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The Effect of 8-Week Plyometric Training on Neuromuscular Activation and Sports Performance for Pre-Pubertal Boys

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Abstract

This study aimed at determining the effects of eight weeks of plyometric training on the neuromuscular activation of the lower extremities and athletic performance of pre-pubertal boys. Twenty-six elementary school boys aged 10–12 years participated in the study (control group: N = 13; training group: N = 13). The training group underwent low-to-moderate-intensity plyometric training three times a week for eight weeks. Before and after the training, four athletic performance tests, namely height of drop jumps, 20-m sprints, standing hops, and an agility test; and electromyographic assessment of the vastus lateralis, biceps femoris, and gastrocnemius during drop jumps, were conducted. After the training, other than the agility test, the performance tests revealed improvement. The drop jump height, standing hop distance, and 20-m sprint time improved by 17.0% ± 9.7%, 10.6% ± 5.2%, and -4.1% ± 1.9%, respectively. Muscle activation in the vastus lateralis and gastrocnemius during the preparatory phase improved in the training group. During the reactive phase, the vastus lateralis, biceps femoris, and gastrocnemius of the training group revealed an increased activation of 98.84% ± 143.89%, 96.65% ± 117.59%, and 84.14% ± 75.38%, respectively. In conclusion, plyometric training enhanced the athletic performance and neuromuscular function of the children.

Keywords: functional task, children, stretch-shortening cycle, drop jump, electromyography

Introduction

Exercise skills, such as agility and power, are basic factors for most athletes, and improving these factors in athletes is the major concern of many strength and conditioning staff. Plyometric training involves an explosive-strength training method; the training combines eccentric and concentric contractions and uses pre-stretch muscles for storing elastic energy and improving the muscle power output during concentric contraction (Durell, Pujol, & Barnes, 2003; Ebben, Carroll, & Simenz, 2004; Ebben, Hintz, & Simenz, 2005; Simenz, Dugan, & Ebben, 2005).

The mechanism underlying plyometric training mainly involves two parts. The first part transforms the elastic energy stored during muscle stretching into the power output of concentric contraction, as mentioned in previous studies (Chu, 1992; Kubo et al., 2007; Markovic, Jukic, Milanovic, & Metikos, 2007; Matavulj, Kukolj, Ugarkovic, Tihanyi, & Jaric, 2001). The second part applies proprioceptor signals induced during muscle stretching to detect the muscle tension and length. The sensory signal then sends nerve impulses into the spinal cord to transfer information to alpha motor neurons that activate agonist muscles, recruit motor units, and suppress the contraction of antagonist muscles; this reaction series is called the stretch reflex (Vaczi, 2000). Chimera, Swanik, Swanik, and Straub (2004) mentioned that the stretch reflex is more likely to recruit motor units during the eccentric phase for the subsequent concentric contraction. Prentice (2004) suggested that in stretch-shortening cycle exercises, which involve eccentric–concentric muscle contraction, muscle spindles participate in the power output through a stretch reflex mechanism. By contrast, another proprioceptor, Golgi tendon organs (GTOs), located in tendons, mainly prevent muscle over-contraction. When muscles are stretched, GTOs act as reflex arcs, which sense the tension and send a neural signal for suppressing the alpha motor neuron and reducing the power output (Prentice, 2004), thus acting as a protective mechanism. However, Hutton and Atwater (1992) reported that plyometric training reduces the sensitivity of GTOs, thus recruiting more motor neurons.

Studies have proven the effects the plyometric training on athletic performance and neuromuscular activation (Gehri, Ricard, Kleiner, & Kirkendall, 1998; Kubo et al., 2007; Markovic et al., 2007; Turner, Owings, & Schwane, 2003). However, previously, plyometric training was mostly provided to adults (Gehri et al., 1998; Kubo et al., 2007; Markovic et al., 2007; Turner et al., 2003) and rarely to children (Allerheiligen & Rogers, 1995; Chu, 1992). Childhood is a crucial phase for cultivating the coordination and agility required in exercises. Faigenbaum (2006) mentioned that the neural plasticity of humans is optimal during childhood. If children undergo plyometric training involving cross hopping, jumping, and running, they are able to not only control their neuromuscular functions but also adapt to and improve their muscle pre-activation capacity. After this growth phase, improving neuromuscular control through subsequent training is less effective.

