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RESEARCH ARTICLE

Land Based Resistance Training and Youth Swimming Performance

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Abstract

Resistance training has been shown to have both performance-enhancing and injury-reducing benefits in youth athletes. The benefits are somewhat overlooked by many swimming coaches, therefore the effects of a structured resistance training programme in highly trained youth swimmers was investigated. Nine competitive youth swimmers (age: 13 ± 1.1 years) underwent a 7 week dry-land resistance training programme. Swimming performance and other relevant physiological parameters were measured pre- and post-training. There was a small non-significant improvement in swimming performance following the 7 week training programme (100 m freestyle; $p > 0.05$, ES = 0.26). Countermovement jump height ($p < 0.05$, ES = -1.26), back and leg strength ($p < 0.05$, ES = -1.85) and number of push ups completed in 60 s ($p < 0.05$, ES = -1.86) all significantly improved. Although the resistance training programme did not significantly improve swimming performance, other physiological parameters, important for success in the pool, did significantly improve. It may be that an adaptation period is needed so the swimmers can learn to efficiently apply their increased force in the water.

Keywords

Swimming, Performance, Strength, Power, Resistance training

Introduction

Swimming performance requires swimmers to cover the event distance in the shortest time where the outcome of a race can ultimately be decided by fractions of a second [1]. Success can be attributed to the differences in biomechanical, physiological and anthropometric factors [2] and subsequently the ability of a swimmer to repetitively overcome the resistance of the water in an efficient manner and produce effective starts and turns [3,4].

Appropriate Resistance Training (RT) has been shown to have performance-enhancing and injury-reducing benefits in youth athletes [5,6]. The awareness of such benefits is demonstrated by an increasing number of swimming coaches working with different age groups that incorporate dry-land training, including RT, into their swimming programmes [7]. Although RT is associated with increased strength, power production [8] and the rate of force development [9], the exact effects of various dry-land training interventions on swimming performance, particularly in youth swimmers is unclear. A number of studies have found a positive relationship between strength, power and swimming performance. For example, Keiner, et al. [10] investigated the influence of maximal strength performance on sprint swimming performances in male and female youth swimmers (17.5 ± 2.0 years) and found there to be strong negative correlations between leg strength (1 RM squat), speed-strength and swim performance particularly for short distances (up to 25 m). They also found a correlation between the strength tests of the upper body and swim performance. The authors therefore concluded that maximal strength of both the upper and lower body can be good predictors of swim performance [10]. Within a similar age group (17.9 ± 2.9 years), an eleven week combined strength and endurance training programme was found to have a significant effect on 400 m freestyle performance, tethered swim force and maximal strength [11]. Similar findings have also been found in international male swimmers where lower body strength and power were significantly related to 'time to 15 m', at the start of a 50 m freestyle maximum effort thus highlighting the importance of strength and power to performance [12].

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Table 1: Characteristics of youth swimmers (mean ± SD).

	Chronological age (years)	Time in competitive swimming (years)	Average training per week (hours)	Average distance per week (km)	100 m freestyle PB (s)
Male (n = 4)	13.5 ± 1.0	5.5 ± 1.0	13.0 ± 1.0	37.5 ± 5.0	66.5 ± 5.7
Female (n = 5)	12.6 ± 1.1	4.2 ± 0.8	11.3 ± 2.4	34.0 ± 6.5	67.6 ± 5.4
All (n = 9)	13.0 ± 1.1	4.8 ± 1.1	12.1 ± 2.0	35.6 ± 5.8	67.1 ± 5.2

However, strength gains have not always been found to be associated with an improved swimming performance. Garrido, et al. [13] investigated the effect of combined dry-land strength and aerobic training in young swimmers over an 8-week period. The main findings suggest that strength training did not improve sprint performance but the authors acknowledge there was trend towards a greater performance improvement in the experimental group over the control group in both 25 m and 50 m freestyle. Furthermore, within a group of male intercollegiate swimmers, an 8-week resistance training programme improved strength but not swimming performance with the authors suggesting that this may be due to the specificity of training used within the dry-land programme [14].

In addition to whole body strength and power, core stability is recognised as an important determinant of successful swimming performance. The core provides a reference point for all movement in the water due to there being no base of support [15]. The ability to maintain posture, balance and alignment in the water can be key to minimising drag and ensuring propulsive forces are generated more effectively [16]. Conversely, lack of core stability can lead to legs dropping or unnecessary lateral movement of the legs and hips causing an increase in drag [17]. Despite the premise that core stability is beneficial to swimming performance research in the area is minimal. Weston, et al. [18] investigated the effects of a 12 week isolated core training programme on 50 m freestyle performance in national youth swimmers. They found that the core training intervention had a large beneficial effect on 50 m freestyle performance, whereby, swimmers improved performance by 2.0%. Despite the lack of significance, due to variation in swimmers response, the authors believe that this improvement represents a clear beneficial effect of the core training programme [18].

