Effectiveness of a Dry-Land Resistance Training Program on Strength, Power, and Swimming Performance in Paralympic Swimmers

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Abstract

Dingley, AA, Pyne, DB, Youngson, J, and Burkett, B. Effectiveness of a dry-land resistance training program on strength, power, and swimming performance in paralympic swimmers. J Strength Cond Res 29(3): 619–626, 2015—This study evaluated the effectiveness of a dry-land resistance training program in Paralympic swimmers to increase swimming power and strength measures, and how these changes affect swimming performance. Seven elite-level Paralympic swimmers (1 man and 6 women; age: 19.4 ± 6.5 years; body mass: 57 ± 12 kg; height: 1.66 ± 0.21 m) performed a 6-week coach-prescribed strength training intervention program designed to improve power, flexibility, and postural control. Exercises targeted the main swimming movements: the start and turn, postural control in the water, and the pull and kick focusing on the gluteals, upper body, and trunk. Swimming-specific tests, involving a 50-m time trial, and timed dive starts were conducted at baseline and after the 6-week program. A bilateral swim-bench ergometer and jump tests were conducted to quantify arm and leg strength and power. After the 6-week intervention, 50-m time trials improved by 1.2%, ±1.5% (mean, ±90% confidence limits). Increases in both mean power (6.1%, ±5.9%) and acceleration (3.7%, ±3.7%) generated during the dive start enabled swimmers to substantially improve start times to the 5-m (5.5%, ±3.2) and 15-m (1.8%, ±1.1%) marks. The resistance training intervention resulted in a very large (r = 0.78, ±0.37) correlation between dive start velocity and the counter movement jump mean velocity. The 6-week resistance training program for Paralympic swimmers yielded substantial improvements in dry-land measures that corresponded with improvements in both timed dive starts and 50-m time trial performance, thus highlighting the usefulness of dry-land training for enhancing swimming performance in Paralympic swimming.

Key Words resistance program, intervention, Paralympic swimming

Introduction

Competitive swimming is about covering a given distance in the shortest period of time—and is determined by the swimmer who is able to maintain the greatest power output for a given distance in an efficient and skillful manner to overcome the resistance of the water (18,19). Two primary factors in determining swimming performance (15,19,34), particularly over sprint distances (35) are muscular strength and power. Substantial correlations between upper-body muscular strength and power output and velocity of swimmers have been shown over sprint distances (3,37), with improvements in swimming performance associated with increases in power output (29,37).

Fitness training for swimming has 2 main approaches: using traditional pool-based training in water (endurance training) and dry-land methods on the pool deck or in the gym (strength training) (15). By overloading the muscles required for swimming, a dry-land program aims at increasing the swimmer’s maximal power output (34) and thus velocity. An important consideration in the design of a dry-land program is specificity of the training methods, since swimming performance improvements depend on this principle (9,20,31); therefore, the selected exercises should be consistent with the types of movement that are involved in swimming (18). The main movements in swimming are arm rotation, kicking, jumping, and body rotation.

A loss of strength, coordination, or range of motion within the kinetic chain can cause a swimmer to fall short of their potential performance (24,27,28) and the deficits in muscle or joint flexibility, muscular stability, and muscular control that occur can lead to decreased efficiency and an increased chance of injury (5,26). The most common anatomical regions with musculoskeletal issues in swimming are...
Resistance Training in Paralympic Swimmers

are as follows: (a) hip flexors and gluteals, which have implications for starts and turns, as well as kicking, (b) shoulder girdle, with stronger internal rather than external rotators (27) often leading to shoulder injuries (38), and (c) overactive upper abdominal muscles compared with weaker lower abdominal muscles, leading to a lack of control of the pelvic position influencing poor body position in the water. In Paralympic swimming, swimmers have physical or nonphysical disabilities (blind or intellectual). By the nature of their physical impairment, many Paralympic swimmers exhibit larger muscular imbalances, limitations in muscle and joint flexibility, and less stability and control of the muscles (27). Therefore, a coach-prescribed strength training program would be beneficial to improve strength, flexibility, and control of the muscles required for specific swimming movements.