Studies have identified that plyometric training enhances children's athletic performance with respect to sprint, vertical jump, standing jump, leg power, and agility. Kotzamanidis (2006) recruited 30 boys aged 10–11 years to participate in plyometric training, which lasted 10 weeks; the sprint and vertical jump performance of the training group was more satisfactory than that of the control group. Diallo, Dore, Duche, and Van Praagh (2001) provided 8-week long plyometric training for 12–13-year-old boy football players and evaluated their performance on vertical jump, sprint, and leg power before and after the training. The training group underwent three training sessions each week involving deep jumps, block jumps, and jumping in place; the results revealed a 12% improvement in the sprint performance and leg power of the training group. Furthermore, Faigenbaum et al. (2007) compared the performance of plyometric and resistance training with that of plyometric training alone in boys aged 12–15 years and revealed considerable improvement with respect to the vertical jump, standing jump, shuttle running, medicine ball throwing, and flexibility of the combined training group. The resistance-training-alone group demonstrated a considerable improvement in medicine ball throwing and flexibility. All the aforementioned studies provided low-to-moderate-intensity plyometric training to children and only evaluated their sport or motor performance (Diallo et al., 2001; Faigenbaum et al., 2007; Kotzamanidis, 2006; Matavulj et al., 2001). These studies also revealed that plyometric training considerably improved children's sports performance. However, these studies could not explain the effect of plyometric training on the lower extremity motor unit recruitment patterns. It is unclear whether motor performance improves because of the neural response or the change in the muscle fiber contraction frequency after receiving plyometric training. Therefore, the present study was aimed at understanding the effect of an 8-week long low-to-moderate-intensity plyometric training on the athletic performance of and lower leg neuromuscular activation in boys.

Materials and Methods

Participants

Twenty-six boys aged 10–12 years volunteered to participate in the study. All boys received locally organized basketball training and belonged to the same team for 1 year. All boys were at Tanner stage 2 according to their self-reported secondary sexual characteristics. Exclusion criteria included any lower extremity surgery in the past two years or unresolved musculoskeletal disorders that prohibited participants from sport participation. Participants were randomly assigned to control (N = 13, average height: 142.5 ± 8.2 cm, average body weight: 40.4 ± 6.9 kg, average age: 10.4 ± 0.7 years) or plyometric training (n = 13, average height: 146.4 ± 7.7 cm, average body weight: 40.3 ± 6.0 kg, average age: 10.4 ± 0.5 years) groups. Before participation, all participants received regular basketball training three times a week for a year. The study protocol was approved by the Institutional Review Board of National Taichung University of Education, Taiwan. The study was conducted in accordance with the Declaration of Helsinki. All participants and their parents understood the study protocol and signed informed consent forms before participation.

Procedure

Electromyographic (EMG) assessment. EMG signals were recorded from the vastus lateralis, biceps femoris, and gastrocnemius of the dominant leg. The dominant leg was determined using two principles: the leg that participants used first for kicking a ball and the leg used while taking the first step for going upstairs. Furthermore, electrode placement and recording technique were performed as recommended by Cram, Kasman, and Holtz (1998). Before placing the electrodes over the skin, the skin of the leg was shaved and cleaned with 70% ethanol. The EMG electrode (Motion Control, Iomed Inc., Salt Lake, UT, USA) apparatus included a reference electrode and two bipolar recording electrode units. Each unit comprised self-adhesive Ag/AgCl bipolar surface electrodes and an on-site preamplifier (Multi Bio Sensors Inc., El Paso, TX, USA). The electrodes were then placed over the leg muscles, 10 mm apart (center-to-center distance); a reference electrode was placed over the proximal tibia. Electrodes were placed by identifying the palpating bony landmarks of the lower extremities and the most prominent contraction of the muscle belly during an isometric contraction. Each EMG preamplifier unit was connected to a high impedance (15 GΩ) differential amplifier (common-mode rejection ratio [CMRR] 130 dB at 60 Hz and gain 1,000). The frequency response of the overall system was 40–4,000 Hz, as defined by -3 dB points, and the EMG activity was examined using the Zebris EMG Measuring System (Zebris Medical GmbH, Isny, Germany). The analysis of the frequency content of the rectified signals revealed a frequency of > 6 Hz for 95% of power. Thus, the rectified EMG data were digitally filtered using a fourth-order, zero-phase-shift Butterworth filter with a cut-off frequency of 6 Hz in this study. The signal was then converted from analog to digital data and saved on a computer, in which the raw EMG data were sampled at 1,000 Hz and stored as American Standard Code for Information Interchange (ASCII) data for further off-line analysis by using the Acqknowledge 3.5.7 software (Biopac Systems Inc., Santa Barbara, CA, USA). To normalize the EMG signals, maximum voluntary isometric contraction (MVIC) was recorded for each muscle group before the main study. Participants were asked to maximize the muscle contraction against a static resistance for 5 seconds. The middle 3 seconds of the EMG readings were averaged and represented the normalizing value (100% MVIC). Furthermore, the EMG data of a drop jump from a 25-cm-high wooden box and from the subsequent vertical jump were recorded. To record the ground contact when the participants performed a drop jump, a foot switch was placed on the bottom of the first toe of each participant; the foot switch was synchronized with EMG recorders connected to a computer. Furthermore, a suspension marker was placed on the ceiling behind the participants. During drop jumps, participants were asked to jump as high as possible to touch the marker. Three trials were performed, and the EMG data were collected. The EMG recordings and signals from the foot switch were divided into two phases (Figure 1): preparatory and landing-reactive phases. The preparatory phase encompassed 150 milliseconds before landing, and the landing-reactive phase comprised an initial ground contact of 350 milliseconds after landing (Chimera et al., 2004; Swanik, Lephart, Giraldo, DeMont, & Fu, 1999).

