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Integrative Neuromuscular Training and Sex-Specific Fitness Performance in 7-Year-Old Children: An Exploratory Investigation

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Context: Integrative neuromuscular training (INT) has successfully enhanced physical fitness and reduced abnormal biomechanics, which appear to decrease injury rates in adolescent female athletes. If not addressed at the proper time, low levels of physical fitness and abnormal mechanics may predispose female athletes to an increased risk of musculoskeletal injuries.

Objectives: To evaluate sex-specific effects of INT on selected measures of health- and skill-related fitness in children during physical education (PE).

Design: Cohort study.

Setting: Public primary school.

Patients or Other Participants: Forty children (16 boys, 24 girls; age = 7.6 ± 0.3 years, height = 124.5 ± 6.4 cm, mass = 29.5 ± 7.6 kg) from 2 second-grade PE classes.

Intervention(s): The classes were randomized into the PE-plus-INT group (10 boys, 11 girls) or the control group (6 boys, 13 girls) that participated in traditional PE. The INT was performed 2 times per week during the first approximately 15 minutes of each PE class and consisted of body weight exercises.

Main Outcome Measure(s): Push-up, curl-up, standing long jump, single-legged hop, single-legged balance, sit-and-reach flexibility test, shuttle run, and 0.8-km run.

Results: At baseline, the boys demonstrated higher levels of performance in most of the fitness measurements as evidenced by greater performance on the push-up, standing long jump, single-legged hop, shuttle run, and 0.8-km run ($P < .05$). In the evaluation of the training effects, we found intervention effects in the girls for enhanced INT-induced gains in performance relative to the control group on the curl-up, long jump, single-legged hop, and 0.8-km run ($P < .05$) after controlling for baseline. Boys did not demonstrate similar adaptations from the INT program ($P \geq .05$).

Conclusions: These data indicate that INT is an effective and time-efficient addition to PE for enhancing motor skills and promoting physical activity in children. Seven-year-old girls appeared to be more sensitive to the effects of INT than 7-year-old boys. Future research is warranted to confirm these effects in larger cohorts of children.

Key Words: fundamental movement skills, motor development, strength training, plyometrics, physical education

Key Points

- Incorporating integrative neuromuscular training into physical education can result in substantial improvements in selected health- and skill-related fitness components in children.
- Integrative neuromuscular training can be a cost-effective and time-efficient method for enhancing motor skills and promoting physical activity in children.
- Among 7-year-old children, girls were more sensitive than boys to the effects of integrative neuromuscular training performed twice weekly during physical education.
- Long-term studies are needed to explore the sex-specific effects of integrative neuromuscular training on school-aged youth and on long-term injury risk.

In the absence of sufficient corresponding neuromuscular adaptation, musculoskeletal growth before and during puberty may facilitate the development of abnormal mechanics during certain activities.[1–3] If not addressed at the proper time, these intrinsic risk factors may persist through adolescence and into maturity and may predispose female athletes to increased risk of a variety of musculoskeletal injuries.[4,5] In a recent longitudinal study, Ford et al[6] noted that pubertal girls demonstrated increased abnormal landing mechanics over time. In addition, they reported that important contributing risk factors for knee injury were greater across consecutive years in young postpubertal female athletes than in boys.[6]

Integrative neuromuscular training (INT) programs have successfully reduced these abnormal biomechanics[7–10] and appear to decrease injury rates in adolescent female athletes. The INT used to enrich the motor-learning environment in preadolescent youth may enhance physical fitness, prevent the proliferation of neuromuscular deficits, and help children with low levels of motor competence "catch up" to their peers with normal motor skills in these measures.[11–14] The mastery of fundamental movement skills (FMS; eg, locomotor, object control, stability skills) may provide the foundation for a lifetime of physical activity.[15]

In a recent systematic review examining FMS in youth, Lubans et al[15] concluded that school- and community-based interventions are needed to enhance FMS competency. These authors suggested that such skills should be taught during preschool and primary school, when children are at an optimal age to master them.[15] By modifying existing physical education (PE) lessons, substantial improvements in FMS mastery can be observed.[16] For example, researchers[17,18] have reported that fitness training that included plyometrics and resistance training with medicine balls was effective for conditioning school-aged youth during PE provided the program was developmentally appropriate and sensibly progressed over time.

The proliferation of neuromuscular deficits in young girls who are not exposed to INT during preadolescence may contribute to a decrease in regular physical activity and an increased risk of sport-related or recreation-related injuries relative to their male peers as they mature.[19–22] Whereas only a small number of young athletes participate in preparatory conditioning programs before sports involvement,[23] current data have indicated that multifaceted interventions may reduce sport-related injury risk in adolescents, and we hypothesize that similar results will be observed in preadolescent populations if such programs are applied before the development of fundamental movement deficits.[21,22,24–27] Given that research on the specific effects of INT during childhood is scant, investigators need to determine if a brief sex-specific time of development exists for implementing INT so that certified athletic trainers and other professionals can optimize training adaptations during the growing years in both boys and girls.

Positive effects of INT on selected measures of health- and skill-related fitness in children during PE have been reported.[28] In most PE programs, physical fitness tests are used to assess a variety of health- and skill-related measures, including aerobic fitness, muscular fitness, and FMS. Therefore, the purpose of our study was to determine the sex-specific effects of INT on selected measures of health- and skill-related fitness in children during PE. Based on earlier findings and clinical observations, we hypothesized that INT would favorably affect health- and fitness-related measures in both sexes but that young girls would be more sensitive to the INT stimulus than their male peers.

