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ORIGINAL RESEARCH

Effect of a Suspension-Trainer-Based Movement Program on Measures of Fitness and Functional Movement in Children: A Pilot Study

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***Purpose*:** The purpose of this pilot study was to assess the efficacy of a suspension-training movement program to improve muscular- and skill-related fitness and functional movement in children, compared with controls. ***Methods*:** In total, 28 children [male: 46%; age: 9.3 (1.5) y; body mass index percentile: 68.6 (27.5)] were randomly assigned to intervention ($n = 17$) or control ($n = 11$) groups. The intervention group participated in a 6-week suspension-training movement program for two 1-hour sessions per week. Muscular- and skill-related fitness and functional movement assessments were measured at baseline and following the intervention. Analyses of covariance models were used to assess the effects of time and intervention. ***Results*:** The intervention participants achieved greater improvements in Modified Pull-Up performance ($P = .01$, Cohen's $d = 0.54$) and Functional Movement Screen score ($P < .001$, Cohen's $d = 1.89$), relative to controls. ***Conclusion*:** The suspension-training intervention delivered twice a week was beneficial for upper body pulling muscular endurance and the Functional Movement Screen score. Future interventions using this modality in youth would benefit from larger, more diverse samples (through schools or community fitness centers) and a longer intervention length.

Keywords: resistance training, pediatrics, physical activity

Youth resistance training programs can lead to positive health outcomes, such as improved metabolic and cardiovascular profiles, body composition, and cognitive and physical functioning (18,29,44). In addition to health-related fitness benefits, resistance training may improve skill-related fitness (eg, balance, agility, and speed) and reduce injury risk in children (10,13,17,18). These health and performance benefits of resistance training interventions implemented in children are likely the result of increases in muscular endurance, muscular fitness, and power (10,17–19,29,35,40).

Functional movement development is a potential contributor to the various improved health outcomes of resistance training and other physical activity interventions (20,24,48). One supported definition of functional movement is the ability to move efficiently and competently in various fundamental movement patterns and motor skills (12,13). Fundamental movements or skills can include basic locomotor, manipulative, and stabilizing movements (25). One previous study reported trivial improvements in Functional Movement Screen™ (FMS; Functional Movement Systems, Inc, Virginia) scores in 22 children aged 11–15 years following a 4-week fundamental movement program that incorporated body weight and elastic band resistance training (48). Further research is needed to determine physical activity training modalities and doses that can improve functional movement in children.

A variety of training modalities have been used in resistance training intervention studies, including body weight exercises, plyometric training, Olympic weight lifting, and selectorized strength machines (eg, machines with weight plates, such as leg press or arm curl machines) (2,6,40). Suspension training is an exercise training modality that may have potential to improve fitness and functional movement performance in children. Suspension-training exercises allow for a variety of modifications and progressions of basic body weight movements that can be used for both aerobic and muscular fitness training (22,23). There is limited cross-sectional research regarding suspension training in adults, and no studies include youth (5,6,31,45,46). Studies that have been conducted in young adult male participants have demonstrated greater muscle activation of core musculature and other (primarily posterior) muscle groups in pushing exercises conducted with suspension trainers versus traditional stable pushing exercises (6,31). In the 2014 International Consensus on youth resistance training (29), the authors noted that children should demonstrate

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competence with basic body weight techniques before progressing to other forms of training involving external resistance. A suspension-training program may be especially useful for young exercisers to obtain this competence. The multijoint movements can be modified or progressed, are body weight based, and provide efficient transitions between exercises and set-up positions (22,23). Similar to other youth resistance training programs, a suspension-training program may promote strength and functional movement. Comparable or additional benefits may be expected because suspension training allows for modifications and progressions that can be easily tailored to each individual and may activate greater core and stabilizing musculature. However, no prior studies have examined the efficacy of suspension training in children.

The purpose of this pilot study was to assess the efficacy of a 6-week movement program mainly based in suspension training on children's muscular- and skill-related fitness and functional movement, compared with a control group. We hypothesized that the intervention group participants would demonstrate greater improvements in muscular- and skill-related fitness and functional movement in comparison with control group participants.