Athletic performance assessment: Drop jumps, 20-meter sprints, standing hops, and the Illinois agility test. Participants performed warm-up jogging for 10 minutes before each test and stood on a 25-cm-high box for performing deep jumps. A piece of reflective striping tape was placed on the xiphoid process of each participant. A JVC video camera (JVCKenwood Corp., Yokohama, Japan) was arranged at a fixed distance for recording the jumping movements, and the Siliconcoach software (The Tarn Group, Dunedin, New Zealand) was used for analyzing the vertical

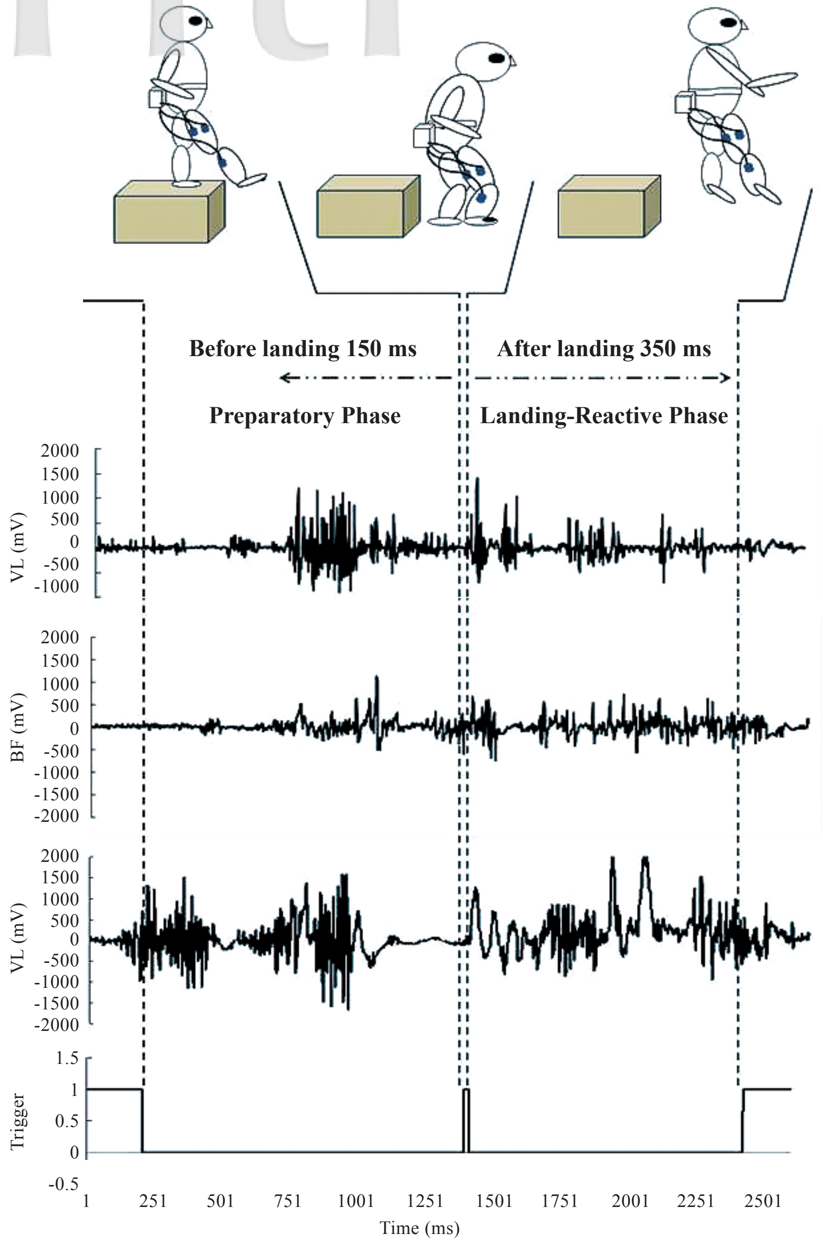

Figure 1. Phases of the drop jump test.

height of the reflective striping tapes. The result was recorded as the height data of the drop jump performance. Furthermore, in standing hop, participants stood on the starting line, with their arms naturally swaying were then asked to jump forward as far as possible, and the jumping distance was measured using a tape measure. In 20-m sprints, participants stood on the starting line, and two wireless infrared interval timers, which were placed on the start and finish lines, were applied for measuring the sprint time. The timer started and stopped when the participants crossed the start and finish lines, respectively, and the recorded time was considered the sprint performance of the participants. The Illinois agility test included linear acceleration, deceleration, and turning in different directions; this test also used the wireless infrared interval timers for recording the time spent. The course was 10-m long and 5-m wide. Four cones were used for marking the start and finish lines and two turning points. Two wireless infrared interval timers were placed at the start and finish line cones for recording the time spent. Four more cones were placed at the center at a distance of 3.3-m apart. Participants were instructed to lie on their front (head toward the start line) with their hands by their shoulders. On the "Go" command, the participants were instructed to quickly get up and run around the course in the indicated direction, without knocking the cones over, to the finish line. Three trials were conducted for each participant, and the most satisfactory trial result of each participant was selected and recorded for analysis. All assessments were scheduled one week before and after the plyometric training intervention.

