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Effects of combined linear and nonlinear periodic training on physical fitness and competition times in finswimmers

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The purpose of this study was to investigate the effect of combined linear and nonlinear periodic training on physical fitness and competition times in finswimmers. The linear resistance training model (6 days/week) and nonlinear underwater training (4 days/week) were applied to 12 finswimmers (age, 16.08±1.44 yr; career, 3.78±1.90 yr) for 12 weeks. Body composition measures included weight, body mass index (BMI), percent fat, and fat-free mass. Physical fitness measures included trunk flexion forward, trunk extension backward, sargent jump, 1-repetition-maximum (1 RM) squat, 1 RM dead lift, knee extension, knee flexion, trunk extension, trunk flexion, and competition times. Body composition and physical fitness were improved after the 12-week periodic training program. Weight, BMI, and percent fat were significantly decreased, and trunk flexion forward, trunk extension backward, sargent jump, 1 RM squat, 1 RM dead lift, and knee extension (right) were significantly increased. The 50- and 100-m times significantly decreased in all 12 athletes. After 12 weeks of training, all finswimmers who participated in this study improved their times in a public competition. These data indicate that combined linear and nonlinear periodic training enhanced the physical fitness and competition times in finswimmers.

Keywords: Combined linear and nonlinear periodic training, Physical fitness, Competition times, Finswimmers

INTRODUCTION

Periodic training, one of the training methods to improve muscular function and athletic performance (Simao et al., 2012), effectively decreases injury resulting from overtraining and fatigue and can promote athletic performance by applying appropriate training periodically for a specific event(Graham, 2002). A periodic training program consists of a macro-cycle of at least 6 months to 1 year, a meso-cycle of 3 to 6 months, and a micro-cycle of 1 week.

Periodic training can be either linear or nonlinear. Linear training is a traditional method that maximizes muscular strength and power and improves athletic performance by gradually modulating exercise intensity from low-intensity, high-volume training to high-intensity, low-volume training on a specific schedule (Baker et al., 1994; Brown et al., 2001). Nonlinear training is a transformative method that enables field application in accordance with environmental changes such as game schedules and off-season training by changing exercise intensity and amount of training on a weekly basis (Simao et al., 2012). Training programs and methods should be selected according to the nature of the event and the degree of training (Kibler and Chandler, 1994). Traditionally, there has been a bias against muscular strength training for swimmers because it was thought to have a negative effect on athletic performance due to reduced flexibility caused by muscular hypertrophy and increased underwater weight caused by the increased lean mass. However, because finswimmers repeatedly perform butterfly-kick movements with a heavy monofin and encounter water resistance, the athletes need whole-body muscular strength to overcome water resistance and gain momentum (Zamparo et al., 2002). Furthermore, because muscle characteristics such as strength and quick adaptation are correlated with speed (Hawley et al., 1992), muscular strength training can improve the athletic performance of finswimmers. Previous studies (Chia et al., 2013; Garrido et al., 2012; Oshita et al., 2013) reported that physical strength and performance of swimmers and finswimmers significantly improved after muscular strength training.

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However, results of previous research comparing linear with nonlinear periodic training have been inconsistent. Monterio et al. (2009) and Peterson et al. (2008) reported that nonlinear periodic training increased strength more than linear periodic training. In contrast, Buford et al. (2007) and Hartmann et al. (2009) reported no difference between the linear periodic training and nonlinear periodic training.

These inconsistent results were thought to be caused by various factors such as genetic differences between athletes and nonathletes, the exercise experiment used, and physiological adaptability (Kibler and Chandler, 1994; Tan et al., 1999), and it has been suggested that studies should be conducted comparing different periodic training methods that make the most of an athlete's ability and that can verify the effects (Daniel, 2007; Graham, 2002).

