to c) have proposed a specific on-land resistance training program for swimmers and d) must have been written in English. The following criteria resulted in the exclusion of studies from this review; a) conference abstracts; b) articles without access to a full-text; c) all non-peer reviewed sources; d) swimming-based publications that were not swim-specific training articles. Of the 425 articles found, 8 were deemed relevant based on the inclusion and exclusion criteria.

DISCUSSION

Concurrent Training

Concurrent training can be defined as the use of resistance and endurance training techniques to simultaneously develop the strength, power and endurance capacity of a musculature system of an athlete (48). Slow-twitch (type I) muscle fibres are recruited at low levels of force with muscle fibre recruitment making a transition so fast-twitch (type II) muscle fibres as force is increased (32). Strength training is typically characterised by a small number of intentionally-induced muscular contractions of maximal or near maximal force (42, 48). Strength training has been shown to develop muscle hypertrophy (34), decrease capillary density (43), increase muscular strength and power output (28-30), as well as increase in the ratio of type IIa to type I muscle fibres (34, 43, 48). In contrast, endurance training can be defined as a comparatively high number of repetitions of sub-maximal muscle contractions (42, 48). Endurance training has been shown to facilitate increases in capillary (14, 27, 48) and mitochondrial density (26, 27), increases in substrate and oxidative enzyme activity (26), as well as decreases to the type IIb type I muscle fibre ratio (27). Therefore concurrent strength and endurance training may theoretically produce an opposing training effect (14,26,27,34,41-43,48). Despite these differences, endurance and resistance training do share at least one common adaptation characteristic; they both transform type IIb into type IIa fibres (27,34,43,48). This characteristic may explain why resistance, and not aerobic training improves an athlete’s anaerobic power and muscular strength. Yet the physiological variables associated with endurance and resistance training do not allow for strength and aerobic endurance to be maximised when trained simultaneously. This is possibly due to some form of overtraining stressors and the subsequent catabolic environment caused by increases in cortisol production (30, 48). Therefore, swim coaches need to consider the potential conflicting outcomes associated with strength and endurance training adaptations when periodising their training programs.

A study by Raglin et al. (39) determined that training load differs across a competitive swim season, with loads ranging from 5,000 metres per day ($m.d^{-1}$) during the general training phase, 8,300 $m.d^{-1}$ during peak training, and as low as 2,300 $m.d^{-1}$ during the taper period. Unfortunately, it was not reported whether the female swimmers in this study were sprint or distance swimmers. However, the authors found that neuromuscular function measured using a ratio of maximal H-wave and M-waves (mV) was significantly reduced (-9%, $p < 0.05$) during peak training when compared to the general training phase. Anaerobic power, measured using peak and mean force (N), was also significantly reduced (-9.6 N and -10.6 respectively, $p < 0.05$) during peak training when compared to general training weeks. Therefore these findings should be taken into consideration when implementing a resistance training program, as the swimmers training load may have implications for the athletes’ neuromuscular function and anaerobic power output. Maximal strength and power training may be most beneficial when implemented during general training times when the athletes neuromuscular system is not significantly affected by the swimmers in-water training load (21, 22, 31).

Concurrent Training and Swim Performance

The use of combined strength and endurance training in modern competitive swimming is common practice. Despite this, very few studies have investigated the performance effects of concurrent strength and endurance training on competitive swimmers. Aspenes et al. (1) examined the impact of a combined intervention of maximal strength and high aerobic intensity interval endurance training for 2 sessions per week over 11 weeks during the competitive season of 20 swimmers over the age of 14. Tethered swimming force, measured using a digital force transducer, significantly increased ($p < 0.05$) in both the female (+8 N) and combined gender (+15.4 N) intervention groups when compared to the control group (+3.7 N). The female intervention group also improved mean maximal strength when compared to the control group (+63.7 N and +32.8 N respectively, $p < 0.05$) during shoulder flexion that was measured using a cable cross over apparatus. The combined male and female intervention group also significantly improved their 400 m freestyle time (mean change -4 s, $p < 0.05$) however no differences were found for 50 m and 100 m swim time. The clustering of genders and the nature of the intervention strategy make it difficult to determine the specific cause and effect of performance improvements. Further, it was found that adding weekly maximal strength and high intensity interval training sessions to a competitive swimmers program did not negatively influence endurance performance (1).