Intervention of plyometric training. Eight-week plyometric training was provided to all participants. The training strength progressively increased from low to moderate, and the training was conducted three times a week. The training sessions were arranged before each regular basketball training session. All participants received regular basketball training, but only training group with the addition of plyometric training. A 25-cm-high box was used in the plyometric training. The jumping skills of participants varied. Therefore, in this study, for achieving a consistent and uncomplicated training movement, only two jump movements (squat and drop jumps) were performed. The training curriculum is shown in Table 1.

Data reduction and statistical analysis. The study mainly focused on the exercise performance and lower limb EMG activity after eight weeks of plyometric training. In this study, drop jumps were conducted for evaluating the EMG variation in the lower limbs of the participants. The preparatory and landing-reactive phases of the recorded EMG data were processed off-line for normalizing them before the integral EMG (IEMG). The time to peak of EMG and the median frequency of the power

Table 1
Plyometric Training Progression for Pre-Pubertal Boys

Week	Exercise[a]	Set	Repetition	Training volume (step)
1	Squat jump	5	16	80
2	Drop jump	5	12	60
3	Drop jump	5	12	60
4	Drop jump	5	16	80
5	Drop jump	5	16	80
6	Drop jump	5	24	120
7	Drop jump	5	24	120
8	Drop jump	5	12	60

[a] 2 min resting interval between set.

spectral analysis of both phases were extracted.

SPSS 17.0 for Windows was used for the statistical analysis, and the result was presented as mean ± standard deviation. The Student's *t*-test was applied for examining the homogeneity of participants' personal information and the change ratio between the control and training groups. Furthermore, the independent variable was the intervention of plyometric training (control and training groups), and the dependent variables were the change ratios of sport performance (drop jumps, 20-m sprints, standing hops, and the Illinois agility test) and of the EMG activity of lower limbs (IEMG, time to peak EMG, and median frequency during the preparatory and landing-reactive phases). The change ratio was calculated by subtracting the pre-training values from the post-training values, dividing them by the pre-training values, and then multiplying by 100. A p-value < .05 was considered statistically significant.

Results

No significant anthropometric differences were observed between the examined groups (height: $F = .003$, $p = .211$; weight: $F = .079$, $p = .133$); thus, the two groups could be considered similar.