Table 1. Participant Demographics and Anthropometrics (N = 40)

Characteristic	Mean ± SD
Age, y	
Boys	7.6 ± 0.3
Girls	7.5 ± 0.3
Total	7.6 ± 0.3
Height, cm	
Boys	123.7 ± 6.9
Girls	125.0 ± 6.1
Total	124.5 ± 6.4
Mass, kg	
Boys	27.6 ± 7.2
Girls	30.8 ± 7.8
Total	29.5 ± 7.6
Body mass index, kg/m²	
Boys	17.8 ± 3.1
Girls	19.5 ± 3.6
Total	18.8 ± 3.4
Body mass index, z-score	
Boys	0.8 ± 0.9
Girls	1.2 ± 0.9
Total	1.0 ± 0.9

METHODS

Participants

We recruited 40 healthy children from 2 second-grade PE classes in a public school to participate in this study (Table 1). Children with chronic pediatric diseases or orthopaedic limitations were excluded. The classes were randomized into either a PE-plus-INT (10 boys, 11 girls) group or a control (CON; 6 boys, 13 girls) group that performed standard PE. The researchers were not blinded to the participants' assigned groups. Parents provided written informed consent, and children provided assent. The study was approved by the Institutional Review Board of The College of New Jersey.

Procedures

Testing. After an orientation session that included a review and practice of skill-based fitness tests, all participants were assessed by qualified professionals (A.D.F., A.F., T.R., M.F.) who had experience in fitness testing of children. During the pretraining assessment, height and body mass were measured using standard techniques with a stadiometer (Seca, Hanover, MD) and standard physician scale (Detecto, Webb City, MO), respectively, and body mass index (BMI) was measured in kilograms per meter squared. We calculated BMI z-scores, which yield a value for the BMI in terms of units of standard deviations from the mean, based on data from the 2000 Centers for Disease Control and Prevention growth charts[29] according to age in months and sex of each child. This age- and sex-specific measure of BMI likely yielded a more appropriate representation of BMI for comparison among children and adolescents than used in previous epidemiologic studies of motor development and injury risk.[30] Standardized protocols for fitness testing were followed according to methods previously described.[31–33] Trials were excluded if participants did not follow the established criteria. Test-retest reliability of standard PE fitness tests with school-aged youth has been reported.[31,34,35]

Briefly, curl-up and push-up tests were used to assess abdominal and upper body strength and endurance, respectively, and the total number of repetitions completed with proper form at a rhythmic pace was recorded. The cadence of the curl-up test was set with a metronome (Lafayette Instrument, Lafayette, IN; 1 curl-up per 3 seconds), and the push-up test required participants to lower their chests to a rubber square until their elbows were at 90° and then return to the starting position with their backs flat, legs extended, and feet positioned wider than their shoulders. Lower body power was evaluated by the standing–long-jump and single-legged hop tests. Participants were required to hold the landing of each jump and maintain body control until the distance was measured. Each jump test was performed 3 times, and the best score was recorded to the nearest centimeter. The intraclass correlation coefficient for the single-legged–hop test performed by 7-year-old children in our laboratory is 0.82. Lower back and hamstrings flexibility were evaluated by the sit-and-reach test. Balance was assessed with the stork stand, which required participants to maintain a stable body position while standing without sneakers on 1 plantar-flexed foot with hands on hips and eyes open. Participants were required to hold this position for as long as possible, and the best time of 3 trials was recorded to the nearest 0.1 second.

Speed and agility were evaluated with the shuttle run (4 × 10 yd [9.1 m]) whereby 2 small blocks were placed behind a line marked 10 yd (9.1 m) from the start line. Participants ran to the blocks, picked up 1 block, returned to the start line, placed the block behind the start line, ran back, picked up the other block, and ran across the start line. The best time of 2 trials was recorded to the nearest 0.1 second. Cardiorespiratory endurance was assessed with the 0.8-km run. A posttraining assessment for all fitness tests was performed during the week after the training period.

Training. The INT program used in this study was designed specifically for primary school children and was modified from earlier reports on resistance training and neuromuscular conditioning for children and adolescents.[36–38] The intervention was performed twice per week (Monday and Wednesday) during the first approximately 15 minutes of each regularly scheduled 43-minute PE class. The regular PE teacher and a certified strength and conditioning specialist provided instruction for every class and developed a supportive and challenging learning environment. The INT program consisted of primary exercises to enhance muscular power, lower body strength, and core strength (eg, abdominals, trunk, hip) and secondary exercises to improve FMS. The general structure and content of the INT program is outlined in Table 2. The specific details of the INT program have been described.[28]

Participants were active throughout the entire INT program and alternated between 1 set of higher-intensity primary exercises and 1 set of lower-intensity secondary exercises, which is characteristic of how children move and play.[39] Participants performed 2 sets of all exercises, and during the 8-week training period, they progressed from 7 to 10 repetitions of the front-squat, squat-jump, and 90° jump exercises and from 10 to 30 seconds of the plank exercise. Secondary exercises aimed at improving object control and stability skills were performed for approximately 15 to 30 seconds. These secondary exercises included single-legged–balance movements and twisting exercises that became progressively more challenging every 2 to 3 weeks. During our INT program, children held a durable punch balloon that was blown up to the size of a basketball. Balloons spark a natural desire to play in youth and increase the likelihood that children master new movements and experience success.[40]