Materials and Methods

Experimental Design

We used a randomized controlled trial study design to examine the effects of a 6-week suspension-training intervention program on fitness and functional movement in youth sports participants. Youth sport participants (ie, children who participated in at least one community- or school-based organized sport during the previous 6 mo) were randomly allocated to an intervention group ($n = 17$) or a control group ($n = 11$) and self-selected one of the 2 study sites. Two-thirds of the study sample was randomized to the intervention group in anticipation of a higher dropout rate due to the schedule demands of the program, and siblings were randomized to the same treatment group. Randomization occurred after all of the participants had been screened, and baseline visits had been completed. Participants received their treatment group assignment at the conclusion of the baseline visit in a concealed envelope. The intervention group attended two 1-hour suspension-training movement sessions per week for 6 weeks. The control group continued participation in regular activities, which included their regular athletic practices and events, and were not exposed to the intervention program. All participants completed baseline (within 2 wk prior to the intervention start date) and follow-up assessments (within 2 wk of the intervention cessation).

Participants

Eligible participants had no limitations to regular physical education participation and had not participated in a resistance-training program within the previous 6 months (as indicated on the screening form completed by parents). Participants were recruited through flyer distribution, youth athletic association and program communications, Facebook, and word-of-mouth advertising through 2 study locations. In total, 28 children (aged 7–12 y), who participated in at least one organized youth sport, were enrolled in this study. Reported organized youth sports included soccer, basketball, gymnastics, track and field, baseball, hockey, lacrosse, snowboarding, skiing, swimming, and rock climbing. Thirty-three percent of the participants participated in 1 sport, 50% participated in 2 sports, and 17% participated in 3 or more sports throughout the previous 6 months. The University of Massachusetts Institutional Review Board for the Protection of Human Subjects in Research approved this study. After risks and benefits were explained to participants and their parents, written permission was obtained through parental permission and child assent.

Measurements

All participants completed baseline and follow-up assessment visits for premeasurements and postmeasurements for all variables. Measurement visits were conducted at the participants' selected study location. Trained research assistants from the University of Massachusetts Amherst conducted all measurements. With the exception of 1 participant (due to a schedule conflict), all measurement visits were held in the afternoon. Due to facility and equipment availability, participants were rotated through several assessment stations, with participants beginning at a random starting point.

Physical Measures. Weight was measured to the nearest 0.1 kg with a portable scale (5125 model; ScaleTronix, White Plains, NY). Height was measured to the nearest 0.1 cm using a portable stadiometer (Shorr Height Measuring Board; Weigh and Measure, LLC, Olney, MD). Body mass index (BMI) was calculated, and BMI percentiles were determined using age and sex (9).

Muscular Fitness. Muscular fitness measures were assessed with select FITNESSGRAM® assessments (ie, Trunk Lift, 90° Push-Up, and the Modified Pull-Up) (32). The Trunk Lift test assessed torso muscular strength and flexibility. Participants assumed a prone position on the ground and lifted their upper body off the floor as high as possible. An upright ruler was placed 1 inch in front of the participant's chin to measure the distance between their chin and floor to the nearest 0.5 cm. The Push-Up test assessed upper body pushing muscular endurance. Participants completed as many consecutive 90° push-ups as possible at a rhythmic pace, and total repetitions were recorded. General reliability of FITNESSGRAM assessments administered by 23 teachers on third- and fifth-grade students was reported to be acceptable by Morrow et al (34) (86%

agreement and .72 modified kappa for the Trunk Lift, and 74% agreement and .40 modified kappa for the Push-Up). In the same study, validity of teacher raters compared with expert raters was 71% agreement, with a modified kappa of .42, for the Trunk Lift and 76% agreement, with a modified kappa of .52, for the Push-Up. The Modified Pull-Up test assessed upper body pulling muscular endurance. Participants were positioned on their backs (in a supine, straight body position) with shoulders aligned under the barbell (secured in a weight-lifting rack), with a pronated grip on the bar. They were instructed to complete as many pull-up repetitions as possible (pulling their chest toward the bar), while maintaining a straight body position with their heels on the floor. The number of completed repetitions while maintaining correct form was recorded. Criterion referenced reliability for the Modified Pull-Up was acceptable in a sample of 62 fifth- and sixth-grade students (95% agreement and .90 modified kappa) (42).