It is especially thought that the duration of field and underwater training needs to be shortened in accordance with the athlete's condition and training situation. Furthermore, additional specific training that can stabilize core muscles is required because finswimmers especially need lumbar muscular strength. Training programs also need to be adapted for the different events, that is, short-, middle-, and long-distance races. Consequently, the purpose of this study was to examine how combining both linear and nonlinear training affects body composition, physical strength related to athletic performance, and swimming times of high school short-distance finswimmers through linear periodic field training and nonlinear periodic underwater training that regulates the amount of training to suit the training purpose, the specific event, and the finswimmers' environment. Our goal is to present an effective periodic training method for short-distance finswimmers.

MATERIALS AND METHODS

Subjects

The subjects were 12 elite high school finswimmers who had been swimming competitively for at least 3 yr. The participants were informed about the purpose of the experiment, the procedures, and the possible discomforts, risks, and benefits of the study before they signed a consent form. Data were collected before and after the training program. Subject characteristics are shown in Table 1.

Table 1. Subject characteristics

Group	Mean ± SD
Age (yr)	16.08 ± 1.44
Height (cm)	172.68 ± 5.30
Weight (kg)	72.99 ± 8.11
%fat (%)	20.04 ± 3.70
FFM (kg)	53.91 ± 4.45
Career (yr)	3.78 ± 1.9

Body composition

Weight (kg), fat free mass (kg), and percentage fat were measured using the Inbody 3.0 System (Biospace, Seoul, Korea). BMI was calculated as weight/height^2 (kg/m^2). Waist circumference was measured at the midpoint between the lower border of the rib cage and the iliac crest.

Physical fitness

Physical fitness was measured by flexibility, agility, isotonic strength (1 rep max [1 RM]), and isokinetic strength. Flexibility was defined as mobility and suppleness of the lumbar area, as measured by the mean ranges of forward trunk flexion and backward trunk extension in the water (Batista et al., 2009). Forward trunk flexion was measured using the NTCS1001 (Nuritec, Seoul, Korea), and backward trunk extension was measured using the TKK-5404 (Takei, Japan).

The sargent jump test was used to measure the ability to start and turn in water, and it was measured using the TKK-5406 (Takei, Japan). During the test, the subject stands straight, with both feet on the ground; then, the subject reaches up as high as possible and returns to the same position as at the start. This was repeated twice, and the best score was recorded.

The modified 1 RM squat and deadlift were calculated as indicated by Escamilla (2001) for isotonic muscular strength. The subject could lift up to a maximum of 10 repetitions and perform a set with the chosen weight, completing as many repetitions as the subject could until failure without exceeding 10 repetitions. If the subject exceeded 10 repetitions before failure, the subject tried a heavier weight after resting for 10 minutes until the weight could not be lifted for more than 10 repetitions.

Isokinetic muscular strength was measured as trunk extension and flexion (30°/sec) using the Biodex System 3 (BIODEX, USA). The test was repeated 3 times continuously. The final value was divided by body weight, and the best score was recorded.

Competition times

The competition times were noted for both 50 m and 100 m swims from the 2013 conference pre-training times and 2014 conference post-training times.

Table 2. Linear periodic training program

Date	January	February		March	April
Race period	Ready			Race 1	Race 2
Exercise	Adaptation (2 weeks)	Maximal muscular strength (4 weeks)	Speed (2 weeks)	Power-endurance (2 weeks)	Maintains (2 weeks)
Type	Circuit	Resistance	Resistance	Resistance	Resistance
Intensity	1 RM 40-70%	1 RM 85-100%	1 RM 75-85%	1 RM 50-70%	1 RM 80-85%
Content	Little high 4 sets 15-30 repetition	Moderate 5 sets 4-8 repetition	Little high 4 sets 6-10 repetition	Low 5 sets 15-30 repetition	Little low 3 sets 6-8 repetition
Speed	Aerobic endurance	Anaerobic power	Specific speed	Power-Endurance	Specific speed

RM, Repetition maximum.