In competitive swimming, an effective start off the blocks is an important component (6,7) contributing up to 26% (8,30) of total race time in sprint distances and is the stage where velocity is greatest (2,7). To produce a fast entry, the important requirements are a high take-off velocity and a streamlined position underwater to maximize and maintain velocity for as long as possible (7,11). In Paralympic swimmers, it seems the underwater phase is a critical phase with those swimmers with a greater severity of physical disability or having a disability that affects their lower body (e.g., cerebral palsy or leg amputees) disadvantaged in this kick dominant phase and spending a greater proportion of time in the free swim phase (11). The dive start is the stage of a swim where the highest velocities throughout the entire race are recorded (2,7,39); therefore, fast starts are reliant on explosiveness with a powerful leg drive an important component (18). Previous studies have found significant correlations between starting performance in swimmers and measures of lower-body power in able-bodied swimmers (6,22). Therefore, improvements in jumping ability and muscular leg power may improve a swimmer’s start time (17). Clearly, the focus is to develop sports-specific strength and power to enhance dive starts and free swimming velocity.

Paralympic swimmers compete in 14 classes: locomotor impairments are grouped for classes 1 (most severe disabilities) to class 10 (least severe disabilities). Swimmers with a visual impairment are in classes 11–13, and those with an intellectual impairment form class 14. In the locomotor impairment classes, there are a large range of physical disabilities that variously affect the whole body (e.g., cerebral palsy and small statured), lower limb (e.g., leg amputee or spinal cord injury), or upper limb (e.g., arm amputee) (13). Therefore, the challenge for prescription of dry-land programs is even greater in Paralympic swimming given the diverse nature of the disabilities. Inclusion of speed training and drills, as well as a strength element in the program, should also be effective in improving a swimmer’s sprint performance (14,15). To the best of authors’ knowledge, there is no published research on dry-land programs for Paralympic swimmers, which is surprising given the rising interest and investment in Paralympic sports by many leading sporting nations.

Therefore, the primary aim of this study was to evaluate the effectiveness of a dry-land program that focuses on improving measures of power and strength in Paralympic swimmers. A secondary aim was to determine whether these improvements transfer to swimming performance in Paralympic swimmers. This study tested the hypothesis that a dry-land strength training program would lead to improvements in swim-starts and faster sprint performance, greater than the typical yearly improvements reported in Paralympic swimming of ~0.5% (12), and within the improvement range of 1.3 and 4.4% of existing studies of the effect of dry-land strength programs on sprint performances in able-bodied swimmers (9,32).

METHODS

Experimental Approach to the Problem

During preparations for the Paralympic selection trials (March), a 6-week pre-post experimental trial examined the effect of a dry-land program on strength and power measures and swimming-specific movement patterns. The intervention was completed 4 weeks before competition. Given the unique physical characteristics and limited numbers of these international level athletes, we used a single experimental group design of high ecological validity albeit with some limitations in experimental control.

Over a period of 72 hours, each swimmer undertook 5 different testing sessions in clinical (anthropometry), laboratory (jump testing and swim-bench ergometry), and pool (time trial and timed dive starts) settings. To minimize the effects of residual or cumulative fatigue from daily training on test performance, swimmers and coaches were asked to avoid any stressful training on the days before and during the testing period. No changes in the diet were requested.

Subjects

In this study, 7 (1 man and 6 women) elite Paralympic swimmers (age: 19.4 ± 6.5 years; body mass: 57 ± 12 kg; height: 1.66 ± 0.21 m; mean ± SD) participated in this study. All subjects competed at the 2012 Paralympic Games in the following classes S14 (intellectual I7 years), S13 (visually impaired, 20 years), S10 (cerebral palsy, 16 years), S9 (leg amputee, 20 years), S8 (cerebral palsy, 13 years), and S6 (cerebral palsy, 17 years and small statured, 33 years). Written informed consent was obtained from the subjects, before voluntary participation in the study for participants aged above 18 years, whereas for minors and the subject who was intellectually disabled, a guardian and the subject provided written informed consent. The study was approved by the Ethics Committee of the Australian Institute of Sport (approval number 20110809), and the University of Sunshine Coast, Queensland, Australia.

