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The Effects of an Eight Week Plyometric-based Program on Motor Performance Skills and Muscular Power in 7–8-Year-Old Primary School Students

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ABSTRACT

Background of Study: Competence in motor performance skills is important in enabling children to be physically literate. Plyometric-based training has been suggested as an effective means to enhance motor performance skills in young athletes. However, no studies have reported the effects of a whole body plyometric-based program integrated into physical education on motor performance skills with young children. **Objective:** This study aims to examine the effect of a plyometric-based program on primary school students' motor performance skills, upper and lower body muscular power, and reactive strength index. **Method:** The sample was composed of 61 primary school students, 29 girls and 32 boys, aged 7–8 years old, from two second-grade Physical Education (PE) classes. Both groups participated in their regular eight-week PE lessons (50-minute classes twice a week). During the study, the plyometric group performed a plyometric-based program in the 15-minute warmup of each class, while the comparison group performed regular warmup activities. Student's motor performance skill proficiency, reactive strength index, lower and upper body muscular power were assessed before and after the eight weeks of PE lessons. The data were analysed using a two-way analysis of variance, followed by pairwise comparisons with the Bonferroni adjustment. **Results:** The data analysis indicated significant increases in motor performance skill proficiency, upper and lower body muscular power in the plyometric group vs comparison group ($p \leq 0.05$). **Conclusion:** These results suggest that including a plyometric-based program in the PE warmup phase of the lessons may improve motor performance skills and muscular power in primary school students.

Key words: Resistance Training, Movement Skills, Children, Physical Education, School, Plyometrics

INTRODUCTION

Lifelong engagement in physical activity can minimise the risk of significant adverse physical health effects, such as cardiovascular disease, type two diabetes, obesity, osteoporosis, breast and colon cancer (Pedersen & Saltin, 2015). During childhood and adolescence, adequate levels of daily physical activity increase the tendency to engage in physical activity into adulthood (Alvarez-Pitti et al., 2020). It is recommended that primary school-aged students include at least 60 minutes of moderate to vigorous intensity physical activity per day and participate in muscle and bone strengthening activities (McCarthy et al., 2021). Moreover, in the Active Healthy Kids Australia report, schools are encouraged to engage students in activities designed to improve motor performance skill proficiency and develop muscular fitness components such as power and strength (Schranz et al., 2018). Despite the benefits and recommendations, physical inactivity is a concern for government health authorities as only 26% of children aged five to twelve in Australia were achieving the Australian physical activity guidelines in 2018 (AIHW,2020). Considering that the decline in physical activity levels commences from an early age, researchers have postulated that augmenting a child's motor performance skills level of proficiency could be critical to attenuating this decline (Barnett et al., 2016).

'Motor performance skills' is a term used in the paediatric exercise science and physical education disciplines to mirror a variety of terms previously used in the research literature (i.e. fundamental movement skills, motor skills and fundamental sports skills) to elucidate goal-directed human movements which require specific skill learning, practice and stimuli to develop proficiency (Behringer et al., 2011). In children, a solid foundation in motor performance skills is likely to assist in overcoming the theoretical 'proficiency barrier' (Seefeldt, 1982). Advanced motor performance skill proficiency developed in childhood may result in higher participation levels in health-enhancing physical activity and fitness activities later in life (Jones et al., 2020). Motor per-

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formance skills are the foundation for more complex motor activities such as sport-specific skills (Behringer et al., 2011).

During middle childhood (ages five to seven), the development of motor performance skills is critical and a sensitive period for rapid adaptations (Lloyd & Oliver, 2012). A relevant setting to accomplish this development of motor performance skills is during primary school Physical Education (PE). PE curriculum has been identified as an ideal setting to assist children in developing their overall motor performance (e.g. running, jumping, throwing) and physical activity behaviours (MacNamara et al., 2015). Evidence from the 2015 New South Wales 'Schools Physical Activity and Nutrition Survey' (SPANS) suggests that there has been minimal improvement in motor performance skills since the decline from 2004 to 2010 (Hardy et al., 2017; Schranz et al., 2018). It can be inferred that despite the availability of PE in schools, there is scope for improvement in PE movement education concepts to enhance student skills to achieve proficiency in motor performance skills. This inference aligns with the 2018 Active Healthy Kids Australia Report (Schranz et al., 2018), in that the lack of achievement may in part be due to neglecting the development of physical capabilities such as muscular power.

Children may be best-offered opportunities during childhood to engage in activities that provide adequate stimuli to develop the neuromuscular system during PE classes. A type of neuromuscular power training such as plyometric training can enhance motor learning by eliciting specific neural adaptations (Granacher et al., 2011; Tumkur Anil Kumar et al., 2021). Plyometrics is a form of exercise intended to link movement speed to strength and produce explosive strength, which is commonly known as muscular power (Davies et al., 2015). Plyometric movements involve a rapid, explosive movement during an eccentric contraction followed immediately by an explosive concentric contraction. This sequence is also referred to as the stretch-shortening cycle. Recently, this form of exercise has been employed to improve motor performance skills of volleyball, basketball and soccer players while reducing the time engaged in sport-specific skill development within training (Cherni et al., 2019; Gjinovci et al., 2017). More importantly, meta-analytic studies have suggested that plyometric exercise could enhance motor performance skills, although there is a need for research in children (Behringer et al., 2011; Harries et al., 2012). The research to date on plyometric training and children has mostly been restricted to improving aspects of fitness or a limited range of sports skills for team events.