Table 3. Resistance training program

	Mon/Thur	Tue/Fri
Warm-up	Running 10 min	Running 10 min
Exercise type	Squat (Leg press) Leg extension, Leg curl, Lunge, Calf raise, Sit up 45° (Sit up board), Back extension	Dead lift, Bench press, Shoulder press, Bent over row, Lat pull down, Barbell curl, Leg raise
Exercise method	1-2 weeks	4 sets, 15-30 reps, 40-70% RM intensity, 30-60 sec rest (exercise), 2-3 min rest (set)
	3-6 weeks	5 sets, 4-8 reps, 85-100% RM intensity, 3-5 min rest (set)
	7-8 weeks	4 sets, 6-10 reps, 75%-85% RM intensity, 3-5 min rest (set)
	9-10 weeks	5 sets, 15-30 reps, 50%-70% RM intensity 5-7 min rest (set)
	11-12 weeks	3 sets, 6-8 reps, 80-85% RM intensity, 3 min rest(set)
Cool-down	Stretching 15 min	Stretching 15 min

Reps; Repetition, RM; Repetition maximum.

Periodic training

The periodic training program consisted of combined linear and nonlinear training (Table 2). During the preseason, from December to April, the finswimmers participated in linear periodic resistance training and nonlinear periodic underwater training. Weeks 1–2 were for adaptation, weeks 3–6 for maximal muscular strength, weeks 7–10 for power endurance and speed, and weeks 11–12 for maintenance (Simao et al., 2012).

Resistance training

Resistance training was used to improve lower and core muscle strength (Table 3), with lower muscle training on Mondays and Thursdays and core muscle training on Tuesdays and Fridays.

Underwater training

The finswimming underwater exercise program was modified from that used by Gautier et al. (2004). The endurance program consisted of basic, threshold, and overload endurance training, and the sprint program consisted of lactate tolerance and lactate production training (Table 4).

Statistical analysis

Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) version 18.0 for Window (IBM, Chicago, IL, USA). The results are expressed as means and standard deviations. The paired t-test was used to compare body composition, physical fitness, and competition times before and after training. Statistical significance was set as $P < 0.05$.

RESULTS

Body composition

Table 5 shows the finswimmers' body composition characteristics before and after the 12-week periodic training program. Weight ($P < 0.01$), body mass index (BMI) ($P < 0.001$), and percent fat ($P < 0.01$) were significantly decreased in both groups.

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Muscle mass after training was not significantly different compared with before training.

Physical fitness

As shown in Table 6, all measured physical fitness characteristics were significantly increased after 12 weeks of periodic training, including factors indicating flexibility, trunk flexion forward ($P < 0.05$) and trunk extension backward ($P < 0.001$); the factor indicating agility, the sargent jump ($P < 0.05$); and factors indicating strength, 1-repetition-maximum (1 RM) squat ($P < 0.001$) and dead lift ($P < 0.001$). Knee flexion on the right ($P < 0.05$) and trunk extension were also significantly increased after 12 weeks of periodic training ($P < 0.01$).

Competition times

The finswimmers' best scores during competitions in 2013 and 2014 were collected. As shown in Table 7, the competition times were significantly decreased after 12 weeks of periodic training in both 50-m ($P < 0.05$) and 100-m ($P < 0.05$) races.

DISCUSSION

Our study demonstrates significant improvement in body composition and physical strength appropriate for swimming events as a result of 12 weeks of combined linear and nonlinear periodic training in high school finswimmers.

Swimmers generally have less than 10% body fat, although be-

Table 5. Change of body composition

Variable	Pre	Post	t	*P*
Weight (kg)	72.52±9.09	69.93±8.34	4.689	0.001**
BMI (kg/m^2)	24.28±2.35	23.43±2.28	4.877	0.000***
%fat (%)	19.60±4.84	17.50±4.75	4.249	0.001**
Fat free mass (kg)	53.75±4.68	53.34±4.58	1.735	0.111

BMI, Body mass index; Pre, Pre-training; Post, Post-training; ** $P<0.01$; *** $P<0.001$.