Dry-Land Training Program

A 6-week strength program was designed to improve strength, flexibility, and control of 3 main functional qualities
while also developing power. The program incorporated exercises specifically targeting the main movements in swimming: the start and turn, postural control in the water, and the pull and kick. Three times per week (Monday, Wednesday, and Friday), swimmers performed exercises that focused on the (a) lower body for development of control and power through the gluteals (e.g., medicine ball prone chest throw on a glute-ham raise bench and 2 × 2-m grid monster walk in each direction), (b) upper body for strengthening of the stability of the shoulder girdle (e.g., push press and weighted narrow grip chins), and (c) trunk for activation and control of the core (e.g., prone bridge and swimmer’s roll). Strength training sessions were 60 minutes long with a 5-minute warm-up on a cycle ergometer, followed by 5 warm-up/injury prevention exercises (e.g., swissball freestyle kick and TRX stop signs). The same format was followed in session with 3 exercises focusing on each area with a 2-minute rest between each set. A maximum of 8 repetitions, with an average of 6 repetitions per set was met, with 3 sets per exercise. Intensity of the training varied from 90% (weeks 1 and 4), 95% (week 2), 102% (weeks 3 and 5), and 85% (week 6). The session ended with 2 abdominal exercises (e.g., weighted seated Russian twist and bench oblique crunches) for which 20 repetitions or 55 seconds. The aim was to develop movement by binding all of these structural and functional components in order for the kinetic chain to deliver forces in a coordinated fashion.

Body Composition (Day 1, 6–8 AM)
Swimmers presented between 6 AM and 8 AM in a fasted state, and an anthropometric profile was conducted by a level 3 accredited anthropometrist, in accordance with the recommended methods of the International Society for the Advancement of Kinanthropometry (21). Body mass, stretch stature, skinfold thickness at 7 sites, and chest circumference were recorded. Changes in lean mass were quantified using the LMI index previously validated for swimmers (23).

Strength and Power Assessment
Swim Bench (Day 1, 2–4 PM). A calibrated bilateral swim-bench ergometer (Weba Sport, Wien, Austria) was used to measure the force produced in left and right arms, respectively, during simulated freestyle. After a standardized 10-minute warm-up, swimmers performed 2 × 60-second maximal efforts with a 5-minute rest period between trials. During efforts, encouragement was limited to the 15-, 30-, and 45-second periods to coincide with informing the swimmer of time progression of trial. The swimmer was lying in a prone position on the bench with their hips attached to the bench using a strap (33). Each arm stroke was measured independently, and the mean power and peak force were recorded. The SEM in our laboratory is 2 N and 2 N, respectively.

Jump Testing (Day 2, 10–12 AM). Subjects undertook a 10-minute standardized warm-up that consisted of 5-minute
cycling on a cycle ergometer and 5-minute dynamic stretches, followed by a jump testing protocol to estimate lower-body power and velocity. The jump test protocol involved 5 countermovement jumps and 5 squat jumps at body mass, separated by a 2-minute rest period. All jump movements were video-recorded with the use of a 50-Hz Sony digital camera (TRV950—Sony Corporation, Tokyo Japan) to allow for the confirmation of correct technique. Any jump that was not deemed to be performed correctly was repeated. To maintain correct execution of the squat jump, subjects would hold a stable position at the bottom of the squat for 1–2 seconds, and from there, move upwards, rapidly extending the legs and the hips (avoiding any counter movement [prestretch] around the knee and hip joints). The Gymaware system (Kinetic Performance, Mitch-ell, Australia) was used to collect data on power and velocity for both tests, with the SEM 0.05 m·s⁻¹.

**Swimming-Specific Assessment**

*Fifty-Meter Time Trial (Day 3, 6–8 AM)*. In a 50-m pool after a 1000-m individualized pre-race up, each swimmer performed 2 maximal 50-m freestyle time trials with a dive start with a 10-minute passive break in between trials. During trials, the audience consisted of 2 other swimmers, the coach and performance analyst, no encouragement or feedback was provided. Trials were swum individually to avoid the influence of other swimmers and recorded through a video with the use of a 50-Hz Sony digital camera (TRV950–Sony Corporation) and with electronic timing. The following measurements were recorded during each effort: time, velocity, and drop off between the first and last 25 m. Velocity was calculated with the use of GreenEye Race Analysis (Version 4.8.550–Belconnen, Australia), a program used to analyze race performance. The within-swimmer time trial coefficient of variation was 0.9%.