Tanaka et al. (47) determined the value of adding an 8-week swim specific resistance training program to normal training in 12 collegiate swimmer’s programs. The study found that there were no differences in swim-bench strength and swimming power during a tethered swim test or 22.9 m front crawl swim velocity between the intervention and control groups (see Table 1) (47). The authors therefore noted a lack of positive transfer between dry-land strength gains and swimming propulsive force. The rationale provided was that traditional resistance training is not specific enough to exert meaningful impacts on the highly technical swimming stroke and thus competitive swimmers may not benefit from concurrent training (47).

Garrido et al. (16) also focused on concurrent dry-land strength training and aerobic swimming training in young competitive swimmers (age: 12.08 ± 0.76 years). Specifically the control group undertook 8 weeks (6 sessions per week) of aerobic swim training (mean 3.90 ± 0.33 km per session) with the experimental group also participating in a dry-land program (Table 1) targeting upper and lower body strength and power in addition to the swim training. The authors' found similar results to those of Tanaka et al. (47) with no differences between two testing groups for either 25 m and 50 m swim velocity. These findings also suggest that concurrent strength and endurance training may not improve swim performance in highly trained adult and youth swimmers (16, 47).

Whilst current research is inconclusive, Tanaka and Swensen (48) noted in their review that reductions in strength without the inclusion of resistance training are to be expected, which could hypothetically lead to decreases in performances of competitive sprint swimmers (47, 48). Whilst concurrent training has not been shown to improve endurance performance in competitive swimmers, dry-land resistance training does improve upper-body strength more so than in-water resistance training and consequently may be a valuable form of cross-training throughout a competitive training year (1, 6, 36, 47, 48).

DRY-LAND RESISTANCE TRAINING

In the following section of this review, the effect of different dry-land training protocols on swim performance will be presented. Swimmers are unique to many other athletes, in that they may aim to develop strength, power and endurance training both in-water and on-land. Strength and power, especially in the upper-body, has been noted as a crucial component for swim training and a major determinant of success in competitive swimming, regardless of stroke or distance speciality (1, 6, 8, 13, 16, 17, 19, 20, 23, 36, 45, 47, 48, 50, 51). Consequently, the aim of any dry-land resistance training program should be for a positive transfer of enhanced muscular strength and power as a result of this resistance training to increasing the propulsive forces in water during the stroke. This in turn may also effect improvements to block starts and tumble turn velocities; thus improving overall swim performance (6,8,13,36,51). Several studies have investigated a range of different resistance training modalities on swim performance (Table 1).

Table 1 - Dry-land training protocols and study designs.

Author	Findings	Participant Characteristics	Exercise	Dry-land Intervention	Outcome Measure/s
Aspenes et al. (1)	Significant improvements for intervention group for 400m time (mean -4 s, p <0.05). Significant improvements in tethered swimming force (+15.4N, p <0.05) between intervention and control group. Increased 1RM land strength (+72.8 N, p <0.05) between intervention and control group.	Competitive Swimmers (n =20)	Cable cross-over apparatus to mimic butterfly stroke. Maximal force application during concentric phase and slow eccentric phase.	Maximal Strength: 3 x 5 Maximal Repetitions, 2-5 min rest between sets	Maximal Swimming Force (N) 1RM Land Strength (N) 50m Freestyle (s) 100m Freestyle (s) 400m Freestyle (s) Max Swim Velocity ($m.s^{-1}$) Stroke Length (m) Stroke Rate (Hz)
Bishop et al. **(8)**	Significant differences (p <0.01) between baseline and post-trial swimming block starts for intervention group compared to control group in swim time over 5.5 m (-0.59 s vs. -0.21) and velocity of take-off to water contact (0.19 ms^{-1} vs. -0.07 ms^{-1}). No significant difference was found between groups for angle out of blocks (p = 0.023), and angle of entry into water (p = 0.27).	Adolescent Competitive Swimmers, Plyometric group (n=11, age: 13.1±1.4), Control (n=11, age: 12.6±1.9)	Intensity ranges from low to high. Jumps – tuck, squat, depth, long jump, single leg Hops – hurdle, cone Bounds – double leg, single leg Skipping	Plyometrics: 2 x hours per week 1-4 sets x 1-5 reps, 60-90 s rest	Angle out of blocks (°) Distance to head contact (m) Swim Block Start velocity ($m.s^{-1}$) Time to head contact (s) Angle of entry into water (°) Performance time to 5.5m (s)
Garrido et al. **(16)**	No difference between intervention and control groups 25 m and 50 m swim velocity (p >0.05). Intervention group significantly increased 25 m and 50 m swim velocity (25 m: 6.95%; 50 m: 4.77%, p <0.01). Significant increases in control group 25 m and 50 m swim velocity (25 m: 6.44%; 50 m: 3.16%, p <0.05).	Young Competitive Swimmers, age: 12.08±0.76 (n=25)	Leg extension Counter-movement jumps Counter-movement jump box Medicine ball throws (1kg) Bench press	General Strength & Power: 2-3 sets x 6-8 reps 50-75% 6RM	25m Freestyle Velocity ($m.s^{-1}$) 50m Freestyle Velocity ($m.s^{-1}$) Drag Force (N) 6RM Leg Extension (kg) 6RM Bench Press (kg) Countermovement Jump Height (cm) 1kg Medicine Ball Throw (m) 3kg Medicine Ball Throw (m)