Therefore, this study aimed to compare the effects of plyometric-based training integrated into PE lessons on motor performance skills, reactive strength index, and measures of upper and lower body muscular power in seven- to eight-year-old students. It was hypothesised that plyometric-based training would result in more positive changes than the standard PE program.

METHOD

Study Design and Participants

This study followed a quasi-experimental design to compare the effects of a plyometric-based program embedded into the warmup phase of PE lessons on motor performance skill proficiency, measures of muscular power and reactive strength index. The study involved 61 volunteer students, 32 boys and 29 girls, aged seven to eight years from two heterogeneous second-grade PE classes at a primary school. Similar intervention studies were utilised for sample size calculations (Faigenbaum et al., 2014; Nobre et al., 2017). Based on interaction effects between groups and time in a two-way ANOVA, a priori power analysis (GPower V3.1.9.2, Dusseldorf, Germany) was conducted to estimate the minimum amount of students needed to achieve the desired power (Faul et al., 2007). The priori power analysis indicated that 30 students per group would be sufficient to yield 80% statistical power at a significance level of $p < 0.05$ (Faul et al., 2007). Due to the nature of this study and for practical reasons within a school setting, randomisation of participation was conducted at the class level, supporting this study's classification as quasi-experimental (Handley et al., 2018). Random assignment of groups was conducted by an independent third-party blind to the study, using a coin toss (Moher et al., 2010). The two classes were then assigned randomly into the plyometric (Plyometric, $n = 31$; 17 boys and 14 girls) and the comparison (Comparison, $n = 30$; 15 boys and 15 girls) groups.

Before the commencement of the study, written informed consent was obtained from both the parents/legal guardians and study participants, after they were given a full explanation of the purpose, features and potential risks participating in the study. The study protocol conformed to the current agreement of the Declaration of Helsinki on ethical principles for research involving human subjects and was approved by the University of Wollongong Ethics Committee.

The inclusion criteria for the study participants were as follows: (i) being enrolled in the second grade (grade in which approval for the study was obtained); (ii) being free of injuries or physical conditions that will put the student at risk; (iii) providing the corresponding signed written informed assent by the student; and (iv) providing the corresponding signed written informed consent by the student's legal guardian/s. The exclusion criteria for data were: (i) not attending both the familiarisation, pre-and post-test assessment sessions, and (ii) not attending 80% of the physical education lessons, and (iii) missing more than two consecutive PE lessons.

Program

The plyometric and comparison groups were engaged in two 50-minute PE lessons each week over an eight-week period. Each lesson included a 10–15-minute warmup before participation in the PE Unit titled Games and Sport: Ball Skills (see Table 1). The unit was implemented as part of the regular school PE Curriculum and both classes were taught by the same PE teacher. The plyometric group performed the plyometric-based program as their warmup, and the comparison group performed their traditional warmup twice a week at the start of the PE lessons.

Comparison Group Warmup

Participants in the comparison group participated in their traditional warmup activities, consisting of walking, brisk

Table 1. Overview of the PE unit titled - Games and Sport: Ball Skills

Lesson	General Skills Focus	General Types of Activities
1	Dribbling ball with both feet	Group practice drills, games, modified sport
2	Dribbling ball with both feet	Group practice drills, games, modified sport
3	Dribbling ball with both feet	Practice drills, games, modified sport
4	Bouncing/dribbling the ball with hands	Individual practice, group games
5	Bouncing/dribbling the ball with hands	Individual practice, group games
6	Bouncing/dribbling the ball with hands	Individual practice, group games
7	Catching and throwing	Group practice drills, games, modified sport
8	Catching and throwing	Group practice drills, games, modified sport
9	Catching and throwing	Group practice drills, games, modified sport
10	Throwing and passing	Group practice drills, games, modified sport
11	Throwing and passing	Group practice drills, games, modified sport
12	Throwing and passing	Group practice drills, games, modified sport
13	Kicking	Individual practice, group games
14	Kicking	Individual practice, group games
15	Striking	Group practice drills, modified sport
16	Striking	Group practice drills, modified sport

walking and side steps, followed by dynamic stretches. The traditional warmup lasted 10 to 15 minutes and was followed by the set lessons. The comparison group warmups did not include any ‘plyometric exercises’ or ‘plyometric training’ (see Table 2). After the warmup was completed, the students participated in the same replicated PE lesson. Using checklists, students were observed by the researcher and a general class teacher during each lesson to monitor adherence to the comparison group warmup and the set PE lesson.

Plyometric Group Warmup Intervention

The progressive plyometric-based program was performed during the warmup phase of the PE lesson on non-consecutive days twice per week (Monday and Thursday) for eight weeks under monitored and controlled conditions. The warmup lasted 10 to 15 minutes and was followed by the set lesson. The warmup consisted of a circuit of plyometric stations in which students worked in pairs or individually. The plyometric stations consisted of upper and lower body exercises that have been previously used with children (Faigenbaum et al., 2009), and the structure of the program met the suggested training guidelines for children: training repetitions of 6-10 (Lloyd et al., 2011), at least 30 seconds rest between each exercise (Moreno et al., 2014), frequency of two sessions per week, and 72 hours recovery between sessions (Lloyd et al., 2011).

