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Original Article

Effect of Dry-Land Core Training on Physical Fitness and Swimming Performance in Adolescent Elite Swimmers

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Abstract

Background: We aimed to investigate the effect of a 12-week dry-land core training program on physical fitness and swimming performance in elite adolescent swimmers.

Methods: Thirty subjects were selected and assigned to the core training group (CTG, n=15) and the traditional weight training group (WTG, n=15) in Seoul, Korea, between Sep and Dec 2016. The field fitness test was performed to determine the isotonic maximum muscular strength (one repetition maximum of deadlift and cable pulldown), anaerobic power (Wingate test), core stability (sports-specific endurance plank), core muscular power (front abdominal power, side abdominal power), muscular endurance of limbs (push-up, endurance jump), and swim performance improvement (personal record). Differences between groups after the exercise intervention were analyzed using two-way analysis of variance with repeated measures.

Results: There were no significant interactions in isotonic maximum strength, anaerobic power (mean power, fatigue index), core muscular power, muscular endurance of limbs (endurance jump), and swim record improvement ($P>0.05$). The anaerobic peak power ($P<0.001$), sports-specific endurance plank test ($P<0.001$), and push-up test ($P<0.001$) showed significant interaction effects.

Conclusion: The 12-week dry-land core training program resulted in statistically significant improvements in anaerobic power, core stability, upper extremity muscular endurance, and swimming performance.

Keywords: Adolescent swimmer; Core training; Elite; Swimming performance

Introduction

Swimmers undergo both water and dry-land training to improve performance. The combined training improves technique, speed, endurance, and muscular strength, which is difficult to achieve by water training alone (1). Thus, developing dry-land training regimens optimized for the characteristics of swimming events is important (2).

Generally, dry-land training intervention studies for improving swimming performance are based on the adaptation of dry-land resistance training. Eighteen personal, 8 Korean, and 4 Asian records were attained by applying periodic strength training to improve the performance of national swimmers (3). Additionally, 6 wk of high-intensity training, performed 4 times a week with 3 sets that consisted of 90% 1-repetition maximum (RM) thrice, 95% 1-RM twice, and 1 bout of 100%+1kg 1-RM, resulted in a 7.3% improvement in 50-m freestyle records in competitive swimmers (4). Further, 12 wk of training at 80%–90% 1-RM performed 6 times with 3 sets resulted in a 2.8% improvement of freestyle records (5). In contrast, a significantly reduced 400-m freestyle record was achieved by a strength and endurance combined program (6). However, the above studies had several problems, such as the lack of control group data, small sample size, and lack of randomization (3-6).

Core muscles play important roles as they connect and support arm and leg movements during swimming (7,8). Reinforcement and stabilization of core muscles are necessary to improve these functions. A well-trained core is essential to maximize performance and prevent injury (7). Core reinforcement and stabilization programs can be adapted for sports activity (8).

Thus, we aimed to investigate the effect of the adaptation of dry-land core training on swimming performance and fitness. The training was designed to reinforce and stabilize the core muscles.

Methods

Participants

The subjects of this study were elite adolescent swimmers who were registered with the Korea Swimming Federation. They had no orthopedic history and no physical limitation hindering them from participating in the exercise program in Seoul, Korea, between Sep and Dec 2016. Thirty subjects were selected with consideration of potential dropout during the research period. There was no drop out after the experiment. The subjects were randomly assigned to the core (n=15) and traditional weight (n=15) training groups (CTG and WTG, respectively).

The subjects of this study gave informed consent and voluntarily participated in and progressed with the study, and the study design was approved by the Korea National Sports University. Additionally, both the adolescent subjects and their parents agreed with the study as the subjects were minors. The characteristics of the subjects are shown in Table 1.

Table 1: The characteristics of the subjects

Variables	*CTG (n=15)*	*WTG (n=15)*	*t*	*P*
Age (yr)	13.00±0.88	13.06±0.88	0.001	1.000
Height (cm)	165.68±7.35	164.41±4.92	0.554	0.584
Weight (kg)	53.66±5.85	53.26±6.94	0.020	0.984
Body mass index (kg/m²)	19.47±1.13	19.76±1.85	0.608	0.548
Muscle mass (kg)	25.33±4.18	24.46±3.60	-0.488	0.630
Body fat (%)	13.90±4.80	15.98±3.91	-1.300	0.204
Careers (months)	36.06±9.58	42.86±12.46	-1.675	0.106
Average swimming distance per week (km)	36.00±8.80	37.20±9.10	-0.367	0.716

CTG, core training group; WTG, weight training group
Tested by independent *t*-test

Body composition

Body composition was measured by bioelectrical impedance analysis (Inbody 770, Inbody Co., Seoul, Korea). The subjects were asked to avoid meals, beverages, alcohol, caffeine, and vigorous physical activity for the two hours before the test, according to the 2013 guidelines of American College of Sports Medicine (9).