In addition to the FITNESSGRAM tests, an isometric prone plank test was used to assess core muscular endurance (15). Participants held a correct bent-arm plank position (ie, no lifting or lowering of the torso or hips) as long as possible, and time was recorded to the nearest 0.1 second. In a sample of 1503 children aged 8–12 years, Boyer et al (4) reported good reliability of the isometric prone plank as a field-based assessment of muscular endurance [interrater intraclass correlation coefficient (ICC) = .62; confidence interval (CI), .50–.75; intrarater ICC = .83; CI, .73–.90; and test–retest ICC = .63; CI, .46–.75]. Participants were told to stop if form was no longer acceptable (after 1 correctional verbal cue was given) for the Push-Up, Modified Pull-Up, and isometric prone plank tests.

Skill-Related Fitness. Indicators of skill-related fitness were measured with a standing long jump (28,41) and a 4 × 10-m shuttle run (41). The standing long jump assessed lower body muscular power. Standing with their feet in a hip-width stand, participants performed a partial squat countermovement and jumped as far forward as possible. Each participant jumped 3 times, and the furthest distance was recorded to the nearest 0.05 cm (converted to meters for analysis). Although significant intertrial differences were reported for the standing long jump in a sample of 6- to 11-year-olds [3.8 (12.7) cm] (16), a validity study of this test reported that scores in 6- to 17-year-olds were strongly associated with other lower body muscular strength tests (R^2 = .829–.864) (8).

Speed and agility were assessed with a 4 × 10-m shuttle run (a modified version of the EUROFIT 10 × 5-m shuttle run test; Council of Europe, Strasbourg, France). Two parallel lines were marked on the floor, 10 m apart. Participants completed 2 consecutive repetitions of sprints, and the quickest time for the 2 trials was recorded to the nearest 0.1 second. Ortega et al (36) demonstrated the acceptable reliability of the 4 × 10-m shuttle run in a slightly older age group [aged 13.6 (0.8) y] than our sample [nonsignificant intratrial difference of 0.1 (0.7) s in males and 0.1 (0.8) s in females].

Functional Movement. Functional movement was examined with the FMS (12,13). The FMS was designed as a screening tool to assess fundamental movement patterns that require a combination of mobility and stability of the joints involved. The FMS movements place the participant in specific body positions where inefficiencies and imbalances can be observed if appropriate stability and mobility are not utilized. Wright et al (48) reported results of intrarater and interrater reliability of FMS scores between 2 researchers for their study sample of 22 children (aged 11–15 y). Percent agreement ranged from 11% to 83% and from 23% to 88% for intrarater and interrater reliability, respectively. With the exception of the rotary stability and trunk stability push-ups, the individual FMS movements were categorized as "substantial" to "almost perfect" in reliability. Furthermore, among 28 adolescent hockey players (aged 13–16 y), Parenteau-G et al (37) reported an ICC of .96 (CI, .92–.98) for field raters of the overall FMS score. For the current study, participants completed all 7 movements of the FMS: deep squat, hurdle step, inline lunge, shoulder mobility, active straight-leg raise, trunk stability push-up, and rotary stability. Each movement was scored by the same trained research assistant based on the FMS criteria with a range of 0 (lowest score) to 3 (highest score). A score of 0 was recorded if the participant reported any pain. If no pain was present, the participant could perform each movement up to 3 times. However, if they met the criteria for a score of 3 on the first or second attempt, no additional repetitions were conducted. The highest score for each movement was used for the final score. Unilateral movements were conducted on both sides of the body. The lowest score for unilateral movements was carried over to the final score. Final FMS scores were reported for each individual movement and for a total score (sum of individual movement scores; with a maximum score of 21).

Intervention

Participants assigned to the intervention group completed the program at either a university (*n* = 7 in intervention) or an off campus (*n* = 10 in intervention) training facility. The intervention group participated in a 6-week movement program that consisted mainly of suspension-training movements (with a small percentage of body weight only movements), adapted from TRX Training for Schools (Fitness Anywhere, LLC, San Francisco, CA) for two 1-hour sessions per week. Coaches employed by the off campus site and research assistants selected from the university site served as intervention leaders for the movement-training sessions in their respective locations. Intervention leaders held personal training certifications, completed TRX® Suspension Training professional education courses, had experience working with youth athletes, and completed a training session to learn the protocols for this study. A ratio of 1 intervention leader to 8 youth participants or less was maintained. Intervention leaders attended a 2-hour training session with the curriculum developer and completed daily reports of the sessions (ie, how closely they adhered to the original lesson plan and modifications that were made to each lesson). A research assistant not involved with leading the sessions attended at least 2 sessions per study location to observe and document how closely the intervention leaders adhered to the lesson plan.