Due to the importance of strength, power and core stability to overall swimming performance and the lack of research conducted using a mixed-sex group of adolescent swimmers, the aim of this study was to investigate the effect of a 7-week in-season dry-land resistance training programme, which included concurrent development of core stability and balance, on swimming performance and other meaningful physiological and anthropometric variables. It was hypothesised that there would be a significant improvement in muscular strength and power measures and overall swimming performance.

Methods

Experimental overview

This investigation used a one-group pre-post-test experimental design where all participants were required to complete a continuous 7-week dry-land training programme. The programme aimed to develop overall strength and power and was carried out twice a week in addition to normal swim training sessions. Between and within sex comparisons were made in all performance, physiological and anthropometric characteristics to assess pre- and post-training differences.

Participants

Nine competitive youth swimmers (4 male and 5 females) from a local community swimming club volunteered to participate in the study. All swimmers were regional level swimmers and trained for a minimum of eight hours a week in the pool but had little experience of structured land based resistance training. Participants reported no injuries or illness prior to or during the training period and attended all regular training sessions in the pool during the intervention. Training characteristics are outlined in Table 1. The study was approved by the Abertay University's ethical committee and all procedures were explained to the participants and their parents, who signed an informed consent form and medical history questionnaire.

Procedures

The 7-week dry-land training programme consisted of two 60 minute sessions per week separated by at least 48 hours and performed prior to regular in-water training sessions. The duration of the programme (May to June) was determined due to competition commitments with the national championships taking place two weeks after the completion of the training intervention. The training programme was designed in accordance with the youth resistance training guidelines ensuring appropriate progression for each individual swimmer [8]. Progression and technique were closely monitored by a Certified Strength and Conditioning Specialist throughout the training programme with all loads monitored and recorded for each individual swimmer. Due to the age and inexperience of the participants, the initial 4 weeks of the programme were designed to develop whole body strength and technique to minimise the risk of injury from improper movement patterns. The following three weeks of the programme were subsequently aimed at further developing strength in addition to whole body power. Across the 7 weeks, exercises also aimed to concurrently develop core stability, balance, flexibility and co-ordination. All sessions were preceded by a 10 minute dynamic warm-up which included skipping, leg swings (forward/back and left/right), straight arm behind back claps, shoulder bridge, arm rotations, body weight squats, forward rolls with jump up and any specific stretching. Over the 7 weeks participants were asked to maintain their habitual pool training regime and dietary intake. Adherence to the resistance training programme ranged between 85.7% and 100% where one swimmer missed 2 of 14 sessions and two swimmers missed 1 of 14 sessions. All training sessions are presented in Table 2.

On the week prior to and the week following the training programme all participants reported to the Human Performance Laboratory to complete a range of physiological tests. Anthropometric characteristics were also established pre- and post-training using a stadiometer (SECA 216 Mechanical Stadiometer; SECA, Hamburg, Germany) to determine stature to the nearest 0.1 cm and a bioelectrical impedance analysis (Tanita TBF 300, Tanita Co., Ltd. Japan) to determine body composition. Performance in 100 m freestyle, individual's preferred event and time to 5.5 m were all assessed in a 25 m pool prior to a regular early evening training session at least 48 hours after the lab based tests had been completed. Procedures for all tests are described below.

Laboratory tests

The following tests were included to allow overall

Table 2: Seven week training programme.

Week 1	Session 1								Session 2						
	Exercise	Sets	Reps/Time	Rest	Set 1 load	Set 2 load	Set 3 load		Exercise	Sets	Reps/ Time	Rest	Set 1 load	Set 2 load	Set 3 load
1	Back squats	3	12	2 min	**Load recorded individually for each exercise. Progression monitored by qualified strength and conditioning coach**			1	Push ups (loaded if needed)	3	12	2 min			
2	Standing shoulder presses	3	12	1 min				2	Isometric squats	3	30 sec	1 min			
3	Lunges	3	12 (6 each leg)	1 min 30 s				3	Pull ups (assisted if needed)	3	8-10	2 min			
4	Bent over rows	3	12	1 min 30 s				4	Isometric legs hold off the ground	3	30 sec	1 min			
5	Planks	3	45 sec	45 s				5	Triceps dips	3	12	2 min			
6	Push ups	3	12	45 s				6	Dorsal raises	3	15	1 min			
7	Sit ups	3	12	30 s				7	SL balance with eyes closed	3	30 sec each leg	1 min			
Week 2	Session 3								Session 4						
	Exercise	Sets	Reps/Time	Rest	Set 1 load	Set 2 load	Set 3 load		Exercise	Sets	Reps/ Time	Rest	Set 1 load	Set 2 load	Set 3 load
1	Back squats	3	10	2-3 min				1	Hand stands	3	12	2 min			
2	SL shoulder presses	3	10 (5 each leg)	2 min				2	Walking lunges	3	8 each leg	2 min			
3	Step ups	3	10 (5 each leg)	2-3 min				3	Pull ups (assisted if needed)	3	8-10	2 min			
4	Body rows	3	10	2-3 min				4	Calf raises	3	12	2 min			
5	Superman	3	30 sec each side	1 min				5	Mountain climbers	3	10	2 min			
6	SL good morning	3	8 each leg	1 min				6	Side planks	3	30 sec each side	1 min			
7	Abs with MB throws	3	15	2 min				7	Sit ups	3	15	2 min			
Week 3	Session 5								Session 6						
	Exercise	Sets	Reps/Time	Rest	Set 1 load	Set 2 load	Set 3 load		Exercise	Sets	Reps/ Time	Rest	Set 1 load	Set 2 load	Set 3 load