Isotonic maximal strength

Deadlift for the lower limb and cable pulldown for the upper limb were measured to determine maximum strength. Measurement of 1-RM was obtained by estimation from that of 10-RM using an estimation table. The resistance training skills and strengths of the subjects were low, which posed a risk of injury (10).

Anaerobic power

A cycle ergom (Excalibur Sport, Lode Co., Netherlands) was used to measure anaerobic power. Height and space between the front and back were adjusted to the body shape of the subject. This was adjusted to full extension of the knee joint when the subject pedaled with the heel in the 6 o'clock direction while in the sitting position. Pedaling was maintained at about 90 rpm for 30 sec before measurements were taken. Counting was started 5 sec before measurement. The pedaling was initiated by signal, and the load was set at 0.075 kp per kg of body weight for 30 seconds. Power during these 30 sec was measured at maximum speed. This study calculated the peak power/kg, mean power/kg, and fatigue index (11).

Core muscular function

A sports-specific endurance plank test, whose validity and reliability were examined, was conducted to measure core stabilization (12). The front and side abdominal power tests (FAPT and SAPT, respectively) were performed, using a 2 kg medicine ball, to determine core muscle power (13). For the FAPT, after 90° knee joint flexion and shoulder-width stance of the foot in the sitting position, the subject would lie down grabbing the medicine ball. The subject was asked to explosively throw the medicine ball as far as possible while lifting the upper limb from the lying position. For the side abdominal power test, after 90° knee joint flexion and shoulder-width stance of the foot in the sitting position, the subject straightened the arm and rotated the body 90° rightward and rotated the body leftward to explosively throw the medicine ball around the left knee. The distance from the end of the foot to the medicine ball was then recorded, respectively (14).

Muscular endurance

Thirty-second push-ups and 30-second endurance jump tests were conducted to measure muscular endurance of the upper and lower limbs (15).

Exercise training program

The exercise program for the two groups was conducted three times a week for 80 min, and the intensity was increased by 5%-10% fortnightly. Dynamic stretching for 10 min and lower intensity static stretching for 10 min were conducted as warm-up and cool-down, respectively.

The CTG used the core exercise program described, who reported a significant improvement in sprint ability in adolescent swimmers (16). According to the periodization theory, the program consisted of core stabilization (4 wk), core muscular power (4 wk), and power endurance (4 wk). Bridge, plank to push-up, and bird dog were conducted for stabilization. Deadlift, squat, and row were conducted using a single arm or leg for resistance exercise. For the power exercise, core training motions such as medicine ball slam, one-arm dumbbell snatch, and chop exercises were conducted.

The WTG used the program described by Song: tissue adaptation (2 wk), maximum strength (4 wk), power muscular endurance switch (4 wk), and then maintained for 2 wk because the subjects were adolescents (1). The exercise program consisted of upper limb (lat-pulldown, barbell press, pull-up, and pullover), lower limb (deadlift and squat), and trunk (sit-ups, back extension, and twist) exercises. The power exercise consisted of barbell snatch and clean.

Statistical analysis

All data from this study are presented as mean±standard deviations, calculated using Windows SPSS, version 21.0 (IBM Corp., Armonk, NY, USA). Two-way analysis of variance with repeated measures was conducted to examine time × group interaction effects. An independent t-test was conducted as a post-hoc test when significant differences were found between groups. Statistical significance was set at $P<0.05$.

Results

Maximum isotonic strength

Analysis of deadlift 1-RM revealed no significant difference in interaction (F=2.554, P=0.121) and group (F=0.343, P=0.563), as shown in Table 2. Analysis of differences observed before and after training within each group revealed a significant difference between the groups (F=307.023, *P*=0.001). Both CTG (*P*<0.001) and WTG (*P*<0.001) showed statistically significant improvement after training. In the case of cable pulldown 1-RM, there was no significant difference in interaction effect (F=3.500, *P*=0.072) and groups (F=0.447, *P*=0.509). Analysis of differences observed before and after training within each group revealed a significant difference between groups (F=128.180, *P*=0.001). Both CTG (*P*<0.001) and WTG (*P*<0.001) showed statistically significant improvement after training.