Gergley et al. **(18)**	Both intervention and control groups improved, however the control groups increase in tethered swimming peak $V0_2$ was significantly greater (+0.21 $l.min^{-1}$, $p < 0.05$) than the intervention groups increase. Significant increases ($p < 0.01$) in control groups tethered swimming peak VO_2 (18%) and Swim-Bench Ergometry peak VO_2 (19%). Intervention group significantly ($p < 0.01$) improved $V0_2$max during tethered swimming (11%) and Swim-Bench Ergometry (21%) tests.	College-aged male recreational swimmers (n=25)	Swim bench pulley system to mimic freestyle stroke rate of 72 $strokes.min^{-1}$	Swim Specific Bench Pulley System: 6 sets x 4 min with 3-5 min recovery	Treadmill Running, Tethered Swimming & Swim-bench Ergometry: VO_{2max} ($ml.min^{-1}$) VO_{2max} ($ml.min^{-1}.kg^{-1}$) VE_{max} ($L.min^{-1}$, BTPS) Maximum Respiratory Exchange Heart Rate Max ($b.min^{-1}$) Exercise Time (min:s)
Girold et al. **(20)**	A significant improvement ($p < 0.05$) in 50 m time (s) was reported for the strength (2.8±2.5%) and resisted- assisted- sprint (2.3±1.3%) groups compared to control group (0.9±1.2%). No significant difference ($p > 0.05$) between strength and resisted- assisted- sprint groups in 50 m time. Significant ($p < 0.05$) decrease in stroke depth for strength (0.03 m) and resisted- assisted- sprint (0.02 m) groups. Significant increase in stroke rate (1.3 $cycle.min^{-1}$, $p < 0.05$) for resisted- assisted- sprint group.	Regional to national level swimmers (n=21)	Upper body press, pull-up, and draw with barbells Lower body squats and plyometric jumps (undefined)	Maximal Strength Training: 3 sets x 6 reps 80-90% 1RM	50m Freestyle (s) Stroke length (m) Stroke rate ($cycle.min^{-1}$) Stroke depth (m) Strength of elbow extensors in isometric (N.m) Strength of elbow flexors in isometric (N.m) Strength of elbow extensors in concentric at 60°.s^{-1} (N.m) Strength of elbow flexors in concentric at 60°.s^{-1} (N.m) Strength of elbow extensors in concentric at 180°.s^{-1} (N.m) Strength of elbow flexors in concentric at 180°.s^{-1} (N.m)
Sadawski et al. **(40)**	Significant increase (9.64%, $p < 0.02$) in tethered swimming strength in intervention group. No significant increase ($p > 0.05$) in performance in intervention group in shoulder flexion strength, stroke frequency, stroke distance, and 25 m front crawl sprint time.	Regularly trained male youth swimmers (14±0.5 years, n=26)	Train power whilst simulating underwater phase of shoulder	Hydro-isokinetic ergometer: 6 sets x 50 sec of work, 10 sec rest between sets	Isometric shoulder flexion strength (N) 25m Freestyle velocity ($m.s^{-1}$) Tethered swim strength over 10 s (N) Stroke frequency (1/min) Distance per stroke (m)
Tanaka et al. **(47)**	No significant difference ($p > 0.05$) between intervention and control groups in any outcome measures.	Intercollegiate male swimmers (n=24)	Dips, chin-ups, lat pull-downs, elbow extensions, bent arm flys	Hypertrophy & Swim Specific: 3 sets x 8-12 reps	22.9m Freestyle velocity ($m.s^{-1}$) 365.8m Freestyle velocity ($m.s^{-1}$) Swim bench power (W) Tethered swim power (W) Distance per stroke (m)
Trappe & Pearson **(51)**	No variation ($p > 0.05$) between weight-assisted group and free-weight group in 22.9 m front crawl sprint time, mean tethered swim power and biokinetic swim bench power. Weight-assisted group did experience a significant decrease (-0.34 s, $p < 0.05$) in 22.9 m front crawl sprint time when compared to baseline.	Highly trained collegiate swimmers (n=10)	Weight-assisted (WA) dips and pull-ups Non weight-assisted (NWA) Lat pull downs, elbow extension and flexion, bent arm flys, quadriceps extension on Nautilus machine, hamstring flexion on Nautilus machine	Swim Specific : WA group 1 x set until volitional fatigue, 1 x set until volitional fatigue with 13.6kg removed from body weight, 1 x set until volitional fatigue with 22.7kg removed from body weight, 1 min rest between sets NWA group 3 sets x 8-12 reps	Body weight (kg) Lean body mass (kg) Fat percentage (%) 22.9m Freestyle (s) 22.9m Freestyle velocity ($m.s^{-1}$) 365.8m Freestyle (s) Stroke rate (sec per 4 strokes) Distance per stroke (m) Swim bench power (W) Tethered swim power (W)