1	Back squats	3	8	2-3 min				1	Forward rolls with a jump	3	8	2 min			
2	Shoulder raises with theraband	3	15	2 min				2	Med ball backward lunges	3	8 each leg	2 min			
3	Lateral lunges	3	8 each side	2 min				3	Pull ups (assisted if needed)	3	8-10	2 min			
4	SL balance & catch	3	10 each side	1 min				4	One exercise of choice	3					
5	MB twist throws	3	16 (8 each side)	2 min				5	Burpees	3	8	2 min			
6	Press, rotate & push	3	8	1 min				6	Sit ups	3	15	2 min			
7	SB jacknives	3	15	1 min				7	SL balance with eyes closed	3	30 sec each leg	1 min			
Week 4			Session 7								Session 8				
	Exercise	Sets	Reps/Time	Rest	Set 1 load	Set 2 load	Set 3 load		Exercise	Sets	Reps/ Time	Rest	Set 1 load	Set 2 load	Set 3 load
1	Back squats	3	6	2-3 min				1	Push ups (loaded if needed)	3	8	2 min			
2	Cable rows	3	6	2-3 min				2	Unloaded squat jumps	3	10	2 min			
3	Speed lunges	3	10 (5 each leg)	2 min				3	Pull ups (assisted if needed)	3	8-10	2 min			
4	Body rows	3	10	2 min				4	Explosive med ball passes against wall	3	8	2 min			
5	Overhead squats	3	Technique focus					5	One exercise of choice	3					
6	Lateral step ups	3	8 each side	2 min				6	Dorsal raises	3	20	1 min			
7	Roll outs	3	10	2 min				7	Hanging leg raises	3	15	2 min			
Week 5			Session 9								Session 10				
	Exercise	Sets	Reps/Time	Rest	Set 1 load	Set 2 load	Set 3 load		Exercise	Sets	Reps/ Time	Rest	Set 1 load	Set 2 load	Set 3 load
1	Jump squats	3	6	2-3 min				1	Push ups (loaded if needed)	3	12	2 min			
2	Straight arm pull downs	3	12 (5 each arm)	1-2 min				2	Isometric squats	3	30 sec	1 min			
3	Speed lunges	3	12 (6 each leg)	2-3 min				3	Pull ups (assisted if needed)	3	8-10	2 min			
4	Body rows	3	10	2 min				4	Isometric legs hold off the ground	3	30 sec	30 sec			
5	Russian twists	3	20	1-2 min				5	Triceps dips	3	12	2 min			
6	Planks	3	45 sec	1 min				6	Dorsal raises	3	15	1 min			
7	Hanging	3	30 sec	1 min				7	SL balance with eyes closed	3	30 sec each leg	1 min			

Week 6	Session 11								Session 12						
	Exercise	Sets	Reps/Time	Rest	Set 1 load	Set 2 load	Set 3 load		Exercise	Sets	Reps/ Time	Rest	Set 1 load	Set 2 load	Set 3 load
1	Jump squats	3	7	2-3 min				1	Hand stands	3	12	2 min			
2	45 degree cable rows	3	12 (6 each arm)	2 min				2	Explosive calf raises	3	12	2 min			
3	Walking lunges	3	10 (5 each leg)	2-3 min				3	Pull ups (assisted if needed)	3	8-10	2 min			
4	Push ups	3	12	2 min				4	Mountain climbers	3	10	1 min			
5	Superman	3	30 sec each side	1 min				5	Push ups	3	12	2 min			
6	Hamstring bounce backs	3	8	2 min				6	Side planks	3	30 sec each side	1 min			
7	V-ups	3	15	1 min				7	Normal sit ups	3	20	2 min			
Week 7	Session 13								Session 14						
	Exercise	Sets	Reps/Time	Rest	Set 1 load	Set 2 load	Set 3 load		Exercise	Sets	Reps/ Time	Rest	Set 1 load	Set 2 load	Set 3 load
1	Jump squats	3	8	2-3 min				1	Forward rolls with a jump	3	8	2 min			
2	Shoulder raises with theraband	3	15	1-2 min				2	Med ball backward lunges	3	8 each leg	2 min			
3	Standing jumps	3	5	2 min				3	Pull ups (assisted if needed)	3	8-10	2 min			
4	Body rows	3	10	2 min				4	One exercise of choice	3					
5	Cable twists	3	16 (8 each side)	2 min				5	Burpees	3	8	2 min			
6	Supine bridges (each leg)	3	40 sec	1 min				6	Normal sit ups	3	20	2 min			
7	SL balance & catch	3	8 each side	1 min				7	SL balance with eyes closed	3	45 sec each leg	1 min			

