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Plyometric training effects on physical fitness and muscle damage in high school baseball players

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INTRODUCTION

The game and training of baseball involve the repetition of identical movements such as pitching, catching, and hitting the ball, as well as sprint running. To perform these movements successfully, high levels of physical fitness, including speed, power, and agility are essential¹. Furthermore, overhead sports such as baseball involve repetitive, high-intensity, whole-body movements, so adolescent athletes playing such sports should enhance their multi-dimensional exercise capacity, including the anaerobic power and agility of the upper and lower extremities²⁻⁴. A number of studies have thus highlighted that suitable training programs for adolescent overhead athletes are crucial to enhance sport-specific performance⁴, and that various training programs have assisted in maintaining high-level performance and preventing injuries^{5,6}.

Plyometric training is a method of jump-type training known as the stretch-shortening cycle (SSC) that is based on neurophysiological mechanisms⁷. It increases the power of follow-up movements by exploiting the elastic components of muscles and tendons, as well as the stretch reflex⁸. Several studies have indicated that regular plyometric training could improve neuromuscular function and power in adolescent athletes, and that the method can improve performance in sports that require explosive power⁹⁻¹¹. Some recent studies have also reported that plyometric training effectively enhances physical fitness, including speed, power and agility in adolescent athletes^{12,13}.

Conversely, in several studies, plyometric training had no significant effect on sprinting, pitching speed, pitching strength, or physical fitness including agility in adolescent athletes^{14,15}. Some even suggested that the method may not be suitable for adolescent athletes, as the repetition of high-intensity, explosive movements could increase levels of fatigue, muscle damage, and inflammation, with a potential impact on recovery and growth^{14,16-18}, although one study found that the transient increase in muscle damage and inflammation after plyometric training is similar to that occurring after other common training programs¹⁹. Moreover, continuous and regular plyometric training could actually reduce post-training muscle damage, with no negative impact on adolescent athletes²⁰.

Most previous studies regarding the effects of plyometric training on

[Purpose] The objective of this study was to investigate the effects of plyometric training on physical fitness and muscle damage in high school baseball players.

[Methods] The participants in the study included 21 high school baseball players who are healthy and well-training. The participants were randomly allocated to the plyometric training (n=11) and control (n=10) groups. The plyometric training was applied 3 times a week for a total of 8 weeks and the control group took part in only regular baseball skills training without plyometric training. For physical fitness, measures included maximal strength (left and right hand-grip strength), muscle endurance (sit-up), agility (side-step), power (standing long jump), and balance (left and right Rhomberg test). For muscle damage, creatine kinase (CK) and lactate dehydrogenase (LDH) levels were measured.

[Results] The results showed a significant interaction effect between time and groups in left hand-grip strength (P = 0.022), side-step (P = 0.004), and standing long jump (P < 0.001) after the 8-week plyometric training, with greater improvement in the plyometric training group than the control group. On the other hand, there was no significant interaction effect between time and groups in right hand-grip strength, sit-up, left and right Rhomberg test, CK level, and LDH level (P > 0.05).

[Conclusion] In conclusion, 8-week plyometric training had a positive effect on improving physical fitness, such as maximal strength, agility, and power, in high school baseball players without causing additional muscle damage.

[Keywords] baseball players, creatine kinase, muscle damage, lactate dehydrogenase, physical fitness, plyometric training

adolescent athletes have focused on football, volleyball, basketball, and gymnastics^{10,12,14,21-24}, and only a few have investigated effects in baseball players, so the influence of plyometric training on physical fitness and muscle damage in adolescent baseball players remains unclear. The present study aimed to investigate the effects of 8-week plyometric training on physical fitness and muscle damage in high school baseball players.

METHODS

Subjects

The subjects in the present study were 21 male baseball players in a high school in S-city. The subjects showed no musculoskeletal injuries and were not being treated with a medical drug. The subjects were randomized between the plyometric training group ($n = 11$) and the control group ($n = 10$). A detailed explanation of the study purpose and procedures was given to all subjects, who were subsequently asked to voluntarily sign an informed consent form. The physical characteristics of the subjects in each group are presented in <Table 1>.

Table 1. Characteristics of subjects (Mean \pm SD).