Potential Concerns with Resistance Training Effects on Swim Performance

There is the potential for swimmers and coaches to be apprehensive when it comes to implementing maximal strength resistance training as the concern for increased muscle mass and density may affect their flexibility and buoyancy in the water (11, 33). Chatard, Bourgoin and Lacour (10) found that bigger, heavier individuals are at a disadvantage in swimming events longer than 400 m, with greater body size increasing swimmers drag in the water. However, Chatard, Lavoie and Lacour (11) noted that for sprint swimmers (400 m or less), greater muscle mass allowed for faster swim times as athletes were able to produce greater anaerobic energy outputs. Furthermore, with the majority of swim training being endurance based, generally the physiological effects of maximal strength training (such as hypertrophy) are unable to be maximised (24, 25, 30, 36, 48). Sprint swimmers in particular may benefit from strength increases associated with resistance training, therefore this form of training maybe a useful tool for improving performance in this group of athletes.

Another potential concern of swimmers and coaches is the effect that maximal strength training has on athlete flexibility. Swimmers with greater shoulder, hip, knee and ankle flexibility can create less resistance in the water through the ability to streamline their body (10). Improvements in flexibility of these specific joints has been found by several authors (5, 49) following regular resistance training with light loads (8 RM). It has also been established that the effect of resistance training on flexibility is sport-dependent, therefore if full joint range of motion is required, swimmers should be instructed to perform all exercises to full range (5).

Translation of Maximal Strength Training to Swim Performance

Maximal strength training can result in considerable acute fatigue of both peripheral and central origins and therefore needs to be periodised into a swimmers program (31). The research is divided with reference to the benefits of maximal strength training on swim performance (1,16,20,48). Aspenes et al. (1) found that maximal strength training protocols (Table 1) are strongly correlated with improvement in 400 m swim time (-4.00 s, $p < 0.05$). Substantial improvements were also reported for tethered swimming force production (+15.4 N, $p < 0.05$) and 1RM land strength testing (+72.8 N, $p < 0.05$) after 11 weeks of integrating a maximal strength training protocol combined with high aerobic intensity interval endurance training protocol with normal training. However, the authors did not determine whether improvements in swim performance were the effect of the combined training sessions, aerobic sessions, or maximal strength training sessions only (1). Girold et al. (20) also found that participants undertaking a 12-week dry-land maximal strength training program (Table 1) experienced improvements in swim time over 50 m (2.8 ± 2.5%, $p < 0.05$) when compared to a control group. No significant differences ($p > 0.05$) between the dry-land maximal strength training group and the in-water resisted- and assisted-sprint (RAS) training protocols were found, which suggested that both training protocols were effective in improving 50 m swim time, despite the dry-land group displaying larger increases in muscle strength (20).