Prior to all sessions a 10 minute dynamic warm up to be completed.

strength, power, muscular endurance, flexibility and cardiorespiratory fitness to be assessed. All tests are widely used within an adolescent population and have been found to reliable measures of the aforementioned fitness components [e.g. 19-21].

Sit-and-Reach Test (SRT)

SRT was used to measure hamstring and lower back flexibility as described by Castro-Piñero, et al. [19]. The sit-and-reach box had a starting point of 15 cm, which corresponded with the position of the feet against the box. Participants were seated on the floor with both knees fully extended and their feet flat against the 30 cm high testing box. Arms were evenly stretched with one hand on top of the other and palms facing downwards. Participants were then instructed to slowly reach forward as far as possible whilst pushing the slide ruler with their fingertips along the top of box without jerking or flexing the knees. Maximum distance in centimetres was recorded once the final position was reached and held for two seconds. The test was completed three times and the best value used for data analysis [22,23].

Countermovement Jump (CMJ)

Similar to previous studies [13,22] the CMJ test was conducted on a jump mat (The Just Jump mat, Probotics, Huntsville, AL) and was used to measure the vertical jump height (cm). Participants started from an upright standing position with their legs fully extended and the feet shoulder width apart. An initial downward movement to a self-selected depth was made by flexing the knees and hips while swinging their arms back and then immediately extending the knees and hips again to jump vertically as high as possible. Three maximum vertical jumps were performed with one minute rest between trials. As a measure of maximal performance, the best result was retained for analysis [22,23].

Handgrip strength

For each participant the handgrip was adjusted to a position which was comfortable and the middle knuckles were resting on the grip bar of the digital handgrip dynamometer (Takei TKK 5401, Takei, Japan). Participants stood with feet shoulder width apart whilst holding the dynamometer at shoulder height with the elbow extended [20]. They were instructed to squeeze the grip bar as hard as possible for at least 2 seconds whilst gradually bringing their arm back towards their side. Participants alternated hands between three maximum attempts with each hand. As a measure of maximal performance, the best result was retained for analysis [22,23].

Leg and back strength

Participants stood on the digital leg and back dynamometer (Takei TKK 5402, Takei, Japan) with the chain adjusted so that their arms were aligned straight down from their shoulders and knees were flexed at approximately 115° [21]. Participants were instructed to keep the back straight and then perform a maximum voluntary isometric contraction by pulling the bar as hard as possible whilst keeping the arms straight. Three maximum trials were performed, with one minute recovery between trials. As a measure of maximal performance, the best result was retained for analysis [22,23].

Muscular endurance (push-ups and sit-ups)

The push-up test was used to assess upper body muscular endurance. Whilst in the prone position, participants were instructed to keep legs together and have their hands pointing forward under their shoulders. For each push-up participants were asked to fully extend their elbows whilst keeping the head, spine and hips in line. In the down position, participants were required to flex their elbows 90° and abduct shoulders 45° as visually assessed by researchers [21]. Each individual was asked to perform as many repetitions as possible in 60 s.

The sit-up test was used to assess abdominal muscular endurance. In the supine position, participants were instructed to flex their knees to 90°, with feet flat on floor and arms crossed on their chest. For each repetition, participants were required to sit up fully. Each individual was asked to perform as many repetitions as possible in 60 s.

Assessment of $\dot{V}O_{2peak}$

A Monark (894E) peak bike cycle ergometer (Monark Exercise AB, Varberg, Sweden) was used for a continuous incremental cycling test to assess $\dot{V}O_{2peak}$ via breath by breath gas collection system (Metalyzer® 3B gas analyser, Cortex, Leipzig, Germany). Heart rate (Polar Electro, Kempele, Finland) was recorded continuously throughout the test. For each participant the saddle height was adjusted so their knee remained slightly flexed after the completion of the power stroke (with final knee angle of approximately 170-175°). Toe clips were used to ensure that the participants' feet were held firmly in place and in contact with the pedals. Briefly, following a three minute standardised warm-up at 50-60 r•min^{-1} using 1 kg resistance on the flywheel, 0.5 kg was added every 120 s until volitional exhaustion or the participant was no longer able to maintain a cadence of ≥ 50 r•min^{-1} [24]. $\dot{V}O_{2peak}$ was taken as the highest value averaged over 30-s collection period. Verbal encouragement was provided throughout the test. As equipment was not available for in-water analysis, a $\dot{V}O_{2peak}$ test on a cycle ergometer was used as it is a safe alternative to measure cardiorespiratory fitness in young participants [24].