Group	Age (yrs)	Height (cm)	Weight (kg)
Plyometric training (n=11)	18.64 \pm 0.80	176.73 \pm 3.95	81.00 \pm 12.22
Control (n=10)	18.50 \pm 0.85	175.50 \pm 4.06	77.60 \pm 6.22

Plyometric training

Plyometric training was performed three times a week for 8 weeks. The training time per session was 1 hour, which always included a warm-up (static stretching, 5 min) and cool-down (dynamic stretching, 5 min). A total of three sets (12 times per set) were performed at W1–W4, four sets (12 times per set) at W5–W6, and five sets (12 times per set) at W7–W8. The resting time was 30 sec between sets

and 1 min between each exercise. The plyometric training program was based on the safety guidelines recommended by the Canadian Society for Exercise Physiology and the National Strength and Conditioning Association. <Table 2> presents the details of the plyometric training program, which was based on the programs of previous studies^{7,25}. The control group did not perform the plyometric training but only general baseball training.

Measuring physical fitness

To measure physical fitness, the following indicators were applied: maximal strength (left and right hand-grip strength), muscle endurance (sit-up), agility (side-step), power (standing long jump), and balance (left and right Romberg test). Left and right hand-grip strength was measured using a dynamometer (EH101–37; Camry Electronic, Co., Ltd., China). The subject was guided to place both feet on the ground at shoulder-width and grip the dynamometer; two measurements without recoil or postural change were taken, and the higher value was recorded. The measurements were taken twice in both the left and right hand. The sit-up was measured with the subject lying on a mat. The subject was guided to bend their knees at approximately 130° to form a ready position. Upon measurement, the subject lifted their torso and let their elbow touch the lower part of their thigh. Each sit-up measurement was taken for 60 sec, while the maneuver was performed once. The side-step was measured using three cones positioned on the ground at 1.2-m intervals. The measurement began at the center cone, while the subject moved to the cones at either end by side-step. Each side-step measurement was taken for 20 sec, while the maneuver was performed once. The standing long jump was measured on a board (NJM-425; NISPO, Taiwan). The subject stood on a start line marked on the board, and the point on the board touched by the heel of the subject performing the long jump was noted. The higher record of two measurements was used in subsequent analysis. Lastly, the left and right Romberg test was performed with the sub-

Table 2. Plyometric training program.

Components	Exercise	Sets & Reps						Time	Frequency
Warm-up	Dynamic Stretching							5 min	3 times/week, total 8 weeks
Plyometric training		1-4 weeks		5-6 weeks		7-8 weeks		50 min	
		Sets	Reps	Sets	Reps	Sets	Reps		
		Squat jump	3	12	4	12	5		12
		Split squat jump	3	12	4	12	5		12
		Pike jump	3	12	4	12	5		12
		Double-leg hop	3	12	4	12	5		12
		Double-leg zigzag hop	3	12	4	12	5		12
		Single-leg hop	3	12	4	12	5		12
		Lateral barrier hop	3	12	4	12	5		12
		Skip	3	12	4	12	5		12
		Depth jump	3	12	4	12	5		12
	Depth jump with Lateral	3	12	4	12	5	12		
Cool-down	Static Stretching							5 min	Rest time between exercise: 1 min

ject standing barefoot on a flat surface; one leg was lifted to form a 90°-angle between the hip and knee joints, and both arms were elevated at 90°. While the subject maintained this posture, the time for which the sole of the target foot was detached from the surface or the opposite foot touched the surface was measured. The Romberg test was performed for 120 sec, and the full score was given if the subject maintained the posture for 120 sec without any errors. The subjects had their eyes open, and two measurements were taken on both the left and right sides; the higher record was used in subsequent analysis.

Markers of muscle damage

The markers of muscle damage were creatine kinase (CK) and lactate dehydrogenase (LDH), which are the two most widely used markers to test muscle damage after exercise^{26,27}. To measure the two markers on the morning of the test, the subjects fasted for approximately 10 h and blood was then collected. On the day prior to the blood test, the subjects were guided not to participate in any strenuous physical activity or training. Upon arrival at the designated area of blood test, the subjects were guided to take a rest before a health professional collected approximately 10 mL of blood. The collected blood was centrifuged at 3,500 rpm for 10–15 min, and the separated plasma was transferred to a tube using a pipette to be stored in a cryogenic freezer for subsequent analysis. The tube was taken out upon analysis, and CK and LDH were analyzed using an automated blood analyzer (Miura One; I.S.E. S.r.l., Italy).