Garrido et al. (17) determined the association between strength and power variables and sprint performance in young competitive swimmers. The authors' found that the leg extension (25 m: Spearman's $r = -0.692$, $p < 0.001$; 50 m: $r = -0.622$, $p < 0.01$) and bench press (25 m: $r = -0.575$, $p < 0.01$; 50 m: $r = -0.586$, $p < 0.01$) strength tests were moderate but significantly related to sprint time over 25 m and 50 m in young competitive swimmers. These findings demonstrate the associations between increases in strength and power, and decreases in sprint time over 25 m and 50 m (17). Girold et al. (19) also observed that muscle strength of the elbow flexors and extensors, measured in isometric ($r = 0.57$; 0.54; $p < 0.05$) and concentric conditions at $60°\cdot s^{-1}$ ($r = 0.67$; 0.66; $p < 0.05$) and $180°\cdot s^{-1}$ ($r = 0.64$; 0.66; $p < 0.05$), was a good predictor of 100 m swimming time in competitive swimmers (19). These findings, along with those found by Aspenes et al. (1) and previous work from Girold et al. (20) provide merit to approaches aiming to develop a swimmers maximal upper-body strength using dry-land training (1, 19, 20). It is however suggested that swim training be reduced to no more than 5000 $m.d^{-1}$ in order to account for the neuromuscular demand of maximal strength training so as not to overload the peripheral and central fatigue mechanisms of the athletes (31, 39).

Translation of Power Training to Swim Performance

The rate of force development (RFD) is also a crucial component of power, therefore it is important to incorporate exercises that target this into a swimmers program to improve power output (6, 8, 12, 29, 37). Olympic weightlifting is commonly used in elite dry-land programs, as these lifts have been shown to increase RFD and power output in multiple sports (3, 6, 9, 12, 15), in particularly those that involve jumping type movements. However research needs to be conducted to determine whether training swimmers in the Snatch and/or Clean & Jerk can be transferred into swim performance in the pool (6, 12).

Garrido et al. (16) is an example of a study that incorporated a dry-land power specific training intervention (see Table 1). They found no significant relationship ($p > 0.05$) between a power trained group and a control group in relation to countermovement jump and medicine ball throw ability along with 25 m and 50 m swim velocity after 8 weeks of training (16). Other studies focussing on power tests with Garrido et al. (17), Hawley et al. (23), and Sharp et al. (45) all investigating the relationships between power testing results and swim performance. Garrido et al. (17) found that sprint performance over 25 m and 50 m was moderately but significantly associated with 3 kg medicine ball throw in both the throwing range (m) (25 m: $r = -0.744$; 50 m: $r = -0.726$, $p < 0.001$) and velocity ($m.s^{-1}$) (25 m: $r = -0.727$; 50 m: $r = -0.73$, $p < 0.001$), but not with vertical jump height ($p > 0.05$) in young competitive swimmers. They concluded that exercises like the countermovement jumps lacked specificity for swimming performance improvements over short distances, however they concluded that there may be merit in dry-land power training of the upper body for improving sprint performance in young swimmers (17).

Hawley et al. (23) looked at the relationship between upper and lower body Wingate Anaerobic power test and a 50 m sprint swim performance to determine whether a combination of arm and leg power improves swim performance above that of leg or arm power alone. Their results contradicted those found in the previous studies in that there strong correlations were noted between mean arm ($r = 0.63$, $p < 0.01$) and mean leg power ($r = 0.76$, $p < 0.01$) output in sprint speed over 50 m. They also found that peak sustained workload attained during a maximal sustained power output test was correlated ($r = 0.70$, $p < 0.001$) with 400 m freestyle swim speed.

Sharp et al. (45) tested the relationship between power and sprint freestyle swimming by comparing a dry-land swim bench testing protocol to 22.86 m freestyle sprint velocity. They found that upper body power was strongly correlated ($r = 0.90$) with 22.86 m sprint velocity (45). It is difficult to compare these two studies with the studies by Garrido et al. (16, 17) because the latter used young swimmers and vertical jump testing where the others used adult elite swimmers, Wingate tests and the swim bench testing protocol (23, 45).

Whilst several studies have determined the importance of upper body power during the stroke component of swim performance, three studies by West et al. (52) Cronin et al. (13), and Bishop et al. (8) looked at the importance of leg power measures, block starts and tumble turn velocity in swimmers. A swimmer's ability to turn fast can affect approximately 20.5% of their total race time in a 50 m race, and 33% in events longer than 182.9 m in a short course pool (13). The swimming block start is also a crucial component of any swimmers racing performance, with a strong start accounting for up to 30% of a 50 m race (6, 8). West et al. (52) looked at the key strength and power predictors of start performance in elite male freestyle swimmers by comparing their estimated 1 RM squat strength using 3 RM squat testing, countermovement jump on a force platform, and start time (s) to 15 m under 50 m sprint conditions. They found that start time was significantly correlated ($p < 0.05$) with 1 RM squat strength ($r = -0.74$), countermovement jump height ($r = -0.69$), peak ($r = -0.85$) and relative ($r = -0.66$) power (52).