*Timed Dive Starts (Day 2, 2–4 PM)*. In a 50-m pool after an individualized warm-up, swimmers performed 2 sets of 3 dive starts with a 5-minute rest period between sets, no feedback or encouragement was given. A kicker was in place on the starting block. Participants were instructed to perform the start as they would in a competition and swim maximally to the 20-m mark. Electronic timing was used to signify the start for the swimmer and also trigger the capture of 2 synchronized 50-Hz Sony digital cameras (TRV950–Sony Corporation). The cameras were placed in the sagittal plane, 1 above and 1 below the water and mounted on a purpose-built trolley and rig. The following measurements were collected: mean acceleration, mean power per kilogram, peak power per kilogram, velocity off the block, and time to 5 m and 15 m.

**Statistical Analyses**

Traditional statistical methods and magnitude-based inferences (standardized effects) were used (17) in a single group pre-post intervention design. The dependent measures were swimming time trial performance (over 50 m), dive start, and swim-bench power generation. The independent measure
was the implementation of a targeted dry-land resistance training program. All numeric values were log transformed before analysis to normalize the data and reduce the homogeneity of error. Measures of centrality and spread are reported as mean ± SD. Precision of estimation was made with 90% confidence limits. Magnitudes of correlation were classified using the following criteria: $r = 0.0$ to $0.1$ trivial, $0.1$ to $0.3$ small, $0.3$ to $0.5$ moderate, $0.5$ to $0.7$ large, $0.7$ to $0.9$ very large, and $0.9$ nearly perfect. A correlation was deemed unclear if its confidence interval spanned both a substantially positive ($0.1$) and negative ($-0.1$) threshold value. A sample size of 10 subjects was required for 80% power to detect a substantial improvement in swimming performance in a single group pre-post design assuming a reference change in time trial performance of 2.1%, a typical magnitude of the relationship between sum of skinfolds (body fat) and swimming velocity. At the start of the trial, a large correlation ($r = 0.72$, $0.42$; $r$ value, $0.90$ confidence limits) was evident between sum of 7 skinfolds (body fat) and swimming velocity. At the end of 6 weeks of resistance training, the magnitude of the relationship was moderate for sum of skinfolds and swimming velocity ($r = 0.50$, $0.57$).

Training-induced improvements in jump test velocities in the gym were associated with higher velocities off the block during dive starts. At baseline, relationships between dive start velocity and mean velocity during both the counter movement ($r = 0.15$, $0.67$; $r$ value, $0.90$ confidence limits) and squat jump ($r = 0.15$, $0.67$) tests were trivial and unclear. However, after 6 weeks, the relationships between jump testing and dive start velocity were large (counter movement jump; $r = 0.56$, $0.54$) and very large (squat jump; $r = 0.78$, $0.37$; Figure 2).

**DISCUSSION**

This is the first study to quantify the effects of a dry-land intervention program on swimming performance in Paralympic swimmers. The aim was to evaluate the effectiveness of a dry-land program and to determine whether improvements transferred to swimming performance. Over the 6-week period, intensity and volume of the dry-land strength program was systematically varied to improve dive starts, posture, and swimming performance. Improvements in muscle strength and control were evident in the swimmer’s ability to hold a more stable body position in the water and generate more power in the dive. From these improvements, it seems the transfer of qualities developed in dry-land resistance training can positively influence swimming performance. These results in Paralympic swimmers support previous research in able-bodied swimmers (3,15,32) showing that increases in swimming performance are greater in a combined swimming and dry-land strength training program compared with a swim-only program.

The higher power and acceleration associated with the dive start suggest that the dry-land program improved the muscle activation sequencing used by the Paralympic swimmers. These improvements enabled the Paralympic swimmers to increase their ability to generate higher velocity in a shorter time period, and complete the movement patterns of the dive faster. The improved times to 5 and 15 m from timed dive starts are similar in magnitude to the faster times seen in the 50-m time trials. It seems the 6-week
Resistance Training in Paralympic Swimmers