Familiarization with the suspension trainers (eg, how to set up and adjust the device, how to correctly position the body for each core movement, and how to progress and modify the core movements) was incorporated into the first few sessions and revisited throughout the intervention. Additional time was allotted for this in the first few sessions, and each movement was taught initially in its most basic form. Each intervention session focused on 1 of 4 fundamental movements: plank, squat, push, and pull. Each session began with a brief introduction of the movement-of-the-day. Prior to beginning of the lesson, a 5- to 10-minute dynamic warm-up was conducted including body weight and suspension-training movements. Following the warm-up, participants completed 2 to 3 sets of 8 suspension-training movements with an equal work-to-recovery ratio of 30 seconds. Participants were encouraged to keep a pace of 3 seconds per movements for most movements (ie, 1 s for the concentric phase and 2 s for the eccentric phase) so that approximately 10 repetitions were performed per set. Music with the appropriate tempo was played to help the participants keep pace, in addition to verbal cues by the intervention leaders. All participants started with the most basic modifications for each movement and were given individual progressions as appropriate. If participants demonstrated competence with the basic level of a movement, the intervention leaders encouraged them to progress to a more challenging version of that movement. Not all participants progressed through all levels of each movement (and no participant progressed through all levels of all of the movements). The remaining time included a fitness game that incorporated body weight calisthenics and drills with a review of the suspension-training movements. A sample of a daily lesson plan is illustrated in Table 1. The majority of each lesson consisted of suspension training movements. However, body weight movements were also integrated into the warm-up, review game, and cooldown segments of each lesson. For example, half of the movements included in the Fitness Bingo game listed in Table 1 were body weight movements (a mix of cardiorespiratory and muscular fitness movements). The review game accounted for about 15% of each lesson. Examples of the core suspension-training movements, as well as the progressions that were added at an individual level throughout the intervention, are displayed in Figure 1. Attendance was documented at each intervention session. Participation was also recorded using a scale that was developed for this study: 1) if the participant was present, but not really engaged in the program (ie, sitting out frequently or choosing not to perform the majority of the movements), 2) for some participation (ie, sitting out a little or completing at least half, but not all of the movements), or 3) for full participation (completed all movements for full duration and did not sit out). The interventionists recorded a score at the completion of each intervention session for each participant.

Statistical Analysis

Statistical analyses were completed in Stata 14.0 (StataCorp, College Station, TX), with alpha levels set to $P \leq .05$. All analyses followed the intention to treat principle. If follow-up data were missing ($n = 1$ from control), the average change score for each variable, from participants of the same age and sex in the control group, was computed and used for the follow-up time point value. Descriptive statistics [mean (*SD*) or %] were computed for all measured variables. For each outcome, the dependent variable was the follow-up score, and normality was assessed using the Shapiro–Wilk test. All data were normally distributed. Baseline differences between intervention versus control were assessed with 2-sample *t* tests for continuous variables and Fisher's exact tests for sex. We used analyses of covariance models in our main analyses of time and intervention effect and calculated effect sizes (Cohen's *d*; the ratio of the mean difference to the pooled *SD*) (49) for each of the models. A Cohen's *d* of 0.20 or less was classified a small effect size, moderate if greater than 0.50 but less than 0.80, and large if above 0.80 (11). The treatment group (indicator of randomization to the intervention or control group) served as the independent variable, and separate models were adjusted for baseline score alone (model 1), baseline score and BMI percentile (model 2), baseline score and age (model 3), or baseline score and sex (model 4).

In our analyses, we also presented the uncertainty in our data following recommendations by Hopkins et al (27). The uncertainty of our estimates were expressed as 90% confidence limits calculated with a confidence limits spreadsheet (26), using our analyses of covariance model *F* statistics, *P* values, degrees of freedom, and a chosen threshold of 0.2 between-subjects *SD* (our selected smallest worthwhile effect). Magnitude-based inferences were determined based on the probability that the true effect was beneficial, harmful, or trivial. Probabilities were then categorized as <0.5% for most unlikely, 0.5%–5% for very unlikely, 5%–25% for unlikely, 25%–75% for possibly, 75%–95% for likely, 95%–99.5% for very likely, and >99.5% for most likely (26).