In all performance tests, except the agility test, after the training, both groups revealed a significant improvement of 16.97% ± 9.65%, 11.03% ± 4.76%, and 4.07% ± 1.86% in the height of drop jumps, distance of standing hops, and time of 20-m sprints, respectively ($p < .05$, Table 2).

The EMG activation result of lower limbs is shown in Table 3. In the preparatory phase, only the IEMG from the biceps femoris of the training group revealed non-significantly enhanced activation ($p > .05$); significant differences were observed for all other muscles.

Table 2
Sports Performance Results for Control Group and Training Group (Mean ± SD)

Variable	Control group			Training group				
	Pre-test	Post-test	Change ratio[a] (%)	Pre-test	Post-test	Change ratio[a] (%)	p	Cohen's d effect size
Height of drop jump (cm)	36.08 ± 4.25	36.62 ± 4.96	1.75 ± 9.91	38.23 ± 5.07	44.62 ± 6.17	16.97 ± 9.65	.00*	**1.62**
Standing hop (cm)	170.38 ± 14.89	177.69 ± 11.43	4.65 ± 6.67	168.85 ± 19.6	186.31 ± 19.11	11.03 ± 4.76	.01*	**1.15**
20-m sprints (s)	3.93 ± 0.20	3.89 ± 0.20	-1.09 ± 2.86	3.96 ± 0.31	3.80 ± 0.29	-4.07 ± 1.86	.00*	**1.29**
Agility test (s)	13.55 ± 0.86	13.21 ± 0.76	-2.41 ± 2.86	13.43 ± 1.16	12.98 ± 0.74	-3.08 ± 4.27	.64	0.19

Note. Values in bold indicate Cohen's *d* effect size of greater than 0.8, indicating a large effect.
[a] The change ratio was calculated by subtracting the pre-training values from the post-training values, dividing them by the pre-training values, and then multiplying by 100.
* $p < .05$.

Table 3

Electromyography Results for Control Group and Plyometric Group (Mean ± SD)

	Control group		Change ratio[a]	Training group		Change ratio[a]		Cohen's *d*
Variable	Pre-training	Post-training	(%)	Pre-training	Post-training	(%)	*p*	effect size
Preparatory phase								
VL IEMG (%MVIC)	18.70 ± 9.71	12.17 ± 7.72	-10.89 ± 61.14	14.24 ± 9.63	16.29 ± 7.40	68.61 ± 110.27	.03*	**0.92**
BF IEMG (%MVIC)	5.21 ± 4.14	4.55 ± 0.96	69.00 ± 208.63	5.69 ± 3.81	8.37 ± 5.02	110.33 ± 169.78	.59	0.25
GAS IEMG (%MVIC)	24.25 ± 14.44	27.72 ± 24.53	2.78 ± 63.90	23.92 ± 19.96	35.23 ± 23.21	193.50 ± 249.24	.01*	**0.97**
VL time to peak (ms)	88.69 ± 35.94	99.08 ± 43.66	45.19 ± 104.51	103.15 ± 31.43	75.77 ± 41.76	-22.93 ± 38.12	.04*	**0.90**
BF time to peak (ms)	78.92 ± 49.47	80.92 ± 36.72	118.66 ± 298.82	93.69 ± 43.83	92.31 ± 36.81	22.90 ± 75.77	.27	0.46
GAS time to peak (ms)	56.62 ± 44.28	83.23 ± 45.38	86.97 ± 181.01	82.54 ± 43.19	66.15 ± 37.39	0.61 ± 86.58	.11	0.63
VL FFT (Hz)	299.28 ± 114.89	283.35 ± 87.72	17.82 ± 79.84	296.88 ± 104.11	316.11 ± 73.38	23.84 ± 72.40	.84	0.05
BF FFT (Hz)	267.12 ± 123.76	297.18 ± 94.43	36.51 ± 82.55	286.87 ± 123.82	336.24 ± 117.26	34.38 ± 70.85	.94	0.03
GAS FFT(Hz)	258.41 ± 71.17	275.84 ± 71.65	15.49 ± 45.67	343.14 ± 81.79	313.70 ± 91.03	-4.66 ± 32.92	.21	0.53
Landing-reactive phase								
VL IEMG (%MVIC)	31.93 ± 10.86	24.45 ± 10.68	-11.27 ± 53.81	31.31 ± 17.70	46.88 ± 24.73	98.84 ± 143.89	.02*	**1.06**
BF IEMG (%MVIC)	8.34 ± 4.73	8.92 ± 5.42	18.07 ± 62.96	10.16 ± 6.78	16.15 ± 7.86	96.65 ± 117.59	.04*	**0.92**
GAS IEMG (%MVIC)	20.08 ± 12.72	25.64 ± 33.48	14.91 ± 74.10	17.92 ± 11.70	27.83 ± 11.98	84.14 ± 75.38	.03*	**0.92**
VL time to peak (ms)	178.84 ± 72.08	191.23 ± 70.42	52.40 ± 137.97	181.62 ± 61.88	113.69 ± 65.24	-31.89 ± 41.36	.05*	**0.86**
BF time to peak (ms)	135.08 ± 67.34	160.62 ± 73.13	86.97 ± 181.01	144.01 ± 78.68	133.15 ± 80.91	31.08 ± 94.80	.33	0.42
GAS time to peak (ms)	131.61 ± 78.01	104.23 ± 78.60	-9.48 ± 69.64	146.62 ± 65.54	82.46 ± 75.00	-5.64 ± 159.65	.94	**0.85**
VL FFT (Hz)	307.09 ± 118.35	256.41 ± 91.81	-0.85 ± 56.28	274.64 ± 65.33	254.51 ± 75.46	2.44 ± 57.93	.89	0.06
BF FFT (Hz)	335.64 ± 71.52	293.57 ± 108.06	-6.43 ± 46.71	318.09 ± 103.97	270.79 ± 99.27	-2.18 ± 55.85	.84	0.09
GAS FFT (Hz)	253.91 ± 76.76	322.72 ± 98.39	38.28 ± 71.62	298.38 ± 94.23	321.87 ± 97.97	17.90 ± 50.15	.41	0.34

