

## Original Article

# Effect of adding plyometric training to physical education sessions on specific biomechanical parameters in primary school girls

Nadia L. Radwan<sup>1,2</sup>, Waleed S. Mahmoud<sup>2,3</sup>, Rasha A. Mohamed<sup>4</sup>, Marwa M. Ibrahim<sup>2,4</sup>

<sup>1</sup>Department of Biomechanics, Faculty of Physical Therapy, Cairo University, Egypt;

<sup>2</sup>Department of Health and Rehabilitation Sciences, College of Applied Medical Sciences, Prince Sattam Bin Abdulaziz University, Kingdom of Saudi Arabia;

<sup>3</sup>Department of Basic Sciences, Faculty of Physical Therapy, Cairo University, Giza, Egypt;

<sup>4</sup>Department of Physical Therapy for Pediatrics, Faculty of Physical Therapy, Cairo University, Egypt

## Abstract

**Objectives:** The study aimed to determine the effect of adding a school-based plyometric training program (PMT) to physical education (PE) sessions on the strength, balance, and flexibility in primary school girls. **Methods:** Students from grades 3-6 were randomized equally to a plyometric or control group. In the control group, students took their regular PE classes twice a week. In the plyometric group, students performed PMT twice a week during the initial 20 minutes of every PE session. The Lido Linea closed kinetic chain isokinetic dynamometer, Star excursion balance test (SEBT), and sit-and-reach test were used to assess muscle strength, balance, and flexibility, respectively, before and after nine weeks of training. **Results:** The improvement in extension peak force ( $p=0.04$ ) and extension total work ( $p<0.001$ ) was more prevalent in the PMT group than in the control group. SEBT scores had improved significantly ( $p<0.05$ ) for all directions in the PMT group, except in the anterior direction, which was highly significant ( $p<0.001$ ). Hamstring and lower back flexibility had improved more in the PMT group than in the control group ( $p<0.001$ ). **Conclusion:** Adding PMT to regular PE classes has a positive and notable effect on muscle strength, balance, and flexibility in primary school students.

**Keywords:** Flexibility Test, Isokinetic Dynamometer, Muscle Strength, Plyometric Training, Star Excursion Balance

## Introduction

Participation in regular physical activity during childhood has many physiological and psychosocial benefits for children and improves their quality of life. However, despite these health benefits, evidence from previous research showed that children's physical activity participation is not optimal<sup>1</sup>. Therefore, there is a need to incorporate new techniques into physical education (PE) sessions to increase children's

physical fitness. Recently, it was shown that strengthening and conditioning exercises are safe and effective when performed correctly<sup>2,3</sup>. De Villareal et al.<sup>4</sup> suggested that plyometric training (PMT), a rather recent approach applied to children, is a safe form of resistance training and beneficial for children, regardless of their physical fitness status.

PMT consists of jumping exercises and rapid and forceful motions<sup>5</sup>. PMT involves activity that uses the stretch-shortening cycle (SSC) of musculotendinous tissue, utilizing the stored energy through eccentric stretch that activates the muscle spindles to generate extreme force during the concentric phase of motion known as reactive neuromuscular training<sup>6</sup>. These exercises excite the elastic part of the muscle fibers and connective tissue, allowing the muscle to preserve energy throughout the deceleration phase and produce that energy during the acceleration period<sup>7,8</sup>. The elastic energy stored in the muscle is used to deliver power that can be provided by concentric activity alone<sup>9</sup>.

The value of PMT lies in the speed of the shift from

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Corresponding author: Waleed S. Mahmoud, Department of Health and Rehabilitation Sciences, College of Applied Medical Sciences, Prince Sattam Bin Abdulaziz University, Riyadh, Al-Kharj, Saudi Arabia  
E-mail: waleeds306@yahoo.com