The plyometric-based program intervention was divided into three phases (periods), with the first and second phase spanning three weeks and the last phase being two weeks. The plyometric framework required planned changes over the eight weeks in acute training variables such as; exercise choice, number of repetitions per set, in order to maximise training adaptations (Miller et al., 2006). The first phase was low intensity, higher volume to safely introduce the students to plyometric activities, followed by the second and third phase progressively increasing the intensity while decreasing the repetitions.

Within each session, the plyometric group performed eight different plyometric activities (Tables 3-5). For plyometric exercises involving the use of a medicine ball, students were instructed with a lightweight rubber ball weighing 200 grams before performing them with a weighted 1-kilogram medicine ball. Medicine ball activities in weeks seven and eight utilised a two-kilogram medicine ball.

A qualified PE teacher implemented the plyometric warmup and the PE teaching program. During each lesson, a fidelity checklist and logbook was used to monitor implementation for adherence and quality. The researcher and the general classroom teacher both directly observed the PE teacher and a sample of four students participating to inform the completion of the fidelity checklist and logbook (Loflin, 2015). Fidelity of implementation for all components was > 90% and found to be adequate (Hastie & Casey, 2014). No student experienced injuries or pain during the plyometric warmups.

Measured Variables

Variables in the study included anthropometric indices, test of motor performance skills, measurement of upper, lower body muscular power and reactive strength index. Two familiarisation sessions were delivered prior to the pre-testing day to accustom students to tests of motor performance skills, reactive strength index and muscular power. For both pre-testing and post-testing, tests were completed in two days and each time administered in the same sequence, at the same time each day, by the same research assistants, and students abstained from physical activity in the 24 hours prior to the test. The research assistants were blinded to the group to which students belonged and were trained and familiar with all tests. The students were directed to wear the same

Table 2. Overview of the comparison group warmup

General Movements	Dynamic Stretching
Walking 30m x 4 times	Leg swings forward and back, each leg ten times
Brisk walking 30m x 4 times	Leg swings side to side, each leg ten times
Sidestep walk right 30m	Walking knee hug for 30m
Sidestep walk left 30m	Slow squat to stand, ten times
Follow the leader's actions movement activity	Spiderman climb for 30m, two times
	Overarm rotations, ten times
	Double arm swings across the chest, ten times

Table 3. Description of each plyometric-based session in weeks one to three

Monday	Sets x Reps	Thursday	Sets x Reps
Medicine Ball squats	2 x 10	Jump and freeze	2 x 10
ABC pushes	2 x 10	Doubler leg backward jump	2 x 10
Sticky knees with ball	2 x 10	Triple "X" jump	2 x 10
Medicine ball chest pass	2 x 10	Medicine ball chest pass	2 x 10
Standing jump, reach for the stars	2 x 10	Lateral taps	2 x 10
Medicine ball throw downs	2 x 10	Single leg hops	2 x 10
Single leg hops	2 x 10	Medicine ball throw downs	2 x 10
Straight jump relay	1 x 10	Figure 8 jump relay	1 x 10

*20 seconds for each exercise station; 30 seconds recovery between stations; medicine ball weighed one kilogram

Table 4. Description of each plyometric-based session in weeks four to six

Monday	Sets X Reps	Thursday	Sets x Reps
Jump and turn 90 degrees	2 x 8	Hurdle hops	2 x 8
Push up on knees	2 x 8	Lateral hops	2 x 8
Zig Zag double leg jump	2 x 8	Medicine ball one arm shoulder pass	2 x 8
Medicine ball 1 arm shoulder pass	2 x 8	Zig zag double leg jump drill	2 x 8
Take your marks and jump	2 x 8	Rapid fire medicine ball throw downs	2 x 8
Medicine ball overhead pass	2 x 8	High five jump drill	2 x 8
Medicine ball push pass	2 x 8	Scissor jump with medicine ball	2 x 8
Power skipping relay	1 x 8	Ladder run hop relay	1 x 8

*20 seconds for each exercise station; 30 seconds recovery between stations; medicine ball weighed one kilogram

Table 5. Description of each plyometric-based session in weeks seven and eight

Monday	Sets x Reps	Thursday	Sets x Reps
Medicine ball squat jumps	2 x 6-8	Hexagon drill	2 x 6-8
Explosive push ups on step edge	2 x 6-8	Single leg hop	2 x 6-8
Zig Zag single leg jump	2 x 6-8	Long jump sprint	2 x 6-8
Medicine ball lunge chest pass	2 x 6-8	Medicine ball overhead throw downs	2 x 6-8
Medicine ball push pass	2 x 6-8	Jump and turn 180 degrees	2 x 6-8
Take you marks and jump	2 x 6-8	Medicine ball push pass	2 x 6-8
Medicine ball overhead throw down	2 x 6-8	Tuck jumps	2 x 6-8
Single leg hop relay	1 x 6-8	Power hop relay	1 x 6-8

*20 seconds for completion of each set; 30 seconds recovery between sets; medicine ball weighed two kilograms sports shoes and their traditional PE uniform for both testing sessions. Ten minutes of standard warmup (i.e., submaximal running, dynamic stretches) were executed before testing.