dry-land program assisted swimmers in becoming more powerful, and being able to better control their bodies through the dive both under and above water. This finding is contradictory to previous research (4,6) that found no significant improvements in dive start performance in either a 6- or 8-week resistance training program. It was theorized that this outcome may be due to the specific skills involved in starting, and thus, improvements in jumping ability might not be transferrable (6). The large and very large relationships seen between jump testing and dive start velocity in the current study suggests the possibility of a commonality between vertical jumping and diving (17,22). However, the contrasting results would suggest different exercise tasks. However, these results conflict with those of Tanaka et al. (34) who claimed that strength exercises executed in the water are more efficient than dry-land training, after finding no significant improvements in swimming performances between a group that combined regular swim training with strength training and a control group who performed swim training only. However, the attendance at 7 competitions during the study period may have eliminated possible benefits of the intervention program due to overreaching or overtraining. The design of this study was based on suggestions that exercises in dry-land strength training programs should replicate the movement velocity and joint angle of that in the water (25,36). In this study, the benefits can be seen in the translation of these adaptations to improved sprint swimming performance with more powerful dive starts leading to faster times to 5 and 15 m, and ultimately faster 50-m time trial performance.

The 50-m time trial was substantially faster (1.2%, ±1.5%; mean change, ±90% confidence limits) after the 6-week intervention period. These changes are worthwhile when improvements in Paralympic swimming times are considered. Over a Paralympic cycle (4 years), the winning time for the 50-m freestyle improved by ~1.7% (Beijing 2008) and ~2.2% (London 2012), whereas S14 times for the same event and over a 4-year period increased by ~6.1% (2011 Global Games). The magnitude of these changes implies the implementation of a dry-land resistance training program would be beneficial to improving sprint performance and increase the swimmer’s chances of medaling. The magnitude of improvement in performance after a short 6-week period late in the training season, and without a taper, is larger than would be predicted for a swim-only program over the same time period. However, these changes are slightly smaller than has been reported with previous studies showing between 1.3 and 4.4% improvements with intervention programs (9,32). This difference may be due to the subject groups, with studies showing that improvements in swimming performance in Paralympic swimmers do not seem to be as great as able-bodied swimmers. In this cohort of Paralympic swimmers, typical improvements of ~0.5% per year have been reported (12), whereas in a previous study on able-bodied swimmers (1), that investigated seasonal changes in submaximal and maximal velocity, the performance of male swimmers improved by 1.5% (95% confidence limits ±1.0%) and females by 2.2%. The intervention here was completed 4 weeks before the selection trials, which is the beginning of the international season. It seems that over a short period at a critical time of a season that substantial improvements in strength, power, and sprint swimming performance can be obtained in Paralympic swimmers.

In general, the Paralympic swimmers who generated greater mean power on the swim-bench swim faster in the 50-m trial. However, there was substantial variability between individual swimmers, and this relationship was smaller than has been reported in previous studies. In 21 Paralympic swimmers, a large relationship between mean power and swimming velocity was evident over 100 m ($r = 0.53$, $p < 0.028$; $r$ value, ±90% confidence limits) (10). Similarly, able-bodied swimmers exhibited a very large relationship ($r = 0.90$) between power production on a swim-bench ergometer and velocity over 25 yards (29). We observed that swimmers with certain disabilities (e.g., cerebral palsy) had difficulty in completing the maximal effort 120-second swim-bench protocol. Future investigators might consider using a shorter protocol (30 seconds) to reduce the possibility of some swimmers being disadvantaged.

**Practical Applications**

Dry-land exercises that target specific motor skill and coordination relevant to Paralympic swimming can improve strength, power, dive starts, and free swimming velocity. Despite the large variation in disabilities being a fact of life in Paralympic swimming, this study showed that a generalized program over a 6-week period can elicit improvements in Paralympic swimmers that are transferrable to swimming performance. A dry-land resistance training program that is more individualized in regards to the particular exercises prescribed on a swimmer-to-swimmer basis depending on their underlying disability may elicit greater improvements.

To complement dive start testing and training, it would be beneficial to incorporate a squat jump with concentric only movement given it is closely associated with swimming, as there is no leg-orientated countermovement involved during starts or turns. This adaptation should translate to improvements in the pool and enable strength and conditioning
coaches to track improvements in power generation. Swim
bench testing, however, seems less useful in monitoring the
effects of short-term training.

Coaches and swimmers are encouraged to undertake
continuous dry-land training programs throughout the
season. This approach should enable the development of
the upper body for increases in propulsion through the
water, strengthening of the shoulder girdle to reduce risk of
injury, an increase in strength and power of the lower body
to improve velocity generation during the dive start, and
better activation and core of the core muscle to maintain
body position in the water to minimize drag.

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