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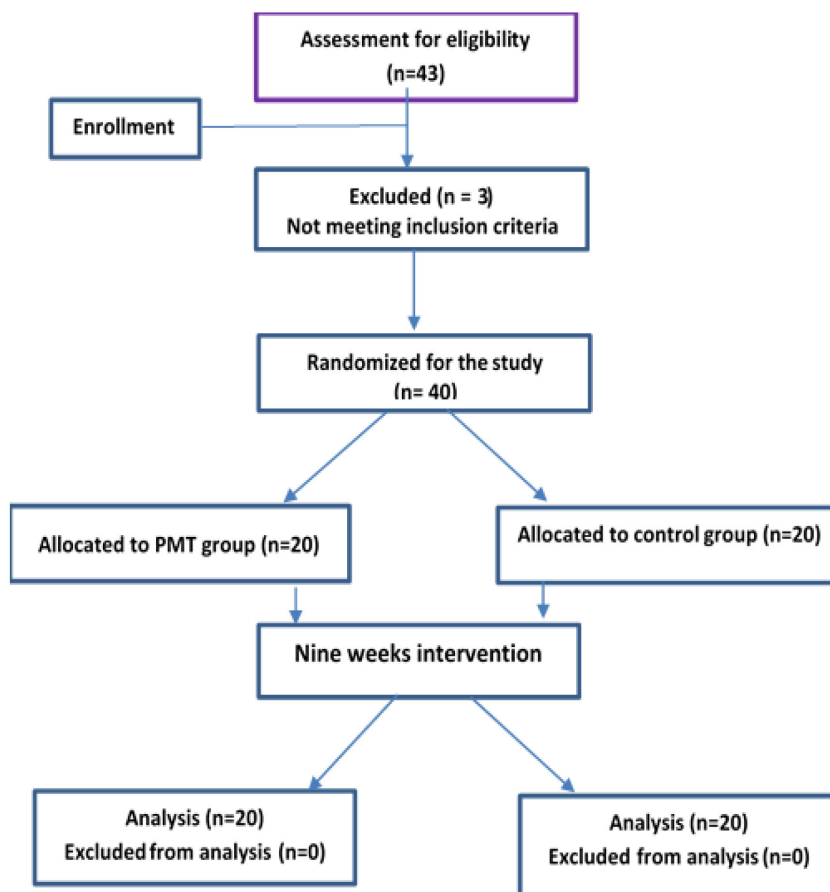


Figure 1. Flow chart of the study.

eccentric to concentric muscle contractions. The muscle shifts rapidly from a flexible state (stretching) to a shortening state (contractility)<sup>10,11</sup>. Therefore, PMT consists of exercises that produce maximal muscle force in the shortest possible time<sup>12,13</sup>.

Previous reviews of research on adults suggested that plyometric exercise improves strength, postural control, and jumping skill<sup>14-17</sup>. However, the outcomes of the application of PMT to children are poorly understood<sup>18</sup>. Deficits in lower extremity strength and postural control have been associated with a high risk of sports-related injuries. Such injuries might occur during PE classes<sup>19,20</sup>. Sufficient intervention training in PE classes or sports clubs might enhance strength and balance and reduce the risk of injuries<sup>21,22</sup>.

Some studies recommended that children and teenagers benefit from PMT, given that age-relevant training rules are followed. For instance, Matavulj et al.<sup>23</sup> reported that jump performance was improved in adolescent basketball athletes, and Kotzamanidis<sup>24</sup> found that PMT improved jumping action and running speed in young men. Faigenbaum et al.<sup>25</sup> examined the effect of a school-based PMT program (i.e., Plyo Play) on children's fitness and performance. Forty children

(8-11 years) participated in the program and 34 age-matched children served as controls. The performance on long jump, sit-and-reach flexibility, abdominal curl, pushup, shuttle run, and halfmile run was assessed at baseline and post-training. They reported that "Plyo Play" can enhance lower and upper body power and aerobic fitness in children. Thus, it appears that PMT improves school-aged children's physical fitness.

Safety is a concern when initiating an exercise intervention for children because of the possibility of injury, muscle soreness, overtraining, or frustration. Regarding the effectiveness and safety of youth resistance training, the position statement of the National Strength and Conditioning Association was set by Faigenbaum et al.<sup>25</sup>. This statement indicated that youth resistance training has the potential to offer health benefits; enhance muscle strength and motor performance; and increase a young athlete's resistance to sports-related injuries that could be recognized by parents, coaches, or teachers. These health benefits can be obtained by most children and adolescents when age-appropriate resistance training guidelines are followed and qualified instruction is available.

The results of the review of Johnson et al.<sup>26</sup> indicate that

PMT is safe and effective in improving running and jumping abilities of school children and athletes aged between 8 and 14 years when the specific guidelines are followed. They estimated that studies that included PMT programs with relatively short duration (10-25 min), included a warm-up and cool down, emphasized correct technique, provided guidelines for progression of the workload, were performed on appropriate exercise surfaces and in spaces, and built safety guidelines into intervention, demonstrated the greatest improvements and safety.