Table 4. Nonlinear underwater training program

Period	Time (week)	Mon	Tue	Wed	Thu	Fri	Sat	Intensity
Adaptation	2 A.M	4,300	4,700	4,500	4,300	4,200	4,300	EN1, EN2
	P.M	2,250		3,000		2,200		EN3, SP1
	Total (m/d)	6,550	4,700	7,500	4,300	6,400	4,300	
Maximal muscular strength	4 A.M	3,600	4,000	4,200	3,600	4,000	4,200	EN2, EN3, SP1
	P.M	3,250		2,250		2,200		EN3, SP1, SP2
	Total (m/d)	6,850	4,000	6,650	3,600	6,200	4,200	
Speed	4	4,050	4,000	4,500	4,200	4,550	3,900	EN2, EN3, SP1
Maintain	2	3,650	3,525	3,250	3,800	3,400	3,200	EN3, SP1, SP2

EN1, Basic endurance training; EN2, Threshold endurance training; EN3, Overload endurance training; SP1, Lactate tolerance training; SP2, Lactate production training.

Table 6. Change of physical fitness

Variable	Pre	Post	t	*P*
Trunk flexion forward (cm)	19.08±5.31	20.56±5.52	-2.327	0.040*
Trunk extension backward (cm)	53.94±5.76	57.01±5.32	-5.159	0.000***
Sargent Jump (cm)	51.16±8.25	55.08±9.40	-2.707	0.020*
Squat (kg)	102.75±27.75	124.67±26.53	-5.417	0.000***
Dead lift (kg)	68.00±27.50	88.83±29.56	-6.108	0.000***
Knee extension on right N (BW)	280.55±43.95	300.10±27.17	-2.353	0.038*
Knee extension on left N (BW)	281.70±44.38	293.06±31.24	-1.533	0.153
Knee flexion on right N (BW)	145.06±21.06	153.27±17.20	-1.717	0.114
Knee flexion on left N (BW)	141.17±23.25	149.81±18.14	-2.175	0.052
Trunk extension N (BW)	376.45±50.39	449.16±60.93	-3.892	0.003**
Trunk flexion N (BW)	196.30±42.71	233.72±41.64	-1.909	0.083
Competition time (sec)	46.57±4.77	43.88±4.53	2.938	0.013*

Pre, Pre-training; Post, Post-training; * $P<0.05$, ** $P<0.01$, *** $P<0.001$.

Table 7. Competition times

	Race	A	B	Difference (B-A)
1	Apnea 50 m	15:70	15:40	00:30
	Surface 100 m	38:56	37:52	01:04
2	Surface 50 m	19:70	18:71	00:99
	Surface 100 m	43:76	42:66	01:10
3	Surface 50 m	19:90	19:90	00:00
	Surface 100 m	45:10	44.65	00:45
4	Surface 50 m	20:60	20:40	00:20
	Surface 100 m	45:30	43:63	01:67
5	Apnea 50 m	20:00	17:80	02:20
	surface 100 m	45:60	40:90	04.70
6	Surface 50 m	23:40	22:69	00:71
	Surface100 m	53:30	49:92	03:38
7	Apnea 50 m	18:01	17:24	00:77
	Surface 100 m	46:80	46:30	00:50
8	Apnea 50 m	17:10	16:87	00:23
	Surface 100 m	38:90	36.99	00:45
9	Surface 50 m	22:83	22:07	00:76
	Surface 100 m	52:00	50:18	01:82
10	Surface 50 m	21:41	20:42	00:99
	Surface 100 m	51:88	46:48	05:40
11	Surface 50 m	21:70	21:15	00:55
	Surface 100 m	47:80	47:61	00:19
12	Surface 50 m	22:30	21:80	00:50
	Surface 100 m	51:20	50:00	01:20

A: 2013' race record, B: 2014' race record.

fore training, our finswimmers had 20.04% body fat, and Ohlberger et al. (2007) similarly reported 21.22% body fat in swimmers. The relatively higher percent body fat in finswimmers may be because they need more buoyancy than other swimmers. However, excessive body fat negatively affects athletic performance by decreasing jumping ability, explosive muscular strength, and speed (Barnard and Wen, 1994). In our study, body weight, BMI, and percent body fat of short-distance finswimmers decreased after 12 weeks of combined periodic training. After training, our finswimmers had 17.50% body fat, a reduction of approximately 10.7%, which should have a positive effect on improving physical strength and swimming time. We did not see any difference in muscle mass after training, which agrees with previous research demonstrating that muscle mass in trained athletes is less likely to change as a result of periodic training (Hartmann et al., 2009; Monteiro et al., 2009). Furthermore, the lack of a change in muscle mass may be because finswimmers spend more time in underwater training than muscular strength training.