Table 2: Maximum isotonic strength in the two groups before and after training

Variables	*Group*	*Pre*	*Post*	*P-value*	
Deadlift (kg)	CTG	36.6±13.1	57.6±12.6###	Time	<0.001***
				Group	0.563
	WTG	37.2±12.7	62.3±12.6###		
				Time × group	0.121
Cable pull-down (kg)	CTG	17.5±3.3	27.2±3.9###	Time	<0.001***
				Group	0.509
	WTG	16.2±2.3	26.9±3.6###		
				Time × group	0.072

Values are mean±standard deviation
***P<0.001; tested by two-way analysis of variance with repeated measures
###P<0.001; tested by paired *t*-test
CTG, core training group; WTG, weight training group

Anaerobic power

Analysis of maximum power revealed no significant difference in interaction (F=2.953, *P*=0.097) and group (F=0.735, *P*=0.398) (Table 3).

Analysis of differences observed before and after training within each group revealed a significant difference between groups (F=17.142, *P*=0.001). CTG (*P*=0.047) showed a significantly higher improvement after training than WTG. As for mean power, there was no significant difference in time (F=0.870, *P*=0.359), interaction (F=0.815, *P*=0.374), and group (F=0.017, *P*=0.896).

Table 3: Anaerobic power in the two groups before and after training

Variables	*Group*	*Pre*	*Post*	*P-value*	
Peak power (W/kg)	CTG	8.8±1.7	10.1±2.3$	Time	0.097
				Group	0.398
	WTG	9.2±1.1	8.7±1.0		
				Time × group	<0.001***
Mean power (W/kg)	CTG	7.2±1.5	7.2±1.1	Time	0.359
				Group	0.896
	WTG	7.3±0.8	6.9±0.8		
				Time × group	0.374
Fatigue index (%)	CTG	9.4±9.6	14.4±10.1	Time	0.030*
				Group	0.794
	WTG	10.7±8.5	11.4±8.9		
				Time × group	0.103

Values are mean±standard deviation
*P<0.05, ***P<0.001; tested by two-way analysis of variance with repeated measures
$$P$<0.05; tested by independent *t*-test
CTG, core training group; WTG, weight training group

Analysis of fatigue status revealed no significant difference in interaction (F=2.847, *P*=0.103) and group (F=0.069, p=0.794). Analysis of differences observed before and after training revealed a significant difference between groups (F=5.203, *P*=0.030) but not within each group (*P*>0.05).

Core stabilization

Analysis of the sports-specific endurance plank test revealed significant differences in time (F=44.815, *P*<0.001), interaction (F=12.882, *P*<0.001), and group (F=6.207, *P*=0.019) (Table 4). On analyzing differences observed before and after training within each group, both CTG (*P*<0.001) and WTG (*P*<0.001) showed significant improvement after training. On analyzing group differences after training, CTG showed a significantly higher improvement than WTG (*P*=0.003).

Core power

Analysis of the power of the front core muscle revealed no significant difference in interaction (F=1.585, *P*=0.218) and group (F=0.722, *P*=0.403) (Table 5).

Table 4: Core stabilization in the two groups before and after training

Variables	*Group*	*Pre*	*Post*	*P-value*	
Sports-specific endurance plank (sec)	CTG	86.4±27.1	233.0±103.9###$$	Time Group	<0.001*** <0.01**
	WTG	96.8±39.9	141.0±31.5##		
				Time × group	<0.001***

Values are mean±standard deviation
*P<0.05, **P<0.01, ***P<0.001; tested by two-way analysis of variance with repeated measures
##P<0.01, ###P<0.001; tested by paired *t*-test
$$P<0.01; tested by independent *t*-test
CTG, core training group; WTG, weight training group

Table 5: Core power in the two groups before and after training

Variables	*Group*	*Pre*	*Post*	*P-value*	
Abdominal power (cm)	CTG	396.9±140.6	485.4±147.2#	Time Group	<0.001*** 0.403
	WTG	386.5±101.5	429.4±63.3#		
				Time × group	0.218
Side abdominal power (cm)	CTG	296.0± 89.5	355.8±83.4###	Time Group	<0.001*** 0.883
	WTG	330.4±49.3	328.8±49.7		
				Time × group	<0.001***

Values are mean±standard deviation
***P<0.001; tested by two-way analysis of variance with repeated measures
#P<0.05, ###P<0.001; tested by paired *t*-test
CTG, core training group; WTG, weight training group

Analysis of differences observed before and after training within each group revealed a significant difference in time (F=13.126, *P*=0.001). Both CTG (*P*=0.013) and WTG (*P*=0.035) showed significant improvement after training. There was no significant difference in side abdominal power between the groups (F=0.022, *P*=0.883). Analysis of differences observed before and after training within each group revealed a significant difference in interaction (F=29.905, *P*=0.001) and time

(F=26.865, *P*=0.001). CTG (*P*<0.001) showed significant improvement, but there was no significant difference between the groups after training.