The impact of PMT on selected biomechanical aspects of primary school students has not been thoroughly studied. New perspectives for implementing resistance exercise as part of a long-term intervention into youth fitness programs to enhance youth physical development are of great importance. Adolescents who do not build muscle strength and motor skills early in life may not develop the necessary competence that would allow them to participate appropriately in a variety of activities and sports later in life. Since high-quality PE training helps children improve their health and physical fitness skills, PE teachers who add PMT to their sessions will need confirmation that this type of training is valuable and beneficial. Hence, this study aimed to investigate the effect of adding a school-based PMT to PE sessions on muscle strength, balance, and flexibility in primary school students. The "Plyo Play" program was used because it is inexpensive, progressive, easy to implement and designed for school-age children who have limited experience in PMT.

## Materials and Methods

### Participants

Forty primary school girls aged 9 to 11 years were enrolled in this study. Students with chronic pediatric disease, orthopedic problems, visual-sensory dysfunction, previous experience in PMT, or previous engagement in any type of sports activity were excluded. Additionally, students who were absent for baseline or post-testing were excluded from the final analysis. Students were age-matched and randomly allocated to two groups: the PMT group (n=20) and control group (n=20). The flow chart showed the participant selection and drop-out, as shown in (Figure 1).

### Study design

The study design had a pretest-posttest control group design. The "Plyo Play" program intended for children was selected for this study<sup>27</sup>. The PMT program was applied in the PMT group twice a week during the initial 20 minutes of each routinely planned 45 min of PE class. In the control group, the girls participated only in their regular PE classes twice a week. The program lasted for 9 weeks and took into account the necessities, concerns, and capacities of students to improve learning, commitment, and recreation<sup>27</sup>. Both the students and their parents were informed about the targets of this work and they provided written informed consent before participation. The study was approved by the Ethics

Committee (NO: RHPT/O20/O19) of Prince Sattam bin Abdulaziz University and was conducted according to the Helsinki Declaration.

### Study plan

Before data collection, all students received a familiarization session. During this session, all data about the test procedures and exercises were demonstrated to the students. Pre-testing was carried out one week before the intervention period, and post-testing was performed one week after the intervention period to ensure recovery from the intense impact of the intervention. Ten minutes of warm-up with low-intensity exercises were performed before the assessment, including a 5 min jog at a self-selected speed followed by 5 min of stretching. The students wore the same clothes and footwear<sup>21</sup>. The same investigator carried out all evaluations and tests<sup>2</sup>. To minimize the learning effects of order influence, the investigator tested the subjects randomly<sup>13</sup>. The peak force (N) and total work (J) in the extension direction of the lower limb muscles, dynamic balance, and flexibility of the hamstring and lower back muscles (cm) were examined before the intervention, and after nine weeks, these measures of interest were re-evaluated.

### Assessment procedures

#### Anthropometric measurements

Height and weight were estimated using a standard stadiometer and doctor's scale, respectively. Body mass index (BMI) was determined by applying the following equation: mass in kilograms/height in square meter<sup>28</sup>.

#### Muscle strength measurements

The Lido Linea closed kinetic chain isokinetic dynamometer (Loredan Biomechanical, West Sacramento, CA, USA) was used to measure the peak force and overall work of lower limb muscles during concentric linear isokinetic leg press movement. The peak force score is described as the extreme force (N) delivered during the total test episode of three repetitions, disregarding the repetition of the extreme force. The overall work score is described as the total amount of work (Nm) achieved during the complete test episode of three repetitions<sup>29</sup>.

Students were instructed to take a semi-recumbent position in Linea's leg press chair; then, they were stabilized by a lap belt. Students were placed in the Lido Linea chair with their knees fully extended, their hips in 70° of flexion, and their feet placed on the foot plates. This position was standardized to ensure that the length of the trunk, thigh, and legs would not be a cause of movement error during testing. A linear range of motion was established so that the knees moved from 90° of knee flexion to 5° of flexion during the complete leg press stroke. A cushion was placed under the popliteal region to avoid knee hyperextension. Students were asked to grasp the handles of the machine during

testing. Each student performed a standard warmup of three submaximal repetitions at a test speed of 50.8 cm/s. After 2 min of rest, the student practiced three bilateral coupled leg-press movements. A bilateral coupled leg press involves a full leg-press movement from knee flexion to knee extension position with both legs placed close together<sup>29</sup>. Students were asked to perform three maximal voluntary linear concentric isokinetic repetitions at medium (50.8 cm/s) speed. One minute of rest was allowed between the three repetitions. The mean of the three attempts was used for the calculation. Strong verbal encouragement was given to evoke maximal exertion. Students were likewise given visual feedback of their achievement during the testing<sup>30,31</sup>. Linea's leg-press was developed to simulate closed kinetic chain exercises, which are a key component in sports rehabilitation. Previous research demonstrated that the Linea's isokinetic dynamometer is a reliable equipment ( $R=0.87$  to  $0.94$ ) for evaluating concentric isokinetic motion during a closed kinetic chain leg press movement<sup>29</sup>.