Results

All intervention participants completed the study and provided baseline and postintervention measures. One

Table 1 Sample Daily Lesson Plan for the Intervention Program

	Time, min	Frame-up	Material	
Arrival	0–5	Attendance	Name game	
		Introductions/ice breaker questions	Name the movement (plank) and muscle of the day	
		Assign partners		
Intro	6–10	Set behavior, expectations, and goals for class	Explain why the plank is important (cue for the day = “no bananas”)	
		Introduce and define suspension training	Demonstrate and practice strap adjustments and positions	
Warm-up	11–16	Half class on the ST movements and half doing body weight movements (alternating 20 s each)	ST movements	Body weight movements
			1. ST squat	1. jumping jacks
			2. ST mid row	2. plank
			3. ST squat row	3. jumping jacks
			4. ST golf rotation	4. plank
			5. ST forward lunge	5. jumping jacks
Core activity	17–45	You-go, I-go format	ST movements	
		2–3 sets of 30-s work (30-s rest per movement)	1. plank	
			2. hip press	
			3. chest press	
			4. standing roll out	
			5. triceps press	
			6. squat	
			7. low row	
			8. low back overhead extension	
Additional activity	46–54	Review game	Fitness BINGO	
Postwork	55–60	Same setup and pattern as the warm-up, with partners taking turns (20–30 s/stretch)	ST static stretches	Body weight static stretches
			1. ST long torso stretch (×2)	1. front shoulder stretch (interlace hands behind lower back) (×2)
			2. ST chest stretch with rotation (×2—both sides)	2. standing quadriceps stretch (×2—both sides)

Abbreviation: ST, suspension training.

control group participant did not complete postintervention measures so that data were imputed. A description of participants is displayed in Table 2. We observed few differences between intervention and control at baseline. No differences were observed in sex distribution or BMI percentile. The mean age of the intervention group was significantly greater at baseline ($P = .029$). Among outcome variables, the only significant difference at baseline between groups was observed in the standing long jump, with the intervention group demonstrating a higher mean score ($P = .035$). In the intervention group, the average attendance rate was 71.7%, and the participation score was 2.92 (0.22) out of a possible score of 3.0. At baseline, total FMS scores were positively associated with Trunk Lift ($r = .55$), Modified Pull-Up ($r = .50$), and Isometric Prone Plank ($r = .38$) scores.

Results (ie, adjusted means and *SE*s, *P* values, and effect sizes) of the analyses of covariance analyses for models 1 (control for baseline only) and 2 (control for baseline and BMI percentile) are presented in Table 3. Models that adjusted for baseline score and age (model 3) and baseline score and sex (model 4) did not alter the results. Controlling for baseline values, participants in the intervention group showed a statistically significant 43.6% improvement in Modified Pull-Up performance (an average increase of 1.88 repetitions) compared with a

Core movements	Start position	End position	Variations
Squat			Squat Forward lunge Front squat Lateral lunge Single-leg squat
Push			Chest press Triceps press Standing roll out
Pull			Low row Mid row High row Overhead extension Assisted pull-up Biceps curl
Plank			Full plank Forearm plank Kneeling roll out Hip press Hamstring curl
Progression options	Stability: change the size and position of the body's base of support (eg, participants started off in a split stance for a standing movement and some progressed to a narrow or single-leg stance in future sessions). Starting position and body angle: change the starting position on or body angle relative to the anchor point (eg, a participant's starting stance for a standing movement may have started farther away from the anchor point, and then, they progressively moved closer to the anchor point in future sessions).		

Figure 1 — Core suspension-training movements, variations, and progressions used in the intervention.

37.0% decrease (an average decrease of 1.91 repetitions) observed in the control group ($P = .01$ for between-group differences at post). This was considered a very likely beneficial effect (27). The intervention group also demonstrated a 28.9% improvement in the total FMS score at follow-up (an average increase in score of 4.06) when

Table 2 Baseline Characteristics of Study Participants

Variable	Intervention ($n = 17$)	Control ($n = 11$)	*P* value[a]
Age, y	9.82 (1.22)	8.54 (1.57)	**.03**
Gender, %male	58.5	27.3	.14
BMI percentile	61.0 (31.16)	80.45 (11.58)	.06
Trunk Lift, cm	18.5 (3.88)	19.3 (6.40)	.68
90° Push-Ups, repetitions	8.1 (6.05)	8.9 (4.92)	.72
Modified Pull-Ups, repetitions	5.4 (3.57)	7.3 (3.06)	.71
Plank, s	39.7 (22.8)	36.7 (15.62)	.16
Standing long jump, m	1.50 (0.18)	1.36 (0.12)	**.04**
Shuttle run, s	12.0 (1.49)	13.1 (2.37)	.17
Overall FMS, score	14.5 (3.14)	15.5 (2.11)	.33

Note. All data are presented as mean (*SD*) except for gender. Bold values indicate statistically significant *P* value (<.05).