Note. Values in bold indicate Cohen's *d* effect size of greater than 0.8, indicating a large effect. VL = vastus lateralis; IEMG = integral electromyographic; MVIC = maximum voluntary isometric contraction; BF = biceps femoris; GAS = gastrocnemius; FFT = fast Fourier transform.

[a] The change ratio was calculated by subtracting the pre-training values from the post-training values, dividing them by the pre-training values, and then multiplying by 100.

* $p < .05$.

In the landing-reactive phase, the IEMG from the vastus lateralis, biceps femoris, and gastrocnemius of the training group revealed significantly enhanced activation ($p < .05$), with 98.84% ± 143.89%, 96.65% ± 117.59%, and 84.14% ± 75.38% activation enhancement in the vastus lateralis, biceps femoris, and gastrocnemius, respectively. The time to peak EMG of the vastus lateralis appeared 67.92 ± 70.25 milliseconds earlier ($p < .05$). However, the median frequency of the vastus lateralis, biceps femoris, and gastrocnemius remained constant during the preparatory and landing-reactive phases.

Discussion

Training improved performances of all tests, except the agility test. The vertical and horizontal jump distances increased by 11% and 17%, respectively, in concordance with numerous previous studies (Chelly et al., 2010; King & Cipriani, 2010; Kotzamanidis, 2006; Meylan & Malatesta, 2009; Potdevin, Alberty, Chevutschi, Pelayo, & Sidney, 2011; Rubley, Haase, Holcomb, Girouard, & Tandy, 2011; Santos & Janeira, 2011; Sedano, Matheu, Redondo, & Cuadrado, 2011; Thomas, French, & Hayes, 2009). Most of these studies reported that 6–14 weeks of plyometric training improves vertical jump performance. The present study revealed that vertical plyometric training can not only enhance the vertical jump performance but also improve the horizontal jump. However, in addition to vertical and horizontal jump training, side-direction plyometric training could not improve the vertical jump height. King and Cipriani (2010) compared the vertical jump height of high school basketball players before and after 6 weeks of vertical and side-direction plyometric training; their results also revealed that side-direction plyometric training could not improve vertical jump height. In the present study, the results revealed that vertical plyometric training improves the vertical and horizontal jump performance, possibly because children more satisfactorily and quickly adapt to plyometric movements. However, we did not assess the side-direction jumping ability and compare the adaption to plyometric training between children and adults. The effect of plyometric training involving directional changes on children and adults should be studied in the future.