#### *Balance assessment*

The star excursion balance test (SEBT) is a valid and reliable test to measure dynamic balance, range of motion, strength and proprioceptive abilities. It is used to detect dynamic balance changes in response to intervention programs<sup>18</sup>. The SEBT was performed, as suggested by Gribble et al<sup>32</sup>. Students stood in the center of a grid located on the ground with eight lines stretching out at 45 degree angles from the center of the grid; every line is named according to the direction of the excursion related to the stance leg: anterior (A), anteromedial (AM), medial (M), posteromedial (PM), posterior (P), posterolateral (PL), lateral (L), and anterolateral (AL). The test was performed without shoes, with foot placement constrained by adjusting the heel in the center of the grid, and the big toe was projected anteriorly<sup>33</sup>. Students used the examined leg for support while moving the other leg as far as possible to touch the selected line by the tips of the toes. The foot was not allowed to achieve strong contact, and therefore, did not help in achieving equilibrium. The student then received double limb support. The point reached by the leg was marked and measured using a measuring tape. One therapist evaluated all students, and imprints were removed after every attempt. To perform the task correctly, the students should place their hands on their waist, and the reach leg should not offer support after touching the ground, the heel of the supporting leg stays in the center of the grid and not lifted from the floor while maintaining equilibrium. Students performed the test, starting with the anterior direction and advancing clockwise around the grid three times in each direction. Before changing to the other leg, a 30-s rest period was permitted. In the supine position, a standard measuring tape was used to measure the distance from the anterior superior iliac spine to the medial malleolus tip, which was the leg length. After that, the reach distances were normalized by dividing each

reach distance by the student's leg length and multiplying the result obtained by 100. The mean value of the three attempts was used for further analysis<sup>34</sup>.

#### *Flexibility assessment*

The sit- and-reach test was used to assess hamstring and lower back flexibility<sup>2</sup>. Students should avoid quick or jerky motion to reduce the risk of injury. The test was performed with the students barefoot. A yardstick was fixed on the ground and a tape was fixed across it at a right angle to the 15-inch mark. The student sat with the yardstick between the legs, with the legs reaching out at right angles to the taped line on the ground. The heel of the feet had to be in contact with the edge of the taped line and be about 10-12 inches apart. The student had to gradually advance with extended arms, putting one hand on top of the other facing palms down, as far as possible, maintaining this position for two seconds. The fingertips had to be overlapped and touch the measuring portion of the yardstick. The student would drop the head between the arms while reaching. The examiner should ensure that the student's knees are extended; however, the student's knees should not be pressed down. The score is the most far point (cm or inch) reached with the fingertips. The best of the three attempts should be recorded<sup>35</sup>.

#### *Training program*

Before the intervention, the authors comprehensively instructed the regular PE teacher about the study's purpose and methodology. The PE teacher was incorporated in this investigation to make the training as reasonable as possible (i.e., to follow the students' daily schedule<sup>22</sup>). One of the authors was assigned to supervise the training program, depending on the PE period times of the participating girls. The author was attending the school 2 days/week to supervise both groups at different periods each day. The regular PE teacher taught the intervention program. Throughout the study period, students exercised in groups of 20 students, and all training sessions occurred in the primary school gymnasium.

Subjects in the PMT group were trained twice per week on non-consecutive days for 9 weeks under supervised conditions. The PMT sessions lasted for 20 min and took place during the first part of regularly scheduled 45 min PE classes. During the remaining class, the subjects participated in traditional PE activities.

Each exercise session commenced with 10 min of warm-up and ended with 5 min of cool-down activities. Proper technique was encouraged throughout the intervention period<sup>36</sup>. The "Plyo Play" training was selected because it is cheap, dynamic, and easy to apply to children who have limited experience in PMT<sup>27,36</sup>. This program involved jumps, skips, hops, sprints, and throws. It also includes preliminary activities such as bodyweight squats and pushups<sup>37</sup>. These exercises were incorporated in the training to increase the children's chances to improve their body mechanics and