Muscular endurance

There was no significant difference in change in muscular endurance of the upper limb between the groups (F=2.440, *P*=0.129) (Table 6). Analysis of differences observed before and after training within each group revealed a significant difference in interaction (F=22.693, *P*=0.001) and time (F=167.680, *P*=0.001). Both CTG (*P*<0.001) and WTG (*P*<0.001) showed significant improvement after training. However, CTG showed significantly higher improvement after training than WTG (*P*=0.036). Analysis of the change in muscular endurance of the lower limb showed no significant difference in interaction (F=4.099, *P*=0.053) and group (F=0.173, *P*=0.681). Analysis of differences observed before and after training within each group revealed a significant difference in time (F=14.624, *P*=0.001). CTG (*P*=0.004) showed a significant increase after training.

Table 6: Muscular endurance in the two groups before and after training

Variables	*Group*	*Pre*	*Post*	*P-value*	
Push-up (reps)	CTG	19.0±9.9	27.8±10.2$^{\#\#\#\$}$	Time	<0.001***
				Group	0.129
	WTG	15.9±9.4	20.0±9.2$^{\#\#\#}$		
				Time × group	<0.001***
Endurance jump (reps)	CTG	35.9±9.8	41.1±10.1$^{\#\#}$	Time	<0.001***
				Group	0.681
	WTG	36.3±9.4	37.9±8.7		
				Time × group	0.053

Values are mean±standard deviation
****P*<0.001; tested by two-way analysis of variance with repeated measures
$^{\#\#}$*P*<0.01; tested by paired *t*-test
$^{\$}$*P*<0.05; tested by independent *t*-test
CTG, core training group;
WTG, weight training group

Discussion

Swimmers have recently adopted dry-land strength training to improve performance. Previously, muscular training was thought to induce a decrease in flexibility and cause side effects due to hypertrophy of muscles. However, muscular functions, such as strength, power, and muscular endurance, are now regarded as important factors in determining performance. Moreover, many countries established good Olympic records through strength training (1). Overall fitness improvement in the conditioning of swimmers has a positive effect on performance improvement (17). Moreover, maximum strength and power show high correlation with start and turn skills. Thus, muscular training, such as plyometric and power lifting, was adopted to improve these factors (18).

For adolescent swimmers who lack strength exercise experience, deadlift and shrug pull, which are basic motions for powerlifting, should be practiced before the main training. Skill improvement and an increase in load of deadlifts that reinforces the gluteus and quadriceps femoris should be a precondition to perform power lifting for improvement of maximum strength and power related to swimming performance (19). A study on muscular strength training development for swimmers also reported that snatch and power clean motion of weightlifting are suitable for smoothly switching the body center and are important factors in developing body muscle. Moreover, they achieved performance improvement by including and adapting the intervention (1).

There was no interaction effect between deadlift and cable pulldown 1-RM. However, CTG showed a 57.0% and 55.1% and WTG showed a 67.5% and 66.2% increase before and after training, respectively. WTG subjects could have had a higher core muscle challenge as it was difficult to apply high-intensity training because they lifted with one leg or got load while in the crawling position during deadlift and cable pulldown exercises. WTG showed a higher increasing rate of 1-RM compared with that of CTG. WTG subjects trained using the traditional exercise method with both legs on the ground. In this study, we failed to investigate a cause-and-effect relationship through multiple regression analysis between swimming record improvement rate and improvement of maximum strength. A study defining fitness factors that largely affect performance according to swimming style and race distance could positively affect performance improvement through more efficient training.

The high correlation between performance and Wingate anaerobic test results in swimmers reflects the high-level skill and anaerobic capacity required in races (20). An advanced study on the anaerobic power of swimmers (21) reported a high correlation between anaerobic power, peak power, and mean power, measured by an arm-ergom, and between fatigue index and 50-m and 40-m swimming speeds measured using a cycle ergom. The improvement of peak power in the Wingate test in the muscular strength training program at each training stage for members of the national team means the improvement of capacity to handle the second half fatigue in the swimming race. Motion repetition number or intensity settings are particularly important at the time that power is switched to endurance (1).