Anthropometry

Anthropometric measures included pre-and post-height and mass. Students' standing height was measured to the nearest millimetre using a portable stadiometer (HART Sport & Leisure, Australia). Body mass was measured to the nearest 0.1 kilograms using the mean of measures from the Innerscan Body Composition Monitor (Tanita BC-541). Additionally, body mass index (BMI) was calculated using height and weight.

Motor performance skills

Change in motor performance skills was measured using the Fundamental Movement Skills Polygon Test (FMS-Polygon) (Bozanic et al., 2011). The FMS-Polygon has been established as a valid and reliable instrument for assessing motor performance skills of children and has concurrent validity with the "Test of Gross Motor Development" (TGMD-2) (Bozanic et al., 2011). The FMS-Polygon consisted of four tasks executed successively in the shortest time possible. In order of execution, the four tasks were: throwing and catching a volleyball against a wall target six times consecutively; running 15 metres and clearing three soft hurdle obstacles (height 50cm, width 100cm and depth 10cm); carrying and placing two 3kg medicine balls on a gymnastics vault (height 110cm, width 150cm and depth 65cm), and then 20 metres straight-line running. The four tasks were measured using an electronic timing system. Students were provided with four attempts, the initial attempt was a trial, and the subsequent attempts were timed and recorded. An overall test result was calculated by averaging the three trial times, which was presented in seconds.

Upper body muscular power

Upper body muscular power was assessed using the medicine ball chest throw (Davis et al., 2008). Before each throw, a one-kilogram weighted ball was covered with magnesium carbonate (e.g., gymnastic chalk) so that when the weighted ball landed on the black flooring, a distinctive white mark is made, allowing for precise measurement. Each student sat on the floor with their legs straight and feet pointing vertically and their back against a wall. A 90cm wide lane was marked out to guide the throw. When performing the medicine ball chest throw, the student placed their elbows against the wall, and then instructed to throw the ball. A two-minute rest was provided after each of the three attempts. The distance of the medicine ball throw was measured using a measuring tape which was taped to the floor, to withstand the force of the ball landing on it. The distance from the wall to the near edge of the mark from the ball on the floor was measured. Each student was provided two trials and then three attempts with only the farthest distance being used for further analysis.

Lower body muscular power

Lower body muscular power was assessed using the results obtained from the squat jump test. The squat jump (SJ) height was measured using the Takei 5406 digital jump belt meter which has a high test-retest reliability (Takei, 5406-Jump MD, Toyko, Japan) (Fernandez-Santos et al., 2015). The jump meter was attached to the waist according to the described standardised protocol provided with the jump meter. Students completed three trials with hands on hips throughout the jump, with a 1-minute rest between trials. The squat jump involved the subject flexing the knee to 90-degree angle position, holding the position for 3 seconds before completing an upward only (concentric) jump. If students failed to adhere to the exact protocol or performed a countermovement, the trial was repeated after an additional 1-minute rest. This test required the students to jump vertically on 2 feet as high as they could, with the jump belt meter attached to their waists and then fall back to where they started to jump. The distance they vertically jumped was recorded on the digital indicator. Each student was provided two trials and then three jumps to see how high they could jump. The student's best jump measured in centimeters (cm) was identified as the final recorded score.

Reactive strength index

The reactive strength index (RSI) was measured using the drop jump (Flanagan, 2008) and a portable electronic jump mat (JustJump; Probotics, Huntsville, AL, USA). Students performed the drop jump test from three different heights (10cm – DJ10cm, 20cm – DJ20cm, and 30cm – DJ30cm). During the test execution, students placed their hands on the hips to eliminate arm swing during the jump take-off phase of the jump mat. The students dropped from a box to the ground after an initial step forward. Immediately upon both feet contacting the Just Jump timing mat, the student jumped as high as possible. The Just Jump timing mat measured and recorded flight time and contact time. Reactive strength index was calculated by dividing contact time by flight time for all three applied drop-jump heights. Initially, subjects were provided with two practice trials. The subject then performed three trials from each specified height with a 2-minute rest between each attempt. The best drop jump for each height was used for further analysis. Test-retest reliability of drop jumps has been previously reported (Quatman et al., 2006). For this study, we calculated intra-session reliability of RSI based on three testing trials for each drop-jump height and note appropriate to high reliability of the pretest and posttest measurements (Pretest: ICC:.91.,96.,93; Posttest:.83.,89.,86, for 10-cm, 20-cm and 30-cm height, respectively).