**Table 1.** Summary of the “Plyo Play” PMT program.

Weeks 1-3 1 set / 10 repetitions	Weeks 4-6 1 set / 8 repetitions	Weeks 7-9 1 set / 6 repetitions
Ball squats	Overhead squats	6/6/6 squats
ABC push-ups	Push-ups	Offset ball push-ups
Heel raise	Ankle jumps	Hexagon drill
Jump and freeze	Hurdle hops	Single leg hops
Curl-ups	Curl-ups with ball	Toe touches with ball
Double leg -backward jump	Lateral hops	Long jump and sprint
Triple “X” jump	Zigzag jump drill	Single leg zigzag drill
Standing jump and reach	Jump and turn 90°	Lunge chest pass
Lateral taps	High-5 drill	Jump and turn 180
Single leg pops	Backwards throw	Tuck jumps
Arrow cone drill	Split squat	Split squat jump
Figure 8 drill	Power skipping	Alternate bounding
	T- drill	X-drill
		Shuttle drill

plyometric muscle power, which are needed to achieve optimal benefits from PMT. To introduce the students safely to this new training type, low-intensity PMT was first practiced (e.g., bilateral leg jump). The low-intensity PMT helped the students feel confident in their capacities before advancing to more challenging movements.

Every PMT session was completed with speed and agility exercises. These exercises were primarily intended to improve the students' capacity to accelerate, decelerate, alter direction, and then accelerate once more. For each PMT to be performed with great force, an adequate recovery period between exercises was allowed. Plyometric drills should last approximately 10 s with a 60-s rest between drills. The PMT program advanced from level one (weeks one to three; one set of ten repetitions) to level two (weeks four to six; one set of eight repetitions), and finally level three (weeks seven to nine; one set of six repetitions). As the intensity of the PMT advanced, the number of repetitions practiced per exercise reduced. The students practiced just one set of every exercise, as the main aim of the PMT program was ideal exercise performance. The students practiced 12-14 exercises every session<sup>38</sup>. The details of each exercise are available elsewhere<sup>27</sup>. The exercises of the PMT program are presented in Table 1.

#### Sample size calculation

The sample size calculation was based on the estimated effect size ( $d=0.80$ ) and a probability of 0.05 using G\*power 3.0.10 software (University of Dusseldorf, Dusseldorf, Germany). The power was set at a 70% chance of correctly rejecting the null hypothesis of no difference with a total of 40 patients. Thus, the sample was increased to a total of 43 to allow for a loss of up to 8%.

#### Statistical analysis

Statistical analyses were performed using the SPSS statistical package version 23 (Chicago, IL, USA). The outcome measures were presented as mean  $\pm$  SD. All data were checked for normalization using the Shapiro-Wilk test. An independent samples t-test was used to explore differences in continuous baseline data. A two-way repeated-measures ANOVA (2x2, group x time, repeated measures) was conducted to outline the changes in dependent variables between the PMT and the control groups before and after treatment. A paired-samples t-test was used to determine within-group changes across Group x Time if there was a significant interaction. The effect sizes (ESs) were calculated using Cohen's  $d$  with threshold values for assessing the magnitudes of ESs: 0.2, 0.6, 1.2, and 2.0 for small, moderate, large, and very large ESs, respectively<sup>39</sup>. The level of significance was set at  $p<0.05$ .

## Results

All students completed the study according to the aforementioned procedures, and no adverse or unwanted responses were reported during the study period. The students tolerated all the evaluation and training protocols well. The students in the PMT and control groups participated regularly in the scheduled PE sessions at an overall attendance rate of 97% during the study period. There were no significant differences ( $p>0.05$ ) between the PMT and the control groups in the anthropometric measures, including age, height, body mass, and BMI (Table 2).

#### Strength of lower limb muscles

Changes were observed in the extension peak force and extension total work pre- to post-treatment across the PMT

**Table 2.** The basic characteristics of both groups (mean  $\pm$ SD).

	PMT group (n=20)	Control group (n=20)
Age, (years)	10.5 $\pm$ 0.8	10.9 $\pm$ 0.5
Height, (cm)	143.3 $\pm$ 2.1	144.4 $\pm$ 2.8
Body mass, (Kg)	39.8 $\pm$ 6	40.5 $\pm$ 6.9
BMI, (Kg.m <sup>-2</sup> )	18.1 $\pm$ 2	17.9 $\pm$ 2.2