Table 2. General Structure of the Integrative Neuromuscular Training Program

Exercises	Wks	Description
Primary	1–8	Front squat
		Squat jump
		90° Jump
		Plank
		Balloon drop and catch
Secondary	1–2	Single-legged balance
		Overhead press and catch
		Knee tap and catch
		Hip twister
	3–5	Single-legged balance and overhead press
		Single-legged overhead press and catch
		Alternate right and left knee tap and catch
		Overhead chop
	6–8	Single-legged balance and chest press
		Get up and catch
		Knee tap, turn, and catch
		Diagonal chop

After INT, children participated in a variety of traditional PE activities (eg, stick handling, ball dribbling, group games) as directed by the PE teacher for the remainder of each class. Participants in the CON group did not perform specific INT but attended their regular PE class twice per week during the study period and were involved in the same traditional PE activities.

Statistical Analyses

Descriptive data were examined for all variables, including distributional properties; it was not necessary to transform any of the outcome variables for analysis. Pretest performance measures were compared between boys and girls using a *t* test. Given the nature of the outcome variables under investigation, we anticipated that sex-specific pretest differences would be found: thus controlling for this initial difference using analysis of covariance (ANCOVA) would be appropriate. To determine the sex-specific responses to INT, we used a 2-way ANCOVA to examine the interaction and main effects of group (PE plus INT versus CON) and sex (male versus female) on the dependent health- and skill-related fitness performance variables measured at posttesting, controlling for pretest values. This method of analysis was chosen as superior to examining a 3-way interaction, including time, due to the size of the sample for this study.

Given that we were interested in the specific effect of the intervention by sex, we deemed it appropriate to conduct exploratory analyses using 1-way ANCOVAs. We performed the 1-way ANCOVAs to compare posttest values (pretest values as covariate) between groups (PE plus INT versus CON) for boys and girls separately. These exploratory analyses were conducted because we anticipat-

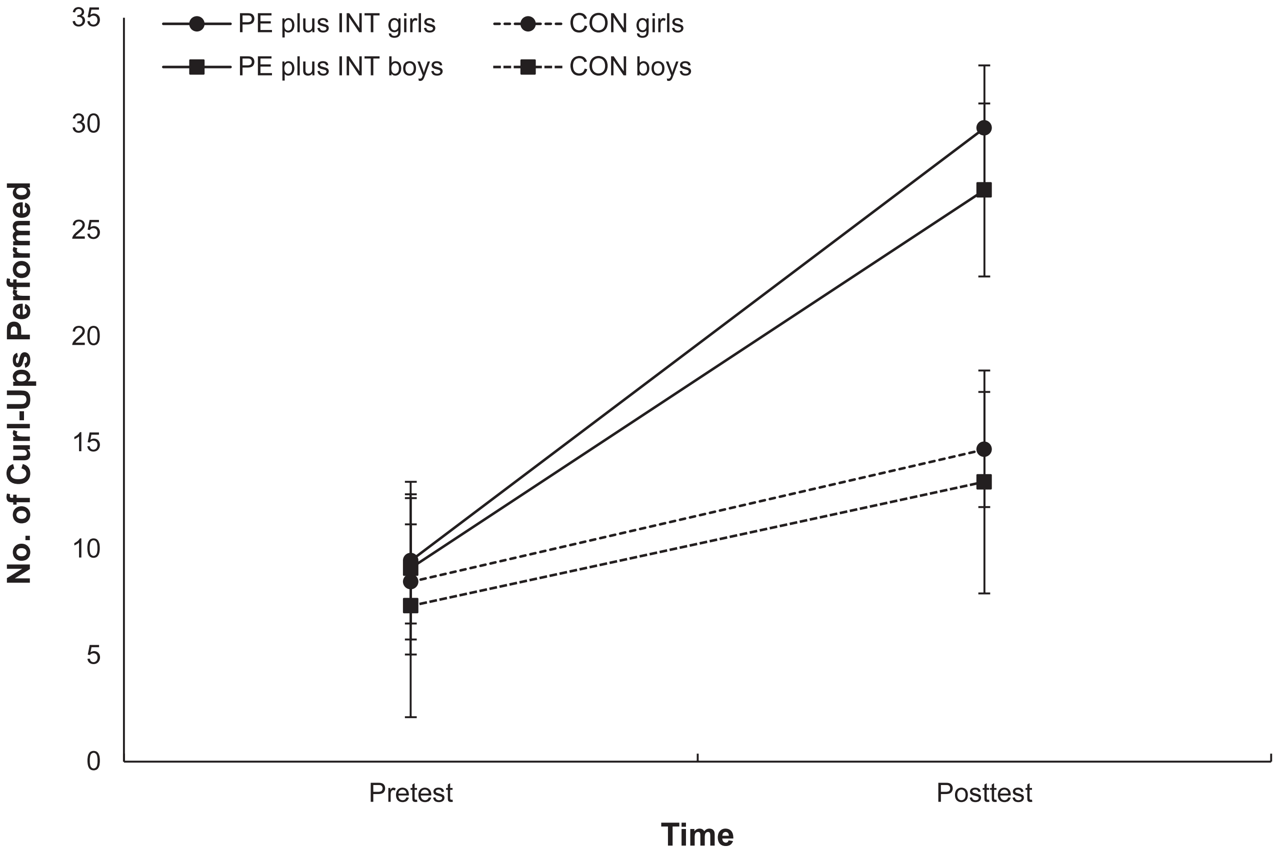

Figure 1. **Curl-up performance. For the curl-up test, we found a time-by-group-by-sex interaction that indicated sex differences in the response to integrative neuromuscular training (INT; *P* = .01). In girls, the INT program increased the maximal number of curl-ups from after the intervention. In boys, we noted a main effect of time: both the standard physical education (PE) and PE-plus-INT groups increased scores from pretest to posttest. Plots represent adjusted mean ± standard error of the mean. Abbreviation: CON, control.**