Similarly, Cronin et al. (13) sought to determine whether dry-land power measures specific to a tumble turn push-off movements might transfer to performance in the water. They found that power output from loaded jump squats, height from the countermovement jump and vertical jump were significantly related ($p < 0.05$) to the swimmers average velocity 2 m and 4 m from the wall, however these correlations were low to moderate ($r = 0.28$-0.41) and were no longer significant after 6 m from the wall. The authors found that it was difficult to determine the best exercise for improving velocity from the push-off as other factors such as technique and streamlining may be of greater importance for improving swim performance (13).

Bishop et al. (8) aimed to identify the effect of implementing a dry-land plyometric training intervention that was specifically selected to improve swimming block starts in adolescent swimmers. The authors determined that the plyometric intervention group experienced a significantly greater increase compared to the control group in swim time over the first 5.5 m (-0.59 s vs. -0.21 s, $p < 0.01$), and velocity at take-off from blocks to contact with water (0.19 m.s^{-1} vs. -0.07 m.s^{-1})(8). The results of these studies have outlined a need for training power in a manner that is swim specific to allow maximum transferability of power gains to swim performance. The use of Olympic lifts have been shown to successfully develop power in other sports and therefore are used regularly develop power in elite swimmers. Currently to our knowledge no research into the translation of gains made from Olympic lifting training to swim performance has been published. Therefore, such research needs to be conducted to determine whether this form of training is an effective dry-land training method for improving stroke, tumble turn and block start power (6, 12, 13, 16, 17, 45).

SWIM-SPECIFIC DRY-LAND TRAINING

Several studies have reported that swim-specific dry-land training is an effective method of improving swim performance when compared to traditional resistance training protocols (18,20,47,48,51). Gergley et al. (18) and Sharp et al. (45) both focused on the specificity of arm training on aerobic power during swimming. Gergley et al. (18) trained a group of recreational swimmers with a standard swim-bench pulley system to determine whether improvements in aerobic capacity during a tethered swimming test and swim bench test occurred. The swim bench trained group experienced significantly improved VO_2max ($p < 0.01$) in both tethered swimming (11%) and swim bench tests (21%). However the swim trained groups peak VO_2 was significantly greater than the swim bench trained group (0.53 l.min^{-1} and 0.32 l.min^{-1} respectively, $p < 0.05$). In these studies, it was suggested that the cause of these improvements was due to the swim bench exercise activating a considerable portion of the musculature involved in swimming. Consequently, aerobic improvements from this type of training are directly transferred to swimming performance. This study did use recreational swimmers and therefore future research may look at the effect of this training on swim performance in elite participants (18). Sharp et al. (45) used a similar swim-bench pulley system to Gergley et al. (18) to assess a group of competitive swimmers and found that the muscular power produced on the swim-bench had a high relationship ($r = 0.09$) with sprint swim velocity (45).

Whilst the abovementioned studies state that the use of swim benches facilitates improvement in swim performance, more recent studies by Tanaka et al. (47), Trappe and Pearson (51) and Sadowski et al. (40) present somewhat conflicting results. Tanaka et al. (47) used a dry-land resistance training program that was intended to simulate the muscle and swimming actions during front crawl. The program utilized weight lifting machines and free weights; with exercises consisting of dips, chin-ups, lat pull-downs, elbow extensions, and bent arm flys. In this example, no significant differences ($p > 0.05$) were found between the training group and the control group in any of the swim power and swim performance tests (47).

Trappe and Pearson (51) used a weight-assisted dry-land training as a swim specific training protocol to determine whether strength gains from weight-assisted dips and pull-ups were comparable with a typical free-weight training program when applied to swimming. The rationale behind this protocol was that weight-assisted training may be more similar to the movements and velocities associated with stroke cycle in front crawl swimming, thus allowing for a positive transfer to performance in the water. They found that weight-assisted training for 6 weeks neither improved nor hindered swim performance when compared to traditional free-weight training, however all exercises were weight-assisted and therefore it was difficult to determine whether any changes in the musculature occurred (51).