Pool tests

Prior to the pool tests all participants completed a standardised warm up. The warm up consisted of 400 m (alternating 50 m freestyle; 50 m backcrawl, R30s), 4 × 100 I.M kick (25 m fast in each 100 m; 1 of each stroke, R15s), 8 × 50 m I.M order (alternating drill and swim, R15s). From a track start on starting blocks, time to complete a distance of 5.5 m was recorded with each participant completing three trials. Time to 5.5 m can be used to measure explosive-reactive power without the influence of variables such as kick strength contributing to performance [25]. Participants then completed 100 m freestyle followed by their preferred event. Between the two swimming trials participants completed 200 m back crawl as active recovery followed by 10 minutes passive recovery. Each trial was performed under simulated race conditions with a block start and instructions to produce a maximal effort. All tests were conducted in the 25 m pool with experienced coaches recording times using a split-timing stopwatch. The use of stop-watches by experienced coaches has been found to have acceptable levels of precision [26] and is similar to procedures used by Weston, et al. [18].

Statistical analysis

Data were statistically analysed using SPSS (Version 22) (IBM, Armonk, NY, USA). Normality of data distribution was tested by a Shapiro-Wilk's test. Differences between pre- and post-test values were determined using a paired t-test. Gender comparisons were evaluated through an independent t-test. Effect Size Statistics (ES) for selected t- and F-ratios were also established. These calculations were based on Cohen's (d) classification of a small ($0.2 \le d < 0.5$), moderate ($0.5 < d < 0.8$) and large ($d \ge 0.8$) ES [27]. Significance was set a priori at $P < 0.05$. All data are presented as mean ± Standard Deviation (SD).

Results

Physiological, strength and performance parameters

At baseline the only significant difference between males and females was in the number of sits ups completed in 60 seconds ($p = 0.011$), therefore changes in physiological characteristics were analysed as one group. The 7 week training programme resulted in significant improvements in CMJ height (cm) (Pre: 25.17 ± 4.20, Post: 29.39 ± 5.20, p = 0.008), leg and back strength (kg) (Pre: 71.06 ± 15.67, Post: 90.94 ± 14.70; p = 0.027) and number of push ups completed in 60 s (Pre: 30.67 ± 9.11, Post: 41.89 ± 7.94; p = 0.000). However, there was a significant performance decrement in time to 5.5 m (Pre: 2.09 ± 0.19, Post: 2.40 ± 0.30; p = 0.007). Table 3 displays the physiological characteristics of the swimmers measured pre- and post-training.

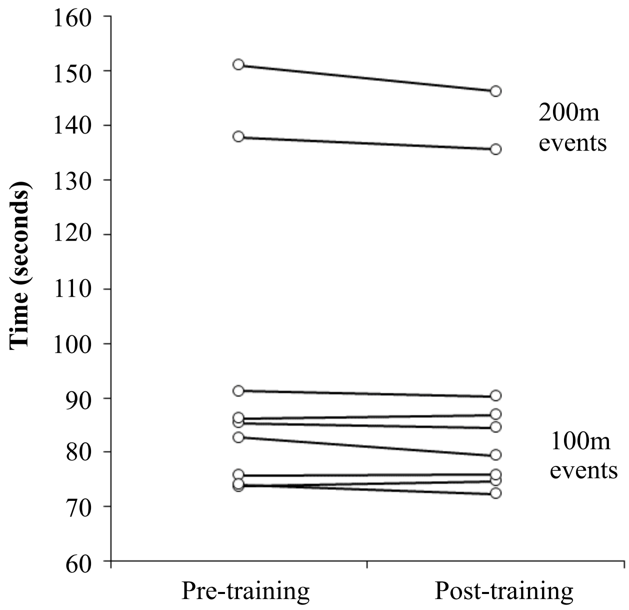

Figure 1: Paired data for individual times (s) pre- and post-training for each swimmers preferred event.

Figure 1 demonstrates patterns of change for individual performance times for each swimmer in their preferred event [28]. Overall, there was a 1.21% improvement in performance times with 6 out of 9 swimmers improving their time post training. The greatest improvement in performance was 4.03% whilst one participant's performance declined by 1.18%. Due to the variation in events statistical analysis of the data was not appropriate.