**Table 3.** Differences in muscle strength, balance, and flexibility between the plyometric and control groups.

Variable		PMT group (n=20)			Control group (n=20)			Group X Time Interaction	
		Pre (mean $\pm$ SD)	Post (mean $\pm$ SD)	% of change	Pre (mean $\pm$ SD)	Post (mean $\pm$ SD)	% of change	p	$\eta^2_{\text{Partial}}$
Strength of lower limb muscles	Extension peak force, N	37 $\pm$ 4.2	42 $\pm$ 2.8*	$\uparrow$ 13.5	35 $\pm$ 3.3	38 $\pm$ 4.1	$\uparrow$ 8.5	0.04	0.204
	Extension total work, J	937 $\pm$ 200	1045 $\pm$ 189*	$\uparrow$ 11.5	918 $\pm$ 165	997 $\pm$ 130*	$\uparrow$ 8.6	<0.001 <sup>a</sup>	0.577
SEBT	A	96.19 $\pm$ 5.05	101.02 $\pm$ 3.63*	$\uparrow$ 5	94.86 $\pm$ 5.65	96.54 $\pm$ 4.97*	$\uparrow$ 1.8	<0.001 <sup>a</sup>	0.535
	AM	81.29 $\pm$ 8.07	86.32 $\pm$ 7.19*	$\uparrow$ 6.1	82.23 $\pm$ 7.38	83.74 $\pm$ 6.85*	$\uparrow$ 1.8	0.001 <sup>a</sup>	0.433
	M	69.41 $\pm$ 7.48	72.12 $\pm$ 6.67*	$\uparrow$ 3.9	69.2 $\pm$ 5.60	70.84 $\pm$ 4.89*	$\uparrow$ 2.4	0.017 <sup>a</sup>	0.264
	PM	78.81 $\pm$ 12.29	81.93 $\pm$ 10.73*	$\uparrow$ 3.9	78.96 $\pm$ 11.65	80.09 $\pm$ 10.95*	$\uparrow$ 1.4	0.027 <sup>a</sup>	0.232
	P	85.6 $\pm$ 11.62	88.82 $\pm$ 10.64*	$\uparrow$ 3.8	84.63 $\pm$ 10.66	86.62 $\pm$ 9.72*	$\uparrow$ 2.4	0.031 <sup>a</sup>	0.221
	PL	89.64 $\pm$ 10.41	92.17 $\pm$ 10.61*	$\uparrow$ 2.8	91.43 $\pm$ 7.29	92.95 $\pm$ 7.87*	$\uparrow$ 1.7	0.039 <sup>a</sup>	0.205
	L	91.3 $\pm$ 7.92	95.08 $\pm$ 5.85*	$\uparrow$ 4.1	89.14 $\pm$ 6.68	91.71 $\pm$ 6.5*	$\uparrow$ 2.9	0.002 <sup>a</sup>	0.205
	AL	97.68 $\pm$ 7.15	102.04 $\pm$ 6.38*	$\uparrow$ 4.5	96.57 $\pm$ 4.37	99.71 $\pm$ 5.61*	$\uparrow$ 3.2	0.006 <sup>a</sup>	0.334
Sit and reach test, cm		24.5 $\pm$ 1.6	27.8 $\pm$ 1.78*	$\uparrow$ 13.47	24.7 $\pm$ 1.35	25.1 $\pm$ 1.2*	$\uparrow$ 1.6	<0.001 <sup>a</sup>	0.614

*Descriptive statistics are presented as mean  $\pm$  SD,  $\eta^2_{\text{Partial}}$ : Effect size of the difference, <sup>a</sup>: Changes from pre- to post-treatment between PMT and control groups are significant at P<.05, \*: Significant within-group changes, PMT: Plyometric training, N: Newton, J: Joule, SEBT: Star excursion balance test, A: Anterior, AM: Anteromedial, M: Medial, PM: Posteromedial, P: Posterior, PL: Posterolateral, L: lateral, AL: Anterolateral,  $\uparrow$ : Increase.*

and control groups (Table 3). There was a significant main effect of group x time in both extension peak force ( $F(1, 19)=4.87$ ,  $p=0.04$ ,  $\eta^2_{\text{Partial}}=0.204$ ) and extension total work ( $F(1, 19)=25.90$ ,  $p<0.001$ ,  $\eta^2_{\text{Partial}}=0.577$ ). The extension peak force increased by 5 N between pre- and post-treatment ( $p<0.001$ ) in the PMT group, while in the control group, it increased by 3 N from pre- to post-treatment ( $p=0.039$ ). There was a significant increase in total extension work in the PMT group by 108 J from pre- to post-treatment ( $p<0.001$ ) and a moderate increase by 79 J in the control group ( $p=0.024$ ).