Sadowski et al. (40) also evaluated the effects of dry-land power training on swimming force, performance and strength in male youth swimmers (14 ± 0.5 years) over a 6-week training block (18 dry-land sessions). The experimental group completed swim and dry-land training using an ergometer to simulate the underwater phase of shoulder work during front crawl (Table 1). Sadowski et al. (40) did find that there was a significant improvement in tethered swimming force for the experimental group (9.64%, $p < 0.02$), with the control group not showing statistically significant improvements (2.86%, $p > 0.05$). However the experimental group’s improvement in shoulder flexion force, stroke frequency and distance, and sprint performance were not shown to be statistically significant ($p > 0.05$) and therefore the study could not clearly state whether power training enhanced swim performance in regularly trained male youth swimmers (40). The swim stroke is highly technical and these studies have suggested that traditional resistance training and swim specific dry-land training is not specific enough to improve swim performance, as stroke mechanics were more crucial than upper body strength in determining a swimmers performance (47, 48, 51).

CONCLUSION

This review was conducted to determine the effect of dry-land training protocols on swim performance. It was found that concurrent resistance training and endurance training is of common practice in competitive swimming, yet research to determine its effectiveness at improving swim performance is varying. It was found that there may be some positive transfer of performance gains in the 400 m freestyle event, however the research does not support the use of concurrent training for improving sprint performance. The different dry-land training modalities were discussed and the effectiveness of each training protocol was critically analysed. Most resistance training protocols direct transferability to swim performance was not high, however maximal strength training was found to be the most effective protocol in improving swim performance. Upper body power testing variables did show significant relationships with swim performance regardless of stroke and distance, however lower body power variables did not show any significant relationship. The need for swim-specific dry-land training was mentioned in several studies, however the research which used a swim specific dry-land training protocol did not find a significant relationship between the training protocol and swim performance, despite the training protocol activating a considerable portion of the musculature involved in swimming. The recommendations for future researchers is to focus on specific dry-land training protocols and their effect on swim performance, and for swim coaches to use this review as a guide when prescribing dry-land resistance training to their athletes.

PRACTICAL APPLICATIONS

There are considerable gaps in the literature in terms of specific dry-land training protocols and their transferability to swim performance. Studies need to be conducted to determine the effects of specific dry-land maximal strength and power training protocols (such as Olympic lifts) on sprint, middle-distance and endurance performance separately. This is supported by already available findings showing strength and power as meaningful contributors to swim performance regardless of stroke specialty and distance (1, 12, 13, 16-20, 23, 36, 38, 45, 47, 48, 51).

From a coaching perspective, it is clear that swimmers complete most of their training aerobically, and therefore a dry-land strength coach should use maximal strength training to increase a swimmer’s strength. This method was found to be most effective at increasing strength when an athlete is involved in high loads of aerobic training, although further swim-specific research needs to be conducted. It is important to note also that swim coaches may need to be educated when integrating dry-land strength and power programs, as reducing aerobic volume in the water to no more than 5,000 $m.d^{-1}$ may be required to allow for maximal strength and power gains (21, 22, 31, 39).

The recommendation of a maximal strength training protocol has been suggested for coaches of national level sprint and middle distance swimmers based on the evidence provided by both Aspenes et al. (1) and Girold et al. (20). It is clear from the evidence provided in these studies that exercises targeting the push/pull shoulder movements and lower body triple extension strength demonstrate a relationship with improved swim performance. It is also clear that the use of a maximal strength prescription of 3 sets of 5-6 repetitions of near maximal effort (80-90% 1RM) with 2-5 min rest between sets is optimal for improving swim performance outcomes of highly competitive swimmers (1, 20). Whilst the aforementioned studies did not assess swimmers strength to bodyweight ratio directly, findings by Aspenes et al. (1) and West et al. (52) demonstrate that it is reasonable to expect that elite swimmers should be capable of lifting 0.7 times their body weight during bilateral 1 RM shoulder pull-throughs (1), and 1.7 times bodyweight in 1 RM squat strength.

When periodising dry-land training for swimmers, it is recommended that they participate in 2-3 dry-land sessions per week based on the evidence provided by Aspenes et al. (1) and Girold et al. (20). Maximal strength dry-land sessions should be conducted as an isolated training session where possible, however if this is not possible they should be conducted prior to in-water training to reduce subsequent carry-over of neuromuscular fatigue from swim training sessions (22, 31, 39).

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