Statistical Analysis

All statistical analyses were performed using SPSS Version 26.0 for Windows (SPSS Inc, Armonk, New York, 2018). Analysis of data followed a multi-step approach. Firstly, assumptions of normality and homogeneity of variance were tested with the Shapiro–Wilk and Brown-Forsythe tests, respectively. Secondly, descriptive statistics were calculated for all values to illustrate the overall characteristics (central tendency and spread of score) of the sample at the beginning of the study. Student's t-tests were also carried out to determine differences among the two groups' initial values. Comparison of group changes for all dependent variables were calculated. Next, to evaluate the effects of the intervention, data were analysed using a series of two (Plyometric vs Comparison) X two (Pre vs Post) ways repeated measures ANOVAs. To evaluate the effect sizes (ES), partial eta-squared values ($\eta 2$) were presented as follows: small ES: >.02; medium ES: >.13; large ES: >.26 (Ferguson, 2009). If a significant repeated measures ANOVA was calculated ($p<.05$), a post-hoc pairwise comparisons (Bonferroni adjusted) was completed. The use of the follow-up pairwise comparison was used to examine the location of the significant difference, whether between-subject (plyometric group, comparison group) and/or within-group (time).

RESULTS

Table 6 shows the descriptive analysis of student baseline physical characteristics. Analysis of assumptions of normality and homogeneity were met for all included data ($p > 0.05$). The descriptive statistics and comparative analysis (Student's t-test) between plyometric and comparison groups for baseline values revealed no statistical differences between groups (Table 7). Table 8 shows the comparison of group changes for all tests.

Results from repeated measures ANOVA revealed a significant group (Plyometric vs Comparison) X time (Pre to Post) interaction effect (F 1, 59 = 88.065, $p< 0.05$, η^2 =.599, see Figure 1) for the FMS Polygon test. Using η^2, there was a large between-groups effect size for the FMS-Polygon test. The results from repeated measures ANOVAs for measures of muscular power and reactive strength index indicated a significant group (Plyometric vs Comparison) X time (Pre to Post) interaction for squat jump (F 1, 59 = 41.81, $p < 0.05$, $\eta 2$ =.415, see Figure 2), medicine ball chest throw (F 1, 59 = 15.806, p < 0.0.05, $\eta 2$ =.211, see Figure 3), 10cm drop jump RSI (F 1, 59 = 15.592, $p <.05$, $\eta 2$=.209, See Figure 4), 20cm drop jump RSI (F 1, 59 = 11.246, $p < 0.05$, $\eta 2$ =.160, see Figure 5) and 30cm drop jump RSI (F 1, 59 = 10.726, $p < 0.05$, $\eta 2$ =.154, See Figure 6).

Bonferroni adjusted post hoc pairwise comparisons indicated significant improvement ($p \leq .01$) for the plyometric group as identified in the FMS-Polygon test at the post-test time point (See Table 9). The plyometric group demonstrated faster (lower) scores for the FMS-Polygon test compared to the comparison group (Figure 1). Post hoc analysis indicated significant improvement for the plyometric group in lower body muscular power at the post-test time point (squat jump, $p \leq .01$) and also for upper body muscular power (medicine ball chest throw, $p \leq .05$). Conversely, post hoc analysis indicated no significant differences in the drop jumps between plyometric and comparison group at post intervention. However, upon visual inspection of Figures 4-6, and comparison of baseline performances, magnitude-based inferences suggest that in response to the plyometric program, the plyometric group had improvements in RSI that were likely greater than the comparison group.

DISCUSSION

The current study aimed to analyse the effects of integrating an eight-week plyometric training program into the first 10-15 minutes of the usual 50-minute physical education lessons in primary school students. The research findings demonstrate the efficacy of infusing plyometric-based training intervention within the warmup phases of primary PE lessons and suggest that eight weeks of the intervention produced significant changes in motor performance skills, upper and lower body muscular power in students aged seven to eight years old. While the plyometric group changes were significant, the observable changes in the comparison group were minimal. This research is the first to date that has employed a whole-body plyometric-based intervention within PE lessons with students aged seven and eight, measuring the effect on motor performance skills, both upper and lower body muscular power, and reactive strength index. As such the findings create new knowledge and extend the understanding associated with the potential benefit of engaging PE students in a plyometric-based program. The significant changes in FMS-Polygon reported in the present study are promising and infer the potential efficacy of including plyometric exercises in primary school PE lessons to achieve curriculum objectives.

The current findings are consistent with other published studies examining efficacy of plyometric training in slightly older children than in the present study (Bedoya et al., 2015; Eraslan et al., 2021). To the best of our knowledge, only two studies (Chaouachi et al., 2014; Nobre et al., 2017) have applied a plyometric-based program on school premises, outside of the PE curriculum, in a slightly older sample than in the current study, and both identified significant improvements in motor performance skills. Nobre et al. (2017) reported that a 12-week lower body plyometric program, significantly enhanced lower body gross motor skills in the intervention group compared to the comparison group. The results of the current study also compare favourably with the research of Chaouachi et al. (2014), that examined the effect of an eight week lower body plyometric program on specific motor performance skills. Chaouachi et al. (2014) reported significant improvements relative to the control group in 30m sprint, agility, star excursion and stork balance assessment, with medium to large effect size (d=0.34 to 1.25). In comparison with the current study, the research conducted by Nobre et al. (2017) and Chaouachi et al. (2014) reported similar findings, however it is noteworthy that the program and the participants differed. For example, the current study utilised a younger and gender-inclusive cohort and examined a lower and upper body plyometric program. The aforementioned studies involved only male children with an average age of nine years or older. In addition, these programs were not aligned with the school curriculum.