Anthropometric characteristics

At baseline there were significant differences between males and females in body fat percentage (Male: 15.8 ± 5.1, Female: 23.8 ± 2.7; p = 0.019) and in fat mass (kg) (Male: 7.9 ± 2.1, Female: 13.3 ± 2.5; p = 0.010). Post-training there was a significant difference in fat mass (kg) between males and females (Male: 8.4 ± 3.1, Female: 13.1 ± 2.2; p = 0.031). Over the duration of the training programme both males (Pre: 157.7 ± 10.3, Post: 159.1 ± 10.22; p = 0.008) and females (Pre: 165.6 ± 6.3, Post: 166.9 ± 5.8; p = 0.031) significantly increased in stature. In male swimmers there was significant decrease in both fat free mass (kg) (Pre: 42.7 ± 7.1, Post: 41.2 ± 7.3; p = 0.040) and muscle mass (kg) (Pre: 40.5 ± 6.8, Post: 39.3 ± 6.7; p = 0.033). There were no changes in fat free mass (kg) (Pre: 42.2 ± 3.0, Post: 42.3 ± 2.8; p = 0.825) or muscle mass (kg) (Pre: 40.1 ± 2.9, Post: 40.2

Table 3: Physiological, strength and performance parameters measured pre- and post-training for male and female swimmers.

Variable	Pre	Post	Percentage change (%)	Effect size
Flexibility (SRT) (cm)	17.9 ± 7.6	19.3 ± 7.3	7.4 (↑)	-0.25
CMJ (cm)	25.2 ± 4.2	29.4 ± 5.2*	16.8 (↑)	-1.26
HG strength right (kg)	22.9 ± 7.9	24.1 ± 6.3	5.2 (↑)	-0.24
HG strength left (kg)	22.5 ± 7.0	22.4 ± 4.3	0.5 (↓)	0.03
Back and leg strength (kg)	71.1 ± 15.7	90.9 ± 14.7*	28.0 (↑)	-1.85
Push ups (number in 60 s)	30.7 ± 9.1	41.9 ± 7.9*	36.6 (↑)	-1.86
Sit ups (number in 60 s)	30.8 ± 6.2	35.0 ± 6.1	13.7 (↑)	-0.97
$\dot{V}O_{2peak}$ (ml.kg.min^{-1})	43.5 ± 5.9	43.9 ± 9.3	1.0 (↑)	-0.08
Time to 5.5 m (s)	2.1 ± 0.2	2.4 ± 0.3*	14.6 (↑)¥	-1.70
100 m frontcrawl (s)	69.1 ± 6.5	68.4 ± 6.0	1.1 (↓)	0.26

N = 9 All values are means (± SD). *indicates significant differences between pre and post ($p < 0.05$); ¥indicates a performance decrement. (↑) indicates a percentage increase; (↓) indicates a percentage decrease; Flexibility (SRT) = hamstring and lower back flexibility; CMJ = countermovement jump; HG = handgrip. A negative effect size indicates an increase in score from pre- to post-training.

Table 4: Anthropometric characteristics measured pre- and post-training.

Variable	Male n = 4		Female n = 5	
	Pre	**Post**	**Pre**	**Post**
Height (cm)	157.7 ± 10.3	159.1 ± 10.2*	165.6 ± 6.3	166.9 ± 5.8*
Body mass (kg)	50.7 ± 5.9	49.9 ± 6.1	55.6 ± 5.2	55.5 ± 4.6
Body fat (%)	15.8 ± 5.1	17.1 ± 6.8	23.8 ± 2.7$^{\Delta}$	21.7 ± 5.0
Fat mass (kg)	7.9 ± 2.1	8.4 ± 3.1	13.3 ± 2.5$^{\Delta}$	13.1 ± 2.2$^{\Delta}$
Fat free mass (kg)	42.7 ± 7.1	41.2 ± 7.3*	42.2 ± 3.0	42.3 ± 2.8
Muscle mass (kg)	40.5 ± 6.8	39.3 ± 6.7*	40.1 ± 2.9	40.2 ± 2.7
BMI	20.4 ± 1.3	19.7 ± 1.6	20.1 ± 1.3	19.5 ± 1.6

All values are means (± SD). *indicates significant differences between pre and post ($p < 0.05$); $^{\Delta}$indicates a significantly higher value for females compared to males under the same condition.

± 2.7; $p = 0.817$) for female swimmers. Table 4 displays the anthropometric characteristics of the swimmers measured pre- and post-training.

Discussion

The purpose of the investigation was to assess the response of young competitive swimmers to a 7-week dry-land training programme. The main findings to emerge from the study were that there was a small, non-significant improvement in swimming performance following the dry-land training programme ($p > 0.05$; ES = 0.26). Although swim performance did not significantly improve in the present study, it is important to note that there was a slight improvement of 1.12% (0.77 s) in 100 m freestyle time and on average swimmers also improved their performance in their preferred event by 1.21% with inter-individual variation ranging from -1.18% to 4.03% (Figure 1). These small improvements could ultimately decide the outcome of a race and therefore incorporating a dry land resistance training programme should be recommended to coaches of competitive swimmers [1].