ed statistical power for the 2-way ANCOVA analyses might be limited. We used SAS (version 9.3; SAS Institute Inc, Cary, NC) for all analyses. The BMI z-score was calculated using SAS (gc-calculate-BIV.sas; available at http://www.cdc.gov/nccdphp/dnpao/growthcharts/resources/sas.htm). The α level was set a priori at .05 to test the main effects for the 2-way ANCOVA and 1-way ANCOVA analyses. However, we used a less conservative a priori α level of .10 for the 2-way ANCOVA interaction (group × sex). When we found an interaction, we applied post hoc evaluations of differences in least square means with Bonferroni correction. When we did not find an interaction, we performed a post hoc power analysis using the GLMPOWER procedure (SAS Institute Inc).

RESULTS

All participants completed the study according to the aforementioned procedures, and no injuries were reported. At baseline, the male students demonstrated higher levels of performance in most of the fitness measurements as evidenced by greater performance on the 0.8-km run, push-up, single-legged hop, standing long jump, and shuttle run ($P < .05$). A visual presentation of the data using the unadjusted values is provided in Figures 1 through 5. These data do not represent the findings from the 2-way or 1-way ANCOVA statistical analyses.

The initial approach was to examine the full model including a group-by-sex interaction. We observed an interaction of group and sex after the intervention for only the 0.8-km run, which demonstrated that the training response was different between the PE-plus-INT and CON groups for boys and girls ($P = .06$). This endurance run showed the greatest improvement after INT, with a reduced time from 343.0 seconds (range, 312.0 to 373.8 seconds) at pretest to 306.3 seconds (range, 279.6 to 333.0 seconds) at posttest for the girls in the PE-plus-INT group compared with the girls in the CON group. In boys, we did not find a measured effect of CON or PE-plus-INT toward improved posttest score relative to pretest assessment ($P = .97$) for the 0.8-km run. We did not note a group-by-sex interaction for the curl-up test ($P = .75$; power = 6%), push-up test ($P = .54$; power > 80%), or standing long jump ($P = .35$; power > 80%). We also did not find group-by-sex interactions for the balance test ($P = .65$; power 5%), sit-and-reach flexibility ($P = .22$; power > 80%), and shuttle-run test ($P = .96$; power = 5%). We found a main effect of group for the curl-up test ($P = .001$) and the single-legged–hop test ($P < .001$).

In the sex-specific models, the girls in the PE-plus-INT group increased the maximal number of curl-ups from a mean (95% confidence interval) pretest score of 9.5 (5.3 to 13.6 repetitions) to 29.8 (21.7 to 37.9 repetitions; $P < .004$) compared with the girls in the CON group after the intervention. In boys, we did not find a group effect ($P = .14$). Performance on the 0.8-km run also revealed a group effect for improved performance in the PE-plus-INT cohort for girls ($P = .009$).