In 20-m sprint, the training group revealed 4% improvement; however, no significant improvement was observed in the agility test. In brief, straight sprint performance was improved, but varying directional running was not affected. Kotzamanidis (2006) revealed that the sprint speed of boys improved after 10 weeks of plyometric training. Consistent with this observation, Diallo et al. (2001) revealed that the effects of plyometric training last for two months. However, Meylan and Malatesta (2009) provided 8 weeks of plyometric training (including jumping, hurdling, bouncing, skipping) to child soccer players requiring frequent directional changes while running; their results revealed that plyometric training reduces the agility running time by 9.6%. Thomas, French, and Hayes (2009) reported similar results.

Dodd and Alvar (2007) reported no improvement in the T-agility test results of athletes after a 4-week plyometric training schedule. In the present study, the participants revealed no significant change in their agility test performance before and after plyometric training, possibly because they were unfamiliar with the route of the agility test. It is suggested that participants should be allowed to practice several times before the test; however, fatigue should be avoided. Our results revealed no significant improvement in the agility test performance, possibly because the training content mainly focused on drop jump training, which is similar to the sports-specific events of basketball. However, the training programs did not include training in directional change while running. Therefore, the performance of participants on the agility test was not more satisfactory than that on other performance tests.

The training group revealed an improved EMG activation of the vastus lateralis, biceps femoris, and gastrocnemius during the landing-reactive phase. Moreover, the time to peak of EMG of the rectus femoris appeared earlier, suggesting a reduced reaction time of muscle contraction. However, the EMG activation of the vastus lateralis and gastrocnemius, and not the biceps femoris, was enhanced during the preparatory phase. Studies evaluating the lower limb EMG variation of children after plyometric training are rare, and most of the related studies only evaluated children's athletic performances. However, studies on adults have revealed that plyometric sports can alter neuromotor control (Bonacci et al., 2011). Arabatzi, Kellis, and De Villarreal (2010) revealed that plyometric training enhances the muscle activation of the vastus lateralis. Wu et al. (2010) suggested that after plyometric training, muscle activation was enhanced and activated earlier. However, Kubo et al. (2007) considered that jump performance after plyometric training improved because of changes in the mechanical properties of the muscle–tendon complex, not because of muscle activation strategies. In this study, we observed that plyometric training not only enhanced the EMG activation of participants' lower limb muscles but also improved their athletic performance. Moreover, the enhanced muscle recruitment of participants' vastus lateralis was similar to that reported by Arabatzi et al. (2010). Our study revealed the simultaneous effect of plyometric training on participants' motor performance and changes in the neuromuscular recruitment of the lower extremities.

We observed that the median frequency of lower limb muscles was not enhanced or reduced before and after plyometric training, suggesting no variation in the contracting frequency of the recruited muscle fibers. We considered that plyometric training does not change type-I and -II muscle fiber composition (McArdle, Katch, & Katch, 2001). However, the training can change the reaction time of lower limb muscle contraction. We suggested that the possible effect of plyometric training for children was enhancement of the reaction time of the lower extremities. Furthermore, after the training, children's ratio of the hamstring and rectus femoris (ratio of vastus lateralis/biceps femoris, BF/VL) revealed no significant change during the preparatory and landing-reactive phases; however, their ratio of BF/VL was different from that of adults. Future studies are required to clarify the differences in the ratio of BF/VL for children and adults.

During the study, no participants were injured because of the training; therefore, the training protocol of the present study was not causing any harm for participants. In addition, only boys were enrolled; hence, we cannot determine whether sex affected the reaction of the lower limb neuromuscular contraction. This is one of the limitations of the current study. Furthermore, the study mainly focused on children who received basketball training. Therefore, most of the designed plyometric movements were sports-specific events of basketball, such as drop jumps. Consequently, the training may be monotonic, and children may feel bored. Future studies can apply different sports-specific events and jumping directions, such as lateral jumps, forward and backward jumps, and turning jumps, in plyometric training design.

Conclusions

Plyometric training improved the performances of all tests, except the agility test. The vertical and horizontal jump distance increased by 11% and 17%, respectively. The training enhanced the EMG activation of the vastus lateralis, biceps femoris, and gastrocnemius during the landing-reactive phase; the time to peak EMG of the vastus lateralis also appeared earlier, suggesting that the reaction time of muscle contraction decreased. However, in the preparatory phase, only the EMG activation of the vastus lateralis and gastrocnemius, but not the biceps femoris, was enhanced. Based on the results, this study suggests that the plyometric training improved the reaction time of the vastus lateralis muscle contraction for active boys.

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