Although there is a dearth of studies that directly compare the effects of plyometric training within PE lessons on motor performance skills, the present results are comparable to those

Table 6. Baseline physical characteristics

Variable	Plyometric Group (n = 31) Mean (±)	Comparison Group (n = 30) Mean (±)	*p*-value
Age (y)	7.35 (0.49)	7.37 (0.49)	0.93
Body height (cm)	128.13 (6.13)	126.30 (6.23)	0.25
Weight (kg)	30.26 (5.91)	28.80 (5.21)	0.33
Body mass index (kg m $^{-2}$)	18.43 (3.42)	18.03 (2.61)	0.60

Values are Mean±Standard Deviation; No significant differences between groups

Table 7. Baseline homogeneity between groups for dependent variables

Variable	Plyometric Group (n=31) Mean (±)	Comparison Group (n=30) Mean (±)	*p*-value
FMS-Polygon (seconds)	34.40 (3.72)	34.83 (4.78)	0.70
Medicine ball chest throw (cm)	209.63 (23.93)	206.63 (36.71)	0.71
Squat jump (cm)	23.45 (5.18)	24.3 (5.21)	0.51
Drop jump (10cm) RSI	40.62 (12.98)	48.78 (15.40)	0.20
Drop jump (20cm) RSI	39.79 (13.89)	46.64 (14.22)	0.16
Drop jump (30cm) RSI	38.60 (13.53)	44.63 (14.94)	0.22

Values are Mean±Standard Deviation

Table 8. Pre- and post-measurements for plyometric and comparison groups (mean±standard deviation) and percentage of change

	Plyometric Group (n = 31)			Comparison group (n = 30)		
	Pre-	Post-	%	Pre-	Post-	%
FMS-Polygon (sec)	34.40±3.72	29.96±3.29	12.91	34.83±4.78	35.03±4.75	0.06
Squat Jump Height (cm)	23.45±5.18	26.61±4.36	13.48	24.3±5.21	23.77±4.20	-2.18
MBCT (cm)	209.63±23.93	223.74±23.23	6.73	206.63±36.71	208.20±32.10	1.57
Drop Jump 10 cm (RSI)	40.62±12.98	48.44±11.75	7.82	48.78±15.40	50.16±12.96	2.83
Drop Jump 20 cm (RSI)	39.79±13.89	46.49±14.10	16.84	46.64±14.22	46.08±11.72	-1.2
Drop Jump 30 cm (RSI)	38.60±13.53	44.38±12.75	14.97	44.63±14.94	46.08±12.75	3.2

% Is the percentage of change from pre to post-test measurements; MBCT = medicine ball chest throw, RSI = reactive strength index

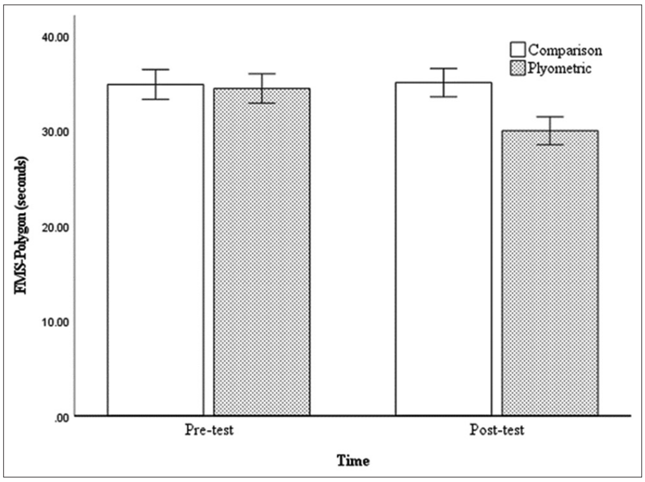

Figure 1. FMS-polygon mean for the treatment by time interaction between comparison and plyometric groups

studies in sports (Fernandez-Fernandez et al., 2016). By way of example, a study by Fernandez-Fernandez et al. (2016) implemented an eight week upper and lower body plyometric program into tennis training and their data identified increased motor performance skills in young male tennis players aged 12 to 13. These performance skills included short sprints, agility testing, serve velocity and accuracy. Consistent with the current study, the intervention was delivered twice per week for eight weeks and was a substitute for part of the training session. These results and study design are similar to the current study and provide further efficacy for allocating 10 to 15 minutes of class time to plyometric training to improve motor performance skills. It is reasonable to conclude from the current study that short bouts of plyometric training are an effective method to accelerate motor performance skill development when confronted with reduced PE curriculum time. Of note is that the comparison group experienced little or no improvement in all measured variables over the duration of the study.