#### Changes in SEBT values

The changes in SEBT from pre- to post-treatment between the PMT and control groups are outlined in Table 3. There were highly significant interactions in the A, AM, L, and AL directions of SEBT ( $p<0.001$ ,  $p=0.001$ ,  $p=0.002$ , and  $p=0.006$ , respectively). The scores of the A, AM, L, and AL directions of SEBT had significantly improved in the PMT

group from pre- to post-treatment ( $p<0.001$ , for all) when compared to the improvement in the control group ( $p=0.01$ ,  $p=0.029$ ,  $p=0.002$ , and  $p=0.013$ , respectively). There were significant interactions in both the M and PM directions of the SEBT ( $p<0.05$ ); however, the scores for the M and PM directions increased profoundly in the PMT group pre- to post-treatment ( $p<0.001$  and  $p=0.008$ , respectively), but not in the control group ( $p=0.010$  and  $p=0.030$ , respectively). There was also a significant interaction in both P direction ( $F(1, 19)=5.40$ ,  $p=0.031$ ,  $\eta^2_{\text{Partial}}=0.221$ ) and PL direction ( $F(1, 19)=4.90$ ,  $p=0.039$ ,  $\eta^2_{\text{Partial}}=0.205$ ). The scores of the P and PL directions showed better improvement in the PMT group ( $p=0.001$  and  $p<0.001$ , respectively) than in the control group ( $p=0.033$  and  $p=0.037$ , respectively).

#### Sit-and- reach test

There was a highly significant difference in the sit-and-reach test scores ( $F(1, 19)=30.25$ ,  $p<0.001$ ,  $\eta^2_{\text{Partial}}=0.614$ )

between the PMT and control groups across time; as the sit-and-reach test score improved by about 3.3 cm from pre- to post-treatment in the PMT group ( $p < 0.001$ ), but not in the control group ( $p = 0.01$ ) (Table 3).

## Discussion

Improving physical activity of children of all abilities is part of the national health initiative. Current national health initiatives recommend 60 min or more of moderate- to -vigorous physical activity most days of the week for school-aged children. Physical activity should be enjoyable, developmentally appropriate, and consist of various activities<sup>40</sup>. The purpose of this study was to evaluate the effect of adding nine weeks of a school-based PMT to PE sessions on muscle peak force and total work, balance, and flexibility in primary school students. To our knowledge, no previous study has investigated those variables. The results revealed better improvement in the PMT group than in the control group in muscle peak force and total work, balance, and flexibility test values. The significant differences between the mean pre- and post- test values in the PMT group, moderate- to- large effect sizes, and the high percentage of the change in most variables should also be highlighted. In this study, the results of the peak force and total work, measured by a closed kinetic chain isokinetic dynamometer, are in accordance with the results of different studies that concluded that PMT improves strength. Saez de Villarreal et al.<sup>4</sup> observed positive improvements in muscle strength and performance with PMT in both male and female athletes and non-athletes. Arazi et al.<sup>41</sup> compared the effect of aquatic and land PMT on strength in addition to balance and sprint tasks in young basketball players. They concluded that PMT in water effectively improved muscle strength, balance, and sprint ability of teenage athletes. As mentioned by Fatouros et al.<sup>7</sup>, PMT can increase leg strength as well as the vertical jump ability. The 37.5% improvement in the extensor peak force reported in our study was similar to that reported by Rahimi and Behpur<sup>42</sup>, who found that the maximal strength of extensor muscles could be improved by 26-33% when PMT was performed by athletes twice per week, for 6 weeks.

In fact, PMT has a noticeable influence on muscle strength even in children with neurological deficits such as cerebral palsy (CP). A previous study examined the effect of PMT on maximum isometric muscle strength (MIMS) in children with CP. The authors reported that the MIMS of the quadriceps and hamstring muscles increased by 19.2% and 23% respectively, at 90° knee flexion<sup>43</sup>.

In the study by Tsang et al.<sup>44</sup> involving women, plyometrics training had a positive effect on the quadriceps/hamstring strength ratio after 6 weeks, as both eccentric and concentric muscle forces had increased.

The reasons for the improved strength include the use of body weight, complex training, neural adaptation due to training, and training stimulus. PMT improves the stretch-shortening cycle properties of the muscle, which results in

the enhancement of the musculotendinous and neural unit and produces maximal force in the shortest time<sup>45</sup>. The adaptation mechanism related to this type of training varies and includes a) elongation of both muscles and tendons, b) consequent increase in the amount of stored elastic energy in the eccentric loading phase, c) stimulation of a large number of motor units, d) increased neural firing frequency and consequent production of maximum power in the concentric phase of the movement, and e) improved joint awareness<sup>46</sup>.

The present results disagreed with those of Ingle et al.<sup>47</sup> and Faigenbaum et al.<sup>27</sup> who reported that PMT had a limited effect on improving muscle strength. This limited effect might be attributed to the different mechanisms of gaining strength between young and pubertal children. The mechanism of gaining strength in children involves intrinsic muscle adaptation and neural adaptation, while in pubertal children, it involves circulating androgens responsible for muscle hypertrophy. In addition, the study by Byrne et al.<sup>48</sup> contradicts our muscle strength findings. They reported a reduction in the peak isokinetic torque of the ankle plantar flexors after PMT, but this observation could be attributed to their fast test velocities.