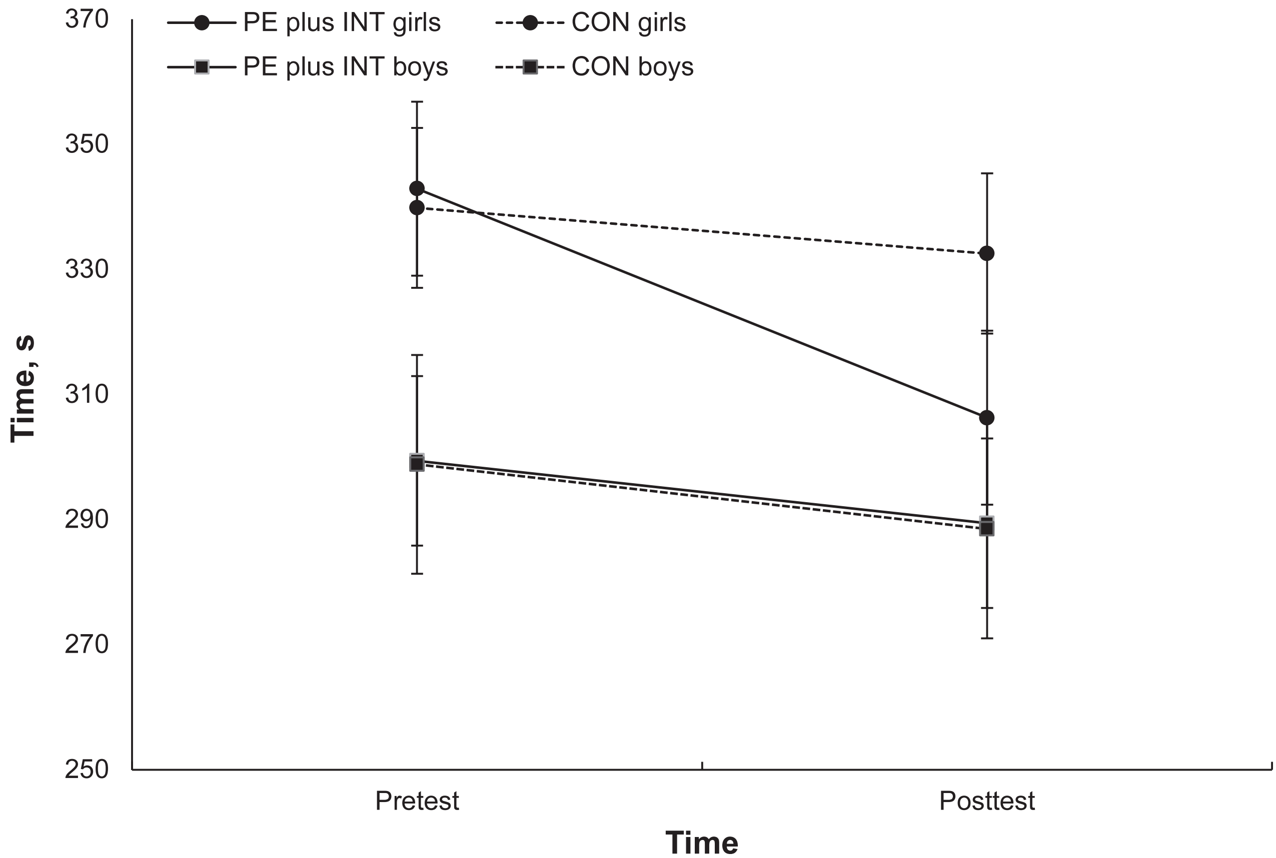

Figure 2. The 0.8-km run performance. For the 0.8-km timed-performance run, we found a time-by-group-by-sex interaction at posttest that indicated sex differences in the response to integrative neuromuscular training (INT; *P* = .03). In the sex-specific female model, performance on the 0.8-km run also revealed a time-by-group interaction for improved performance in the group participating in physical education (PE) plus INT. The endurance run showed the greatest improvement after INT relative to the control (CON) group, with a reduced time from pretest to posttest in the girls. In boys, we did not find a measured effect of either standard PE or PE plus INT toward improved posttest score relative to pretest assessment. Plots represent adjusted mean ± standard error of the mean.

In the sex-specific model, we found a trend toward an increase in the maximal number of push-ups measured at posttest for the girls in the PE-plus-INT group compared with the girls in the CON group, but this finding was not different (*P* = .09). Similarly, we found no difference between boys in the PE-plus-INT and CON groups (*P* = .64).

In the sex-specific models evaluating the single-legged–hop test, a group effect was observed for girls in the PE-plus-INT group compared with girls in the CON group, with the former group demonstrating greater improvement in performance after INT (*P* = .001); results for the single-legged–hop test increased from 69.7 cm (61.4 to 78.1 cm) at pretest to 76.8 cm (69.4 to 84.1 cm) at posttest in the PE-plus-INT group. In boys, we also observed a main effect of group, which indicated that the boys in the PE-plus-INT group increased single-legged–hop distance measured at posttest compared with the boys in the CON group (*P* = .04); the distance for the boys in the PE-plus-INT group increased from 75.4 (63.2 to 87.6 cm) at pretest to 83.8 (73.1 to 94.5 cm) at posttest.

For the standing–long-jump test, we noted a group effect, as the girls in the PE-plus-INT group demonstrated increased performance at posttest compared with the girls in the CON group (*P* = .05). The girls in the PE-plus-INT group increased the standing long jump from a score of 103.9 cm (95.6 to 112.2 cm) at pretest to 108.8 cm (100.8 to 117.0 cm) at posttest. In the boys, we did not find a main effect of group (*P* = .58; Figure 5). We found no group differences between the CON and PE-plus-INT groups in either the boys for the balance test (*P* = .43), sit-and-reach flexibility (*P* = .79), shuttle-run test (*P* = .36) or the girls for the balance test (*P* = .37), or sit-and-reach flexibility (*P* = .47), or shuttle-run test (*P* = .36).

DISCUSSION

Approximately 15 minutes of INT performed twice per week for 8 weeks resulted in greater gains in health- and skill-related fitness measures than normally achieved with standard PE in children. Our exploratory analyses suggest that the 7-year-old girls appeared to be more sensitive to the cumulative effects of INT than to traditional PE as evidenced by their superior adaptation in both health- and skill-related fitness measures. However, this did not appear to be the case for the boys. Given that both groups participated in the same PE lessons during the study period, such differences in fitness performance are likely due to the specific training adaptations that resulted from INT. Although speculative, 7-year-old girls may be in a brief, sex-specific time of development that may make them more sensitive to INT interventions. The reduced ability of the female neuromuscular system to adapt to FMS relative to the *neuromuscular spurt*, which is defined as the natural