There was an interaction effect in peak power for body weight through the Wingate test in this study. CTG showed significant improvement before and after dry-land training, and WTG showed a slight decrease. Even though power was increased, there was no cause-and-effect relationship with swimming performance. A small number of exercise repetitions in the power and endurance periods, non-ideal tempo setting, and the inclusion of sprint to endurance players as subjects could have affected this result. Future studies would have to develop a method to measure anaerobic power that shows the closest correlation to the performance of a swimmer.

Recently, core function has been emphasized for elite player performance improvement. Therefore, exercise to reinforce core muscle is being applied to muscular strength and conditioning programs (8, 22). Improvement of core stabilization is based on the strength of the upper and lower limbs, and has a positive effect on performance improvement. Additionally, even though a well-trained core is essential for optimal performance and injury prevention (7), there is a dearth of well-designed studies on core function improvement showing a positive effect on performance (16). Core training is effective in improving swimming performance and demonstrated improvement of core muscle function and 50-m freestyle records through a 12-week core training program (16).

This study also showed improvement in swimming records and a significant increase in plank pose holding time through adoption of a 12-week core training program for middle-school swimmers. Although CTG showed a relatively lower increase compared with WTG, the significant improvement in core muscular function suggests that improved core muscular function would contribute to an improvement of swimming records. Additionally, although both groups showed significant improvement in front power after application of dry-ground training, CTG showed a significantly higher improvement in side power than WTG. The higher improvement of core function in CTG could be due to the organization of the major core stabilization exercise and the half kneeling and tall kneeling positions that challenge the core muscle compared with the sitting or standing pose of the resistance exercise of the limbs (23).

The arms and legs are direct exercise performance agents in most swimming motions. However, arms and legs can only be reinforced when the core muscle is strong. Lack of core muscular function hampers the secure stabilization of arm and leg motion when it gets strong loads. Training programs for young players during the growth period should start from the core muscles that link and support limbs rather than starting with arm and leg training. A sprint record was improved using this method (24).

During the FAPT, the subject cannot strongly lift the trunk if the front abdominal muscle and pelvic flexor lack power. Instead, this would result in a shorter distance as the subject would have to throw the medicine ball using shoulder extension power because rhythm of trunk lifting motion cannot be used. During swimming, shoulder extension power is the most important motion to build driving force for paddling water. Therefore, it should be based on a strong core muscle. Thus, this method can be widely used as an efficient measurement and evaluation-based training program.

In swimming, the muscular power of the lower limb, which is important for starting and turning, can be improved by squat and plyometric exercise (17). Counter movement jumps and Sargent jumps were performed to measure lower limb muscular power. Adolescent female swimmers showed significant improvement in Sargent jumps by the 8th week of combined plyometric and daily swimming training. Additionally, lower limb muscular strength has been reported to be a particularly important determinant of performance in world-class 50-m swimmers. Moreover, there was a significant negative correlation between jump height and initial 15-m record (25). Both groups showed no significant differences in the current study. The amount of plyometric exercise training or load in the exercise program for the two groups could have been insufficient; therefore, jump capacity did not improve. Plyometric exercise should be organized in the power and endurance formative periods in future program designs.

Swimming is regarded as a classical endurance exercise in which the body continuously repeats a given motion. Leaders and trainers recognize power endurance that repeats motion quickly as an especially important fitness factor for the performance of elite swimmers (1). A study of high-intensity interval training that combined muscular strength and endurance in adolescent swimmers found no significant improvement in muscular endurance and cardiorespiratory fitness but showed 400-m swimming record improvement (6).

This study used push-up tests and endurance jumps to measure muscular endurance, and an interaction effect was found. Both groups showed significant improvement after dry-land training, and CTG showed higher improvement than WTG. In the push-up test, core stabilization plays a basic role as it should maintain the body straight from the cervical region to the foot as well as the upper limb. The CTG showed higher improvement than WTG, although the difference was not statistically significant. During endurance jumps, CTG showed significant improvement after the dry-land training program.

This study had several limitations. First, the subjects of this study were adolescents and in their growth period; therefore, the improvement in fitness and records might be due to growth. Second, in this study, except during the 12-week intervention, sleeping time, diet, and other factors were not controlled. Third, due to the small sample size, the results of this study do not represent the entire Korean swimming population.

Conclusion

Twelve weeks of dry-land training based on the core training program of this study showed improvement of core-muscular function, muscular function of the upper and lower limbs, anaerobic power, and performance. This suggests that core training to improve core-muscular function has a positive effect on performance improvement.

Ethical considerations

Ethical issues (Including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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This article is a condensed form of the first author's doctoral thesis from Korea National Sport University (2017).

Conflicts of interest

The authors have no conflicts of interest to declare.

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