As it is well accepted that jump performance can be used a predictor of muscular power [29], the significant increase in jump height ($p < 0.05$; ES = -1.26), as measured by the CMJ, suggests that over the 7-week period, swimmers significantly increased their lower body power. Similarly, the mean coefficient of variation for the leg dynamometer test has been reported to be 9% in adolescent boys [21] therefore, the significant increase of 28% in leg and back strength ($p < 0.05$; ES = -1.85) suggests that there was a meaningful increase in lower body strength. The hypothesis previously outlined can therefore be partially accepted.

Due to lack of experience with strength and power training and the age of the swimmers within this study the increase in strength and power is likely to be largely due to neural factors such as increased Motor Unit (MU) activation and improvement in MU coordination, recruitment and firing [29]. Although this is somewhat speculative, the decrease in fat free mass (kg) and muscle mass (kg) in the male participants ($p < 0.05$) and lack of changes in the female participants ($p > 0.05$) over the 7 weeks suggests that muscle hypertrophy was not a significant factor in the increase in strength and power and that the improvements were in fact primarily due to improvements in neuromuscular efficiency [30]. There is a common perception among some swim coaches that resistance training will have a negative impact swimming efficiency due to increased drag forces resulting from excessive muscle hypertrophy and a decrease in flexibility [31]. However, in line with the present findings, evidence suggests strength gains in prepubescent individuals are primarily due to neuromuscular changes [32] and researchers and qualified strength and conditioning coaches should work to alleviate this misconception and promote the benefits of resistance training for young athletes [32].

The improvement in lower body strength and power is relevant to the development of overall swim performance. During the turn, the phases of movement are similar to the CMJ in that following initial contact with the wall there is extension of the hip, knee and ankle to generate speed away from the wall [29,33]. During swimming start performance, an explosive movement is used by swimmers to drive from the starting block into the water.

Like the turning phase, the start performance is an important component of overall race performance [34]. Within a 50 m race this initial phase can account for 30% of total race time and so potentially having a significant impact on overall race success [35]. Therefore, in the present study a block start (measured as time to 5.5 m) was included as a performance measure as it can indicate power produced from a block start prior other variables of swim performance becoming a major influencing factor [25]. Despite the improvements in lower body strength and power there was an unexpected performance decrement in time to 5.5 m (0.3 s) ($p < 0.05$; ES = -1.70). It is unclear as to why there was no training transfer to performance. However, within the pool testing environment there are a number of extraneous variables which could have influenced performance including the noise of the pool environment and the swimmers' internal and external motivation. Nonetheless these factors will be present during any competition so for optimal performance swimmers would be expected to deal with the external environment in a way which would not negatively affect their performance.

When Bishop, et al. [25] investigated the effect of an 8-week plyometric training programme in adolescent swimmers (age 13.1 ± 1.4 years) it was found that swim time to 5.5 m was significantly improved by an average of 0.59 seconds in the experimental group, whereas in the control group who continued with their habitual training there was no improvement. The authors suggested that supplementing the swimmers habitual training regime with 2 hours of plyometric training per week resulted in the relevant performance improvement. One possible reason for the differing results of the present study and that of Bishop and colleagues [25] could be related to the type of dry-land training which was implemented. The present study incorporated power training with basic jumping exercises into the dry-land training programme whereas Bishop, et al. [25] utilised a plyometric training programme specifically designed to improve the block start. Among strength and conditioning experts it is well accepted that plyometric training can effectively improve explosive-reactive power [36]. Therefore it is unsurprising that the plyometric training implemented by Bishop and colleagues [25] had a positive effect on block start performance. Developing the dry-land training programme within the present study to incorporate more plyometric exercises and/or for longer period of time may have resulted in an improvement of block start performance. Furthermore, based on best times in front crawl events there is an indication that the group of swimmers within the present study were better trained than the group used by Bishop, et al. [25] and so may have more efficient starts prior to beginning the training programme.

There are a number of previous studies which have investigated the effect of dry-land training programmes on swimming performance with varying results. For example, Aspenes, et al. [11] investigated the effect of combined strength and endurance training on swimming performance in competitive swimmers. Following an 11 week training programme, the intervention group improved 400 m freestyle performance by around 4 seconds ($p < 0.05$), tethered swim force ($p < 0.05$) and maximal strength in bilateral shoulder extension ($p < 0.05$). Within this study the mean age of the experimental group was 17.5 ± 2.9 years (6 of 11 male) whereas in the control group, the mean age was 15.9 ± 1.1 years (2 of 9 male). It is therefore possible that the greater strength gains in the experimental group may be partly related to age and sex characteristics. The swimmers within the present study are younger than those in the study by Aspenes, et al. [11] and more likely to be in a period of growth which is associated with clumsiness in motor co-ordination [37]. This may have limited their ability to efficiently transfer their increase in strength to force production in the water. It is important to note that this is somewhat speculative; however, a significant increase in stature over the 7 week training programme is indicative of a stage of maturation near peak height velocity [38].