Statistical analysis

For data analysis, SPSS software for statistical analysis was used (IBM SPSS Statistics for Windows, ver. 19.0; IBM Corp., USA). All data are presented as mean and standard deviation. To identify whether a significant interaction effect for time (before training and 8-weeks after training) and group (plyometric training group and control group) had occurred after the 8-week plyometric training, repeated-measures ANOVA was used. The level of significance was set to $P < 0.05$.

RESULTS

Changes in physical fitness after 8-week plyometric training

<Table 3> presents the changes in physical fitness after the 8-week plyometric training, including maximal strength (left and right hand-grip strength), muscle endurance (sit-up), agility (side-step), power (standing long jump), and balance (left and right Romberg test). For right hand-grip strength, no significant interaction effect for time or group was found ($P > 0.05$). On the contrary, a significant time-group interaction effect was found for left hand-grip strength ($P = 0.022$), which was increased to a higher level in the plyometric training group than in the control group. For sit-up, no significant time-group interaction effect was found ($P > 0.05$). For side-step, a significant time-group interaction effect was found ($P = 0.04$), whereby the plyometric training group

Table 3. Changes in physical fitness after 8-week plyometric training (Mean \pm SD).

	Group	Pre	Post		F	P	η^2_p
Maximal strength (right hand-grip strength) Unit: kg	Plyometric training (n=11)	43.81	47.54	Time	6.204	0.022*	0.246
		± 8.03	± 7.25	Group	0.195	0.695	0.008
	Control (n=10)	44.30	44.80	Time X Group	3.616	0.073	0.160
		± 5.53	± 5.76				
Maximal strength (left hand-grip strength) Unit: kg	Plyometric training (n=11)	42.00	47.09	Time	6.741	0.018*	0.262
		± 7.04	± 4.43	Group	0.030	0.865	0.002
	Control (n=10)	44.90	45.00	Time X Group	6.232	0.022*	0.247
		± 5.40	± 6.20				
Muscle endurance (sit-up) Unit: reps	Plyometric training (n=11)	48.72	51.63	Time	2.537	0.128	0.118
		± 6.05	± 4.29	Group	0.009	0.924	0.000
	Control (n=10)	50.00	50.70	Time X Group	0.950	0.342	0.048
		± 4.37	± 3.88				

	Group	Pre	Post		F	P	η^2p
Agility (side-step) Unit: reps	Plyometric training (n=11)	25.54	27.63	Time	22.612	P<0.001***	0.543
		±1.86	±1.62	Group	0.132	0.721	0.007
				Time X Group	10.420	0.004**	0.354
	Control (n=10)	26.60	27.00				
		±0.96	±1.05				
Power (standing long jump) Unit: cm	Plyometric training (n=11)	223.63	243.18	Time	103.059	P<0.001***	0.844
		±15.50	±14.36	Group	0.050	0.825	0.003
				Time X Group	18.105	P<0.001***	0.488
	Control (n=10)	228.00	236.00				
		±14.37	±14.49				
Balance (right Romberg test) Unit: sec	Plyometric training (n=11)	114.18	120.00	Time	0.905	0.353	0.045
		±19.29	±0.00	Group	0.905	0.353	0.045
				Time X Group	0.905	0.353	0.045
	Control (n=10)	120.00	120.00				
		±0.00	±0.00				
Balance (left Romberg test) Unit: sec	Plyometric (n=11)	116.63	120.00	Time	0.905	0.353	0.045
		±11.15	±0.00	Group	0.905	0.353	0.045
				Time X Group	0.905	0.353	0.045
	Control (n=10)	120.00	120.00				
		±0.00	±0.00				

*P<0.05, **P<0.01, ***P<0.001.

showed a higher level of increase than the control group. Likewise, for standing long jump, a significant time-group interaction effect was found ($P < 0.001$), whereby the plyometric training group showed greater improvements than the control group. Lastly, in the Romberg test, no significant time-group interaction effect was found on either the left or right side ($P > 0.05$).

Changes in muscle damage after 8-week plyometric training

<Table 4> presents changes in the muscle damage markers CK and LDH after the 8-week plyometric training. In both groups, the levels of CK and LDH were reduced after 8 weeks, while no significant interaction effect for time and group was found ($P > 0.05$).