In this study, flexibility, explosive muscular strength, and isotonic and isometric muscular strength of finswimmers, evaluated as factors related to athletic performance, all showed improvement after 12 weeks of combined training.

Flexibility means range of joint mobility, and it improves speed through increasing momentum and decreasing inner resistance of muscle (Batista et al., 2009). In contrast, lack of flexibility decreases the efficiency of swimming movements and causes injuries (Willems et al., 2014). In this study, trunk forward flexion and trunk backward flexion, evaluated as indicators of flexibility, showed significant improvement in finswimmers after 12 weeks of combined training, probably because the athletes conducted stretching exercises before and after muscular strength training.

Explosive muscular strength is the ability to move muscles quickly with explosive strength (Baker and Newton, 2008), which is especially important for finswimmers. In this study, the sargent jump, evaluated as an indicator of explosive muscular strength, significantly improved after 12 weeks of combined training. It is considered a result that maximum muscular strength turned into the speed and power worked well. Lee et al. (2011) reported that training conducted with 75–85% 1 RM did not show significant improvement of sargent jump performance during turning period from maximal muscular strength and speed into power muscular strength training. Song and Sohng (2012) also reported that 60–80% 1 RM strength training during the speed period did not result in significant improvement of power. In this study, the exercise intensity of 75–85% 1 RM during the speed period and 50–70% 1 RM during the power and endurance training was similar to previous studies. However, unlike previous research, we found significant improvement in the sargent jump performance, perhaps as a result of our periodic program that consistently maintained an exercise intensity of 80–85% 1RM, which is higher than that of previous studies.

Maximum muscular strength, demonstrated by isotonic muscular strength, is an important factor in determining athletic performance (Komi, 1984), especially for 50-m short-distance finswimmers. The squat and dead lift, as indicators of maximum muscular strength, consist of movements needed by finswimmers that use as major muscles the quadriceps and lumbar muscles (Gulbin et al., 1996). After 12 weeks of combined periodic training, maximum muscular strength significantly increased, squat increased approximately 20.01 kg, from 103.08 to 123.67 kg, and the dead lift increased approximately 30.52 kg, from 68.25 to 89.08 kg. Our results after short-term (12 weeks) training show a higher level of improvement than in the study of Lee (2011), showing a 7.6% increase after 10 months of periodic training. In our study, the increase in maximum muscular strength without

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growth of muscle mass accords with previous research reporting the muscular strength of athletes could increase without muscular hypertrophy through improvement of the neuromuscular system and adaptation process. These results suggest that the training methods and intensity of periodic training conducted in this study increased muscular strength by increasing adaptation of the neuromuscular system and efficiency of mobilization capability of the motor unit.

Using isotonic training exercises as a measurement method enables precise muscular functional examination with various angular velocities as speed of motion changes according to the subject's resistance (Fillyaw et al., 1986). In this study, flexion and extension muscular strength of both the knee joint and lumbar muscles increased after 12 weeks of combined periodic training, but no significant difference was seen in flexion muscular strength. Possibly because finswimming is an exercise performed by repeated extensional motions with a monofin, the flexion muscular strength of the quadriceps and lumbar muscles increased (Gautier et al., 2004), but not significantly, and the extensional muscular strength increased because our periodic training program involved more underwater training than muscular strength training. But there are many differences between flexion and extension muscular strength, and because finswimming involves more extension than flexion motion, which could be the cause of injuries, the addition of flexion muscle strength exercises to the training program would probably be beneficial.

In conclusion, linear and nonlinear combined training conducted over a 12-week short-term period is effective in improving athletic performance by improving body composition and physical strength appropriate for the sport of short-distance finswimmers. Additional training to improve flexural muscular strength needs to be added to the program for future research.

CONFLICT OF INTEREST

There are no potential conflicts of interest relevant to this article.

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