However, when Sadowski, et al. [39] implemented a 6 week dry-land power training programme in youth swimmers there were no significant improvements in 25 m freestyle swimming performance in either the experimental or control group ($p > 0.05$). The duration of the training programme within this study was similar to the present investigation, suggesting that a longer duration is needed to elicit significant improvements in swimming performance. This is somewhat supported by the recent findings of Amaro, et al. [31] who found that a 6-week strength and conditioning programme significantly improved dry-land performance (vertical jump and ball throw) in male prepubescent swimmers. No significant improvements in swim performance (50 m freestyle) were found immediately following the 6-week programme, however, after a 4-week adaptation period the experimental group did improve their swimming performance ($p = 0.03$). The authors suggest that this adaptation period may be necessary in young swimmers so they can learn how to efficiently apply the increased force in the water. It can be speculated that in the present study, significant improvements in swimming performance may have been found on the implementation of an adaptation period.

Despite not being specific measures of swimming performance, $\dot{V}O_{2peak}$ flexibility, HG strength and muscular endurance are all fitness components important to successful swimming [13], with deficits in these areas potentially leading to compromised efficiency in the water and increased risk of injury [1]. Of these variables, only upper body muscular endurance significantly improved following the 7-week training intervention ($p < 0.05$; ES = -1.86). An improvement in upper body muscular endurance and therefore improved fatigue resistance should enable swimmers to maintain effective technique and stroke rate over a longer period of time and therefore improving overall swim performance [40]. It is likely that this improvement was due to the training programme incorporating exercises to develop upper body strength and endurance. Even though, there were no significant improvements in the other variables, there was a general a positive trend towards improvement (Table 3). This suggests that the 7 week training programme had a beneficial effect on overall fitness. The lack of improvement in $\dot{V}O_{2peak}$ is not unsurprising given that the overall aim of the training programme was to develop strength and power. However, the authors believed this was an important measure to include in order establishing an overall representation of the swimmers physical capacity.

Finally, the exercises incorporated with the dry-land programme aimed to concurrently develop core stability as it is recognised as a key component of successful swimming performance [15,16]. Although changes in core stability were not directly measured it can be speculated that development of postural stability had a positive contribution in the improvements in muscular strength and power and the ability of swimmers to efficiently transfer force to in-water performance [15]. For future studies, it may useful to include a measurement of core stability as this would enable further recommendations to be made on developing core stability for successful swimming performance [16].

Limitations

The main limitation of the present study was the lack of a control group. Although this is a weakness in the study design, a control group was not possible due to the inherent difficulties in recruiting young competitive swimmers [13] and the numbers of swimmers in the community swim team being able to commit to the duration of the study. Accessing young highly trained athletes can often prove problematic; however, the authors strongly believe that the area warrants further research based on the findings of the present study.

In addition, the growth and development of swimmers over the training period was not measured and may have influenced results. However, there was no access to a physician to allow biological maturity to be clinically assessed and self-assessment using the Tanner scale has often been found to be inaccurate [41]. However, measuring standing and seated height throughout the intervention could have provided a useful indication of maturity offset.

Furthermore, the authors acknowledge that a longer intervention period and/or an adaptation period may provide a greater insight into the impact of resistance training in young swimmers. For future studies this would be taken into consideration along with the inclusion of a more swimming specific tethered swim test.

Conclusions

This study highlights the importance of incorporating a safe and structured dry-land programme within a swimming programme. Any resistance based programme should optimise the development of key performance variables, including, muscular strength and power and core stability. To ensure swimmers potential is reached, coaches of young competitive athletes should be aware of the benefits of land based strength and conditioning and aim to make it an integral part of their training regime. Furthermore, developing strength will also help to minimise the risk of injury. This is pertinent due to the high incidence of injuries particularly of shoulders and knees of swimmers [42]. However, when introducing any dry-land programme for swimmers appropriate supervision is essential for overall safety of participants and to avoid injury as a result of poor technique or excessive overload placed on the muscles [25]. Therefore, to continually improve performance within community swim teams, strength and conditioning coaches and sport scientists should work closely with coaches to develop a safe and effective land based training programme.

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Ethical Statement

All procedures were approved by the Abertay University ethics committee. Participation was entirely voluntarily and participants were made aware of any potential risks. Informed consent was received from both participants and parents prior to commencement of the study.

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