In this study, results indicated that in comparison with standard PE lessons, the inclusion of a whole-body plyometric training seems to be a sufficient stimulus for improving motor performance skills. Although the mechanisms responsible for this improvement in this study are not entirely understood or directly measured within this

Table 9. Bonferroni adjusted post hoc pairwise comparison for dependent variables

Dependent Variable	Mean Difference (Comparison group - Plyometric group)	Std. Error	*p*	95% Confidence Interval for Difference	
				Lower Bound	Upper Bound
FMS-Polygon					
Pre-	0.64	1.32	0.62	-1.99	3.29
Post-	5.24	1.26	0.01*	2.71	7.77
Squat Jump height					
Pre-	0.84	1.33	0.53	-1.81	3.51
Post-	-2.84	1.10	0.01*	-5.04	-0.65
Medicine Ball Chest Throw					
Pre-	-3.01	7.91	0.71	-18.84	12.81
Post-	-15.54	7.16	0.03**	-29.87	-1.22
Drop Jump 10cm					
Pre-	4.08	3.30	0.22	-2.52	10.68
Post-	-4.14	2.97	0.17	-10.09	1.81
Drop Jump 20cm					
Pre-	4.34	3.31	0.19	-2.29	10.97
Post-	-2.13	3.23	0.51	-8.59	4.34
Drop Jump 30 cm					
Pre-	4.93	3.45	0.16	-1.97	11.83
Post-	-1.59	2.93	0.59	-7.45	4.27

* Significant at $P \leq 0.01$; **Significant at $P \leq 0.05$

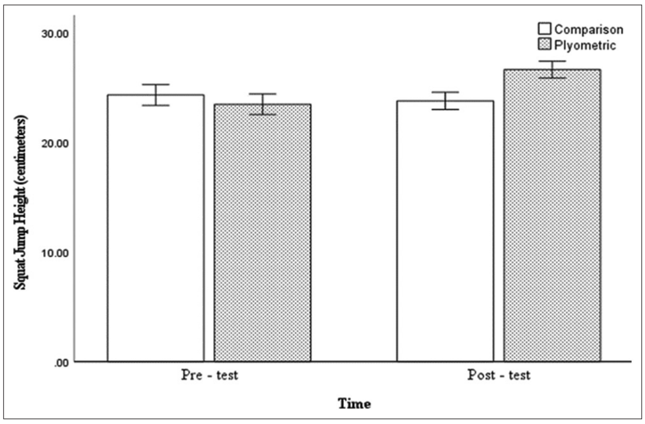

Figure 2. Squat Jump mean for the treatment by time interaction between comparison and plyometric groups

paper, the change could likely be due to various neural or neuromuscular adaptations as exhibited by enhanced measures of both upper and lower body muscular power. The neuromuscular system is essential for performing motor performance skills. Neuromuscular performance is governed by an effective and efficient interaction between both the nervous and muscular system. In children, the neuromuscular system is highly adaptable due to the heightened level of plasticity (Yue et al., 2017). Neuromuscular adaptations as a consequence of plyometric training include changes in motor unit recruitment, firing, and coordination, which are known factors that are vital for optimal movement, and are likely to play a key role in reported motor performance skill proficiency improvements (Behrens et al., 2016; Collins et al., 2019). Research also supports the suggestion that plyometric training imparts both neuromuscular adaptations and muscular power adaptations, both of which have been identified as essential components of motor performance skill development (Behringer et al., 2011; Ramirez-Campillo et al., 2018). Furthermore, there is supporting evidence from systematic reviews that plyometric training improves motor performance skills in children via enhanced neuromuscular development (Behringer et al., 2011; Peitz et al., 2018). This is a logical inference considering the ability of the neuromuscular pathways to develop and adapt, leading to children being better able to move their bodies in different ways, both from a dynamic and static perspective. It is also therefore reasonable to conclude that improvement in the FMS-Polygon performance was likely a result of students' neuromuscular property changes.

The results of this study also support the idea of exposing students to plyometrics early in primary school. Early exposure can accelerate motor performance skills development at an earlier age (Pichardo et al., 2018). It can be suggested from this work that enhanced motor performance skills at an earlier age may result in students acquiring the level of proficiency appropriate for secondary PE, where more specialised sports skills are taught (NESA, 2018). Furthermore, based on the notion that middle childhood is a critical period for the attainment of motor performance skill proficiency (Farooq et al., 2018), plyometric training could support the achievement of PE curriculum objectives, such as moving

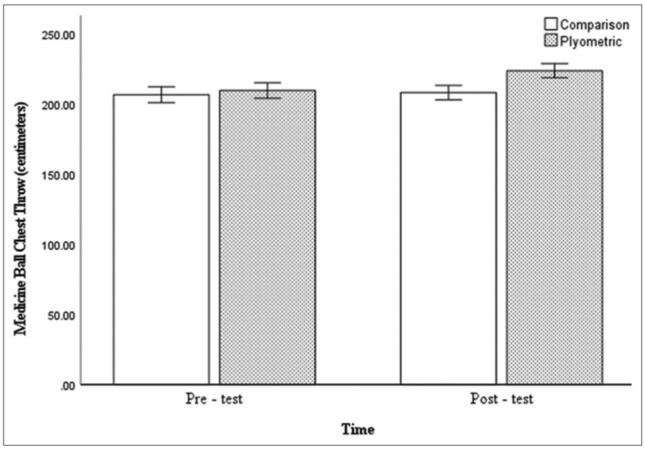

Figure 3. Medicine ball chest throw mean for the treatment by time interaction between comparison and plyometric groups