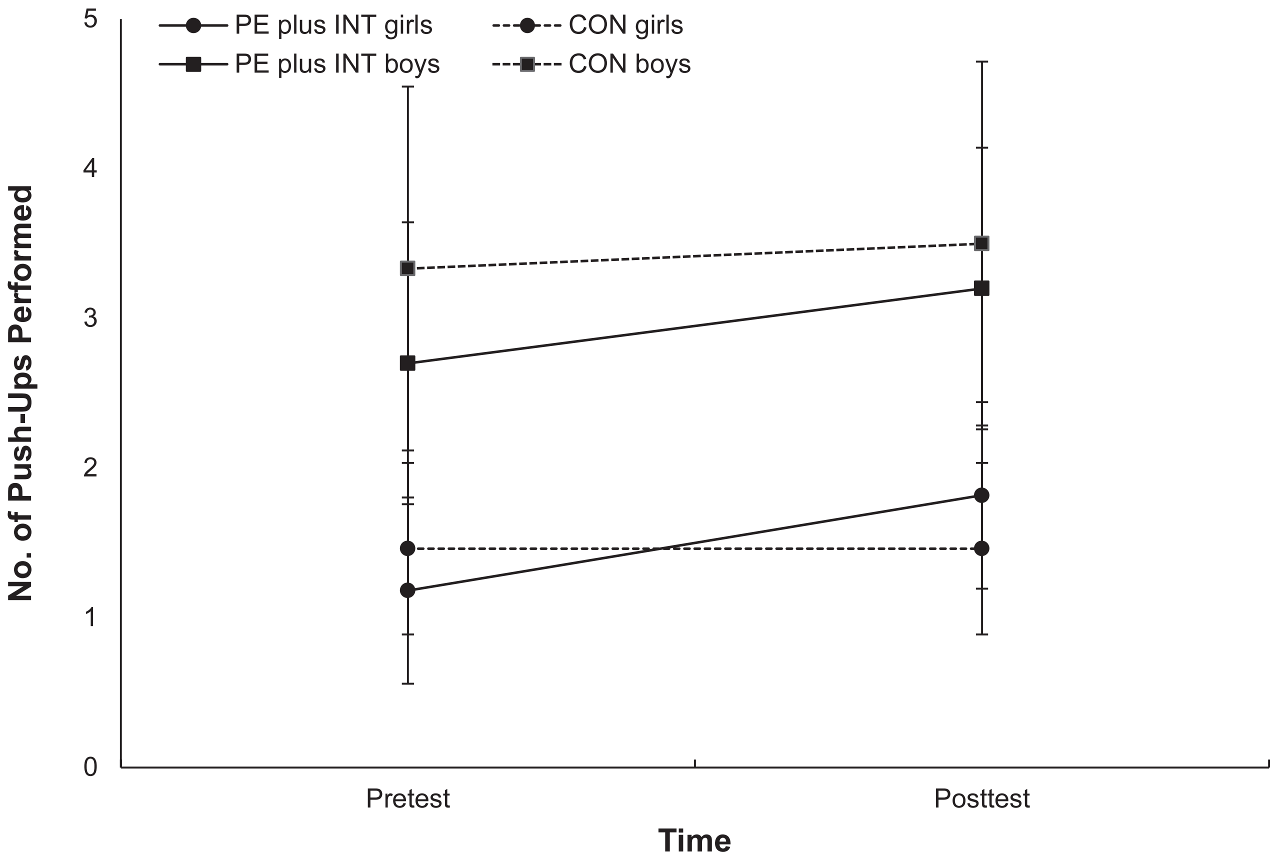

Figure 3. Push-up performance. For the push-up test, the overall time-by-group-by-sex interaction was not different between sexes ($P >$ .05). However, in the sex-specific model, the girls who participated in physical education (PE) plus integrative neuromuscular training (INT) increased the maximal number of push-ups. Plots represent adjusted mean ± standard error of the mean. Abbreviation: CON, control.

adaptation of increased power, strength, and coordination that occurs with increasing chronological age and maturational stage, in adolescent boys may influence the female propensity to adapt to INT. In addition, the reduced performance of girls in pretest measures may have optimized their sensitivity to INT implemented during this period of development.

Musculoskeletal growth before and during puberty in the absence of sufficient corresponding neuromuscular adaptation (eg, posterior chain strength, FMS) may lead to the development of abnormal mechanics (eg, excessive frontal-plane knee loads, deficits in force absorption) during dynamic sport-related activities.[1,2] If not addressed at the appropriate time, intrinsic risk factors may continue to develop through adolescence into maturity and may predispose female athletes to increased risk of various musculoskeletal injuries.[4,5] The INT program used to enrich the motor-learning environment in early youth may enhance physical fitness, prevent the proliferation of neuromuscular deficits, and help children with low levels of motor competence catch up with their peers in these measures.[12–14] Modifying existing PE lessons can result in substantial improvements in physical fitness and FMS mastery.[16–18]

Preliminary data have indicated that INT protocols implemented during preadolescence and early adolescence may artificially induce the neuromuscular spurt.[41,42] The results of INT are particularly effective for enhancing posterior chain strength, postural control, and neuromuscular power, which often are reduced as young female athletes mature.[43] An induced neuromuscular spurt may decrease sex differences in neuromuscular control of the lower extremity and, therefore, potentially reduce the risk of sport-related injury in adolescent female athletes.[10,25,44,45] Our data demonstrated that girls as young as 7 years of age may be particularly responsive to INT aimed at reducing these deficits that accelerate during maturation and eventually may lead to increased musculoskeletal injury risk later in life. The sensitivity to INT in girls may have been due to reduced relative FMS performance that provided a reduced threshold for adaptation given the same stimulus as the boys in our study. Girls also may maintain an earlier sensitive period for adaptation, whereas boys may respond to INT later during preadolescence; however, further study is warranted to support these contentions.