DISCUSSION

This study investigated the effects of 8-week plyometric training on physical fitness and muscle damage in high

school baseball players. The results showed that, after 8-week plyometric training, the maximal strength, agility, and power were improved in high school baseball players. The results agreed with several previous studies that have reported significant improvements in the physical fitness of adolescent athletes, including maximal strength, agility, and power, following regular plyometric training^{7,28,29}. Bedoya et al.⁷ reported that plyometric training substantially improved exercise capacity, such as speed and agility, in adolescent football players. Asadi et al.²⁸ reported that vertical jump, broad jump, and agility were improved by plyometric training in adolescent basketball players. A recent study by Jlid et al.²⁹ also showed that plyometric training for a certain duration could effectively enhance football-related performance, such as the change of direction and dynamic postural control in adolescent football players.

Several previous studies have suggested that regular plyometric training may lead to enhanced strength, agility, and power through neurophysiological changes^{7,30-32}. Markovic & Mikulic³² suggested that improvements in SSC after plyometric training improve the neuromuscular system

Table 4. Changes in muscle damage after 8-week plyometric training (Mean \pm SD).

Group		Pre	Post		F	P	η^2p
CK Unit: IU/L	Plyometric training (n=11)	660.10	408.10	Time	8.169	0.010**	0.312
		± 481.95	± 170.24	Group	0.003	0.954	0.000
	Control (n=10)	582.60	500.70	Time X Group	2.120	0.163	0.105
		± 296.74	± 229.36				
LDH Unit: IU/L	Plyometric training (n=11)	475.90	360.70	Time	14.725	0.001***	0.450
		± 157.10	± 129.71	Group	0.914	0.352	0.048
	Control (n=10)	443.50	313.40	Time X Group	0.054	0.818	0.003
		± 108.36	± 43.80				

CK: creatine kinase, LDH: lactate dehydrogenase; **P<0.01, ***P<0.001.

that generates maximum power within a short period of time to act as a bridge between strength and speed. In addition, Bedoya et al.⁷ suggested that, as adolescent athletes are in a phase of active physical development, applying plyometric training during this phase could induce neuronal adaptation of the muscle, increasing the efficiency of the athlete's body for moments that require fast movements. Moreover, the training improves neuromuscular coordination, allowing more efficient use of physical fitness, such as speed, jump, and agility. Davies et al.³³ showed that plyometric training promoted motor patterning and the automation of activity; such changes may improve neural efficiency and enhance neuromuscular performance.

However, in the present study, plyometric training led to no significant improvement in balance, even though several previous studies have reported a positive effect on balance^{34,35}. Differences in the subjects' characteristics, the duration and contents of the plyometric training program, and the methods of balance measurement likely produced the contrasting results. Further studies should investigate the effect of plyometric training on balance in baseball players.

Meanwhile, the markers of muscle damage, CK and LDH, showed no significant between-group difference after the 8-week plyometric training in the present study. In fact, the levels had actually decreased, perhaps as a result of the adaptation response to exercise. Notably, all subjects were well-trained baseball players, regardless of the group, and the control group did perform general exercise rather than no regular exercise, so muscle damage markers may have decreased rather than increased. Changes in CK and LDH can be influenced by training status³⁶⁻³⁸. In individuals who do not partake in regular training or after detraining, these markers can show a significant increase^{36,39,40}, whereas the markers in well-trained individuals can decrease due to the repeated bout effect of regular training^{37,39}. In a study by Marginson et al.⁴¹, plyometric training applied to young

athletes led to less muscle damage than in adult athletes, and even if muscle damage occurred in the early phase of training, repeated plyometric training exerted a protective effect against muscle damage.

Nevertheless, there were limitations to the present study. First, the physical fitness measured in the present study may not reflect the actual movements of baseball players during the game, which are highly repetitive (e.g., sprint, bat swing, etc.). Second, although the training duration was identical between the plyometric training group and the control group, the training intensity or volume varied. It is very difficult to set an identical training intensity or volume for the two groups. Lastly, the subjects in the present study were high school baseball players (mean age: 18 years); the effects of the plyometric training program used in this study remain unknown in baseball players of other age groups or in female baseball players. Further studies should be conducted on a wider scope of individuals.

The results of the present study suggested that 8-week plyometric training in high school baseball players did not increase muscle damage, but had positive effects on physical fitness, such as maximal strength, agility, and power. These findings indicated that plyometric training is an effective and useful strategy for enhancing the performance of adolescent baseball players.

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