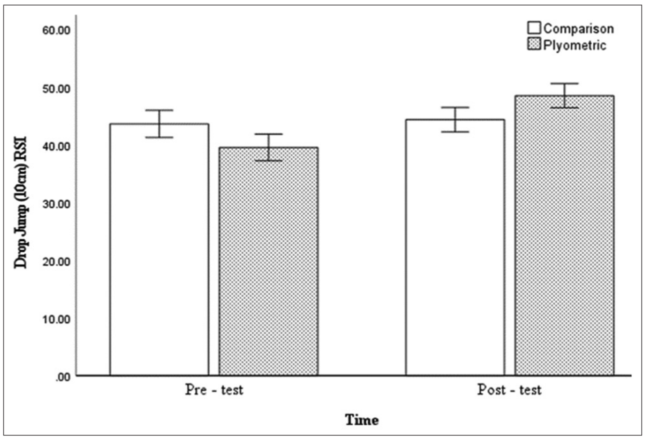

Figure 4. Drop Jump (10cm) RSI mean for the treatment by time interaction between comparison and plyometric groups

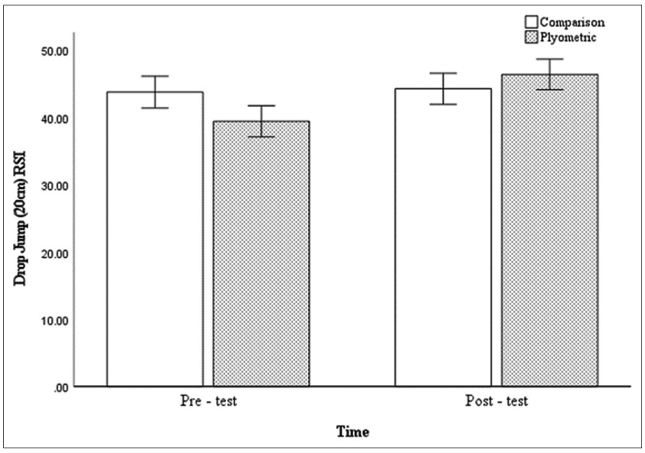

Figure 5. Drop Jump (20cm) RSI mean for the treatment by time interaction between comparison and plyometric groups

with confidence and competence within and across physical activities (NESA, 2018). As such, the study results are important for PE practitioners, in that they provide support for the use of plyometrics in achieving a range of overarching objectives and outcomes. In practice, there is scope for this approach to gain more traction in Australian primary schools.

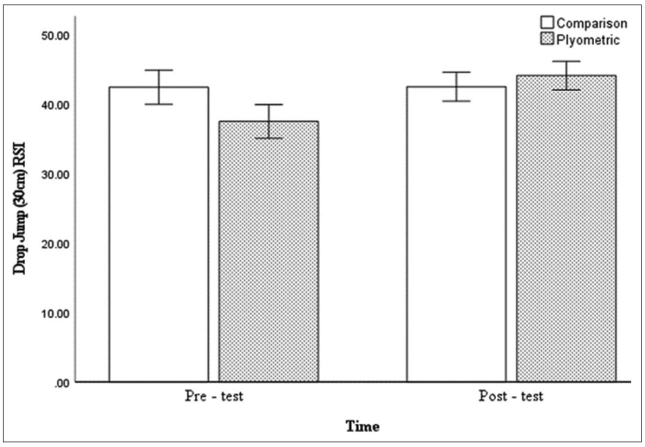

Figure 6. Drop Jump (30cm) RSI mean for the treatment by time interaction between comparison and plyometric group

The current study is important for developing strategies in PE to accelerate the development of motor performance skills and muscular power. However, limitations of the present study included: addressed whole-body plyometric training only in seven and eight-year-old children, results do not provide insight into long-term training adaptations, no collection of psychological responses (i.e., motivation), and lastly, the study did not include a no-PE comparison group in the school setting.

In the current study, a whole-body plyometric training protocol in PE improved motor performance skills and upper and lower body muscular power of seven to eight-year-old primary school students. The protocol was delivered twice a week during the PE lessons' 10–15-minute warmup phase, during eight weeks. The data analysis showed that the plyometric intervention over the eight weeks induced favourable changes in motor performance skills, upper and lower body muscular power, which was significant compared to the comparison group. The findings support the importance of incorporating teaching strategies that develop the underlying capabilities of motor performance skills in PE (i.e., muscular power). The implications of this for teaching practices are twofold. Firstly, by engaging students in plyometric training during the warmup phase of the lesson rather than increasing class time or changing teaching pedagogy, schools can provide their students with an opportunity and stimulus to develop motor performance skills during the warmup, while retaining valuable class time. Secondly, teachers may implement in-class upper and lower body plyometric exercises to enhance skill-related fitness such as muscular power and performance (i.e., jumping, throwing) in children aged seven and eight years.

CONCLUSION

While skill development drills and practice within a game-like environment are often part of the physical education curriculum, our findings indicate that physical education infused with plyometric training can enhance motor performance skill proficiency, and muscular power in young primary students. Hence, PE curriculum infused with explosive strength exercises such as plyometrics can engage students in ways that develop their movement performance skills and muscular fitness while still being sufficiently oriented toward the improvement of motor skills.

Collectively our findings suggest that plyometric training may be a safe and valid physical education pedagogical strategy to aid in the development of motor performance skills.

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