The girls in the PE-plus-INT group made greater gains in selected health-related fitness measures after the training period than the girls in the CON group. These findings indicate that female primary school students respond to INT by increasing their muscular strength and endurance and ability to perform cardiorespiratory exercise. Whereas gains in muscle strength and local muscular endurance after progressive resistance training with external loads have been reported,[46–48] our findings indicate that selected health- and skill-related fitness measures can be enhanced in young girls with an approximately 15-minute INT program that is incorporated into traditional PE. Of interest, balance performance as assessed in our study did not

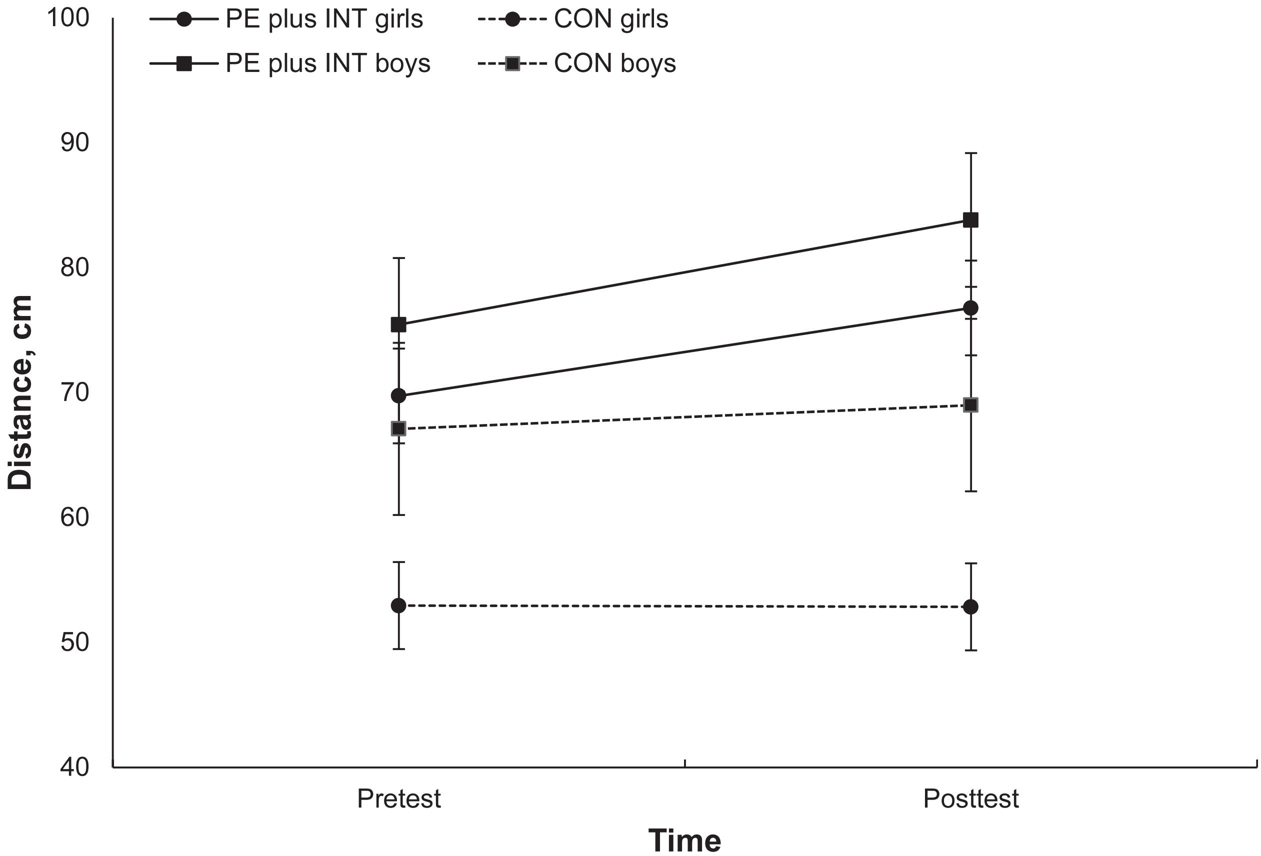

Figure 4. Single-legged–hop performance. For the single-legged–hop test, a time-by-group-by-sex interaction indicated sex differences in the response to integrative neuromuscular training (INT; $P = .02$). In the sex-specific models evaluating the single-legged–hop test, we observed greater improvement for the girls performing physical education (PE) plus INT than girls in the control (CON) group. In the male-specific model, we also observed a main effect of time: both the CON and PE-plus-INT groups improved their pretest single-legged–hop distance. Plots represent adjusted mean ± standard error of the mean.

improve after the training period. The smaller-than-hypothesized effect on balance may have occurred because the 15-minute INT program was not of the magnitude required to enhance balance in 7-year-old children. Additional dynamic stabilization exercises may be needed for training-induced treatment effects in children.

Investigators have indicated that most of the potential to improve neuromuscular function in adolescent girls is related strongly to their initial measures.[9] Verstraete et al[49] evaluated the long-term effect of a comprehensive physical activity promotion program on children's physical fitness and physical activity levels. Whereas the aforementioned intervention did not produce any training effects among the boys or girls in the long jump, the young girls who completed the intervention performed better than their sex-matched peers in this task. Of interest, both boys and girls in the PE-plus-INT group in our study improved their scores on the curl-up test and single-legged–hop test, which highlights the trainability of these performance measures in 7-year-old children.