Regarding dynamic balance, the PMT group showed better improvements in the SEBT results than the control group. This result could be attributed to improved neuromuscular control<sup>49</sup>. Our findings are in line with those of Myer et al.<sup>50</sup> who reported that PMT improved dynamic balance performance in female athletes after 7 weeks of training. Arazi and Asadi<sup>51</sup> found that changes in dynamic balance can be achieved within 8 weeks of PMT in young male basketball players and can reduce the risk of falling and injuries by improving dynamic balance control. Furthermore, Nacaroglu and Karakoc<sup>52</sup> found that PMT can significantly improve overall stability, medial and lateral stability, and balance performance in hard-of-hearing volleyball players. In addition, our results are in line with those of Alikhani et al.<sup>53</sup> who found that six weeks of PMT was sufficient to produce significant improvement in dynamic balance and knee proprioception in female badminton players. They concluded that plyometrics ultimately help develop neuromuscular adaptability that is important in improving lower-body stability.

However, our results partially agree with the results of Paterno et al.<sup>54</sup> who noted that PMT improved postural sway measures only in the anteroposterior (AP) direction. Twist et al.<sup>55</sup> showed contrasting results; they suggested that PMT caused prolonged alterations in proprioceptive function and deteriorate balance performance, considering the possibility that deep tendon and muscle receptors become less sensitive as a result of eccentric exercise or fatigue. These distinctions could be due to differences in the intensity of exercises, the number of participants, the type of plyometrics, methods of dynamic balance assessment, sex, and age.

In our study, the PMT group showed a profound improvement in dynamic balance in all directions with the greatest improvement in the AM and A directions and with the least improvement in the PL and PM directions. PMT involves

AP and mediolateral (ML) displacements of the center of gravity accompanied by a rapid stretch-shortening cycle<sup>49</sup>. Generally, these findings suggest that the dynamic nature of plyometrics can exert stress on equilibrium and postural control through, i) central and peripheral neural adaptations, ii) enhancement of neuromuscular factors, and iii) repetitive stimulation of the joint mechanical receptors near the end range of motion, resulting in an improved sense of joint position, motion, and balance<sup>56</sup>. Improving the dynamic balance is reported to encourage feed-forward adjustments that activate the proprioceptive input and the appropriate muscles before landing<sup>57</sup>. Marigold and Patla<sup>58</sup> reported that plyometrics could enhance the conscious awareness of joint position sense and improve SEBT performance when muscles are stimulated with training. This study revealed that short-term PMT significantly enhanced flexibility in primary school girl students. Similarly, previous results showed that the flexibility of young people also increased after PMT<sup>45</sup>. Faigenbaum and Mediate<sup>59</sup> reported improvements in flexibility after fitness training in children highlighting the value of dynamic movements.

The improved flexibility might be explained by the possible stiffness reduction in the muscle-tendon complex and similar changes in the elastic behavior of the surrounding joint structures<sup>60</sup>. Through motor unit recruitment or frequency of neural firing, PMT can enhance changes in the elastic properties of the muscle and connective tissues and potentiate the reflex arc, which in turn increases neuromuscular adaptation<sup>61</sup>. PMT reduces the sensitivity of Golgi tendon organs to excessive tensile loads in the muscle and allows the elastic components of muscles to undergo increased stretching<sup>56</sup>. Finally, no injuries occurred because of PMT, and no child complained of muscle soreness during the study. These results are consistent with those of Marginson et al.<sup>62</sup> who reported that children are less vulnerable to PMT-induced muscle damage than adults.

#### Limitations

First, the study results cannot be generalized to a larger school population because the students were recruited from one school only. Second, the present study included only healthy school girls; thus, the study findings should be cautiously applied to boys.

In addition, it is recommended in future studies that the effect of adding plyometric training to PE sessions should be measured in terms of the strength of upper limb musculatures and cardiovascular endurance.

#### Conclusion

Adding plyometric training to regular PE classes has a positive and notable effect on muscle strength, balance, and flexibility in primary school girls. The study findings are promising and have significant practical implications for the inclusion of PMT in PE lessons. Additionally, our results support that improvements in certain physical abilities such

as strength, balance, and flexibility can be achieved in as little as 9 weeks of PMT, which can be helpful for young athletes who are considering embarking on school competitions.

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