One limitation of our study was that we addressed only the initial phase of INT in young children. Thus, our results may not be applicable to older populations and do not provide insight into long-term training adaptations. Another limitation was that it was not possible to include a no-PE CON group. Nevertheless, children in this study had an opportunity to improve their physical fitness and develop the skills and confidence that may lead to a greater willingness to participate in sport-related activities later in life.[50,51] Finally, as indicated, these data represent novel analyses that were limited by our small sample size. Future research is needed to confirm our results, and our findings should be interpreted with caution.

CONCLUSIONS

Our findings indicate that incorporating INT into PE can result in substantial improvements in selected health- and skill-related fitness components in children, and this type of intervention can be a cost-effective and time-efficient method for enhancing motor skills and promoting physical activity in boys and girls. The salient finding from our investigation was that 7-year-old girls appeared to be more sensitive to the effects of INT performed twice weekly during PE than 7-year-old boys. These findings will help certified athletic trainers and other professionals design effective youth fitness programs and optimize training adaptations in young children. For example, certified athletic trainers and elementary school PE teachers could work together to create, implement, and evaluate interventions that are designed purposely to enhance physical fitness and reduce sports-related injuries in aspiring young athetes. Long-term studies are needed to further explore the sex-specific effects of INT in school-aged youth and examine the effect of these interventions on long-term injury risk.

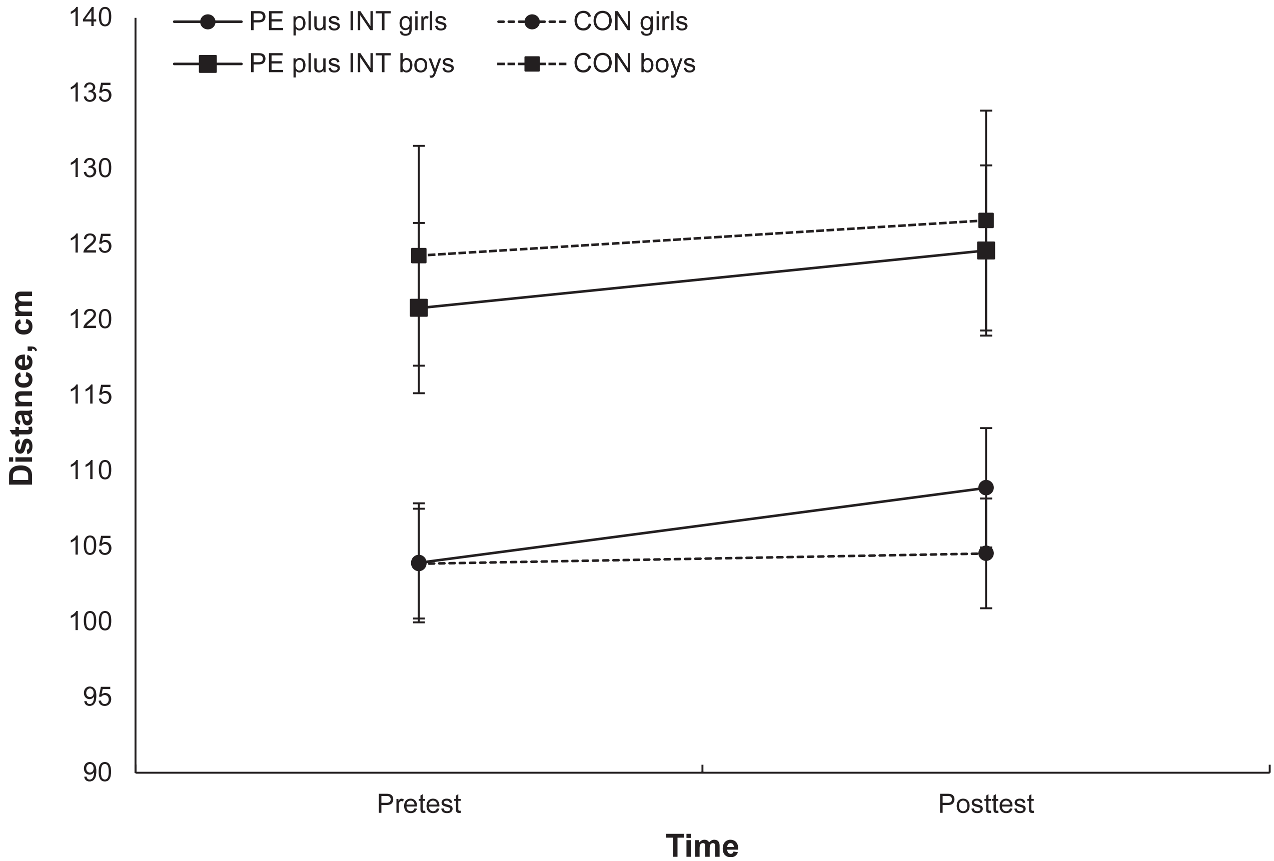

Figure 5. Standing–long-jump performance. For the standing–long-jump test, the time-by-group-by-sex interaction was not different between sexes ($P > .05$). However, in the female-specific model, the group performing physical education (PE) plus integrative neuromuscular training (INT) showed greater improvement than the control (CON) group from pretest to posttest. In boys, we noted a main effect of time: both the CON and PE-plus-INT groups increased long-jump distance from pretest to posttest. Plots represent adjusted mean ± standard error of the mean.

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