Abbreviations: BMI, body mass index; FMS, Functional Movement Screen.

[a]*P* values were calculated using 2-sample *t* tests for continuous variables and Fisher's exact test for categorical variables.

controlling for baseline ($P < .01$), whereas the control group experienced a 7.1% decrease in FMS score (an average decrease in score of 0.91). These significant improvements remained when the models were adjusted for BMI percentile and were considered a most likely beneficial effect (27). In additional multiple regression analyses with individual FMS tests as the dependent variables, randomization to the intervention was statistically associated with greater changes in postscores when adjusted for baseline score for all of the tests except shoulder mobility (and straight-leg raise when adjusted for baseline score and age; data not shown).

There was a statistically significant difference in the postshuttle run scores between groups ($P = .02$). The control group improved their shuttle run score by 9.9% (an average decrease in time of 0.85 s), compared with a 6.7% decrease in the intervention group (an average increase in time of 0.47 s). However, this difference did not remain significant when the model was adjusted for baseline score and BMI percentile. Although Trunk Lift performance at post was not significantly different between groups when controlling for baseline only, when BMI percentile was added as a covariate, the adjusted means became significantly different ($P = .04$). Controlling for baseline or baseline and BMI percentile, the intervention group, compared with controls, did not attain greater push-up repetitions, prone plank time, or standing long jump distance.

Discussion

The primary aim of this randomized controlled trial was to assess the efficacy of a 6-week suspension-training movement program on muscular- and skill-related fitness and functional movement in youth sports participants. Participation in this 6-week suspension-training-based program improved Modified Pull-Up, Trunk Lift, and overall FMS performance. However, no significant improvements in markers of skill-related fitness were observed.

In the current suspension-training intervention, 2 (Modified Pull-Up and Trunk Lift) of the 4 muscular fitness measures were significantly improved. An increase of almost 2 repetitions in the Modified Pull-Up test could represent clinical significance for some individuals (ie, a potential transition from the "needs improvement" category to the "healthy fitness zone" category) and was classified as practically very likely beneficial based on the magnitude-based inferences used in our analysis (27,32). No other youth muscular fitness training studies have utilized suspension training as a modality. Therefore, comparisons to other youth muscular fitness training programs is challenging. However, in a study by Siegel et al (43), the effects of an upper body focused resistance-training intervention (integrating body weight movements, weighted balls, hand weights, and elastic tubing) was examined in a group of 50 third graders compared with a control group ($n = 46$). The intervention participants experienced significantly greater gains in pull-up, flexed-arm hang, flexibility, and right-hand grip strength performance. Although our study also observed improvements in upper body muscular endurance (ie, a 43.6% improvement in Modified Pull-Ups performance), the percent increases demonstrated by Siegel et al's intervention participants were higher for the flexed arm hang in girls (~87%) and for both boys and girls in pull-ups (~58% and 50%, respectively). This could possibly be related to a greater intervention dosage in the Siegel et al's study (12 wk of 30-min sessions, 3 d/wk). In another study, an 8-week integrative neuromuscular training program that was incorporated into a second-grade physical education program elicited a significant improvement in push-up

Table 3 Adjusted Postscore Means From ANCOVA Models 1 and 2

	Model 1[a]				Model 2[b]			
	Adjusted mean (*SD*)		*F* [effect statistic ± 90% CL] (*P* value)	Effect size (Cohen's *d*)	Adjusted mean (*SD*)		*F* [effect statistic ± 90% CL] (*P* value)	Effect size (Cohen's *d*)
	INT	CON			INT	CON		
Trunk Lift, cm	27.1 (6.6)	22.9 (6.3)	2.8 ± 2.8 (.11)	0.59[c]	27.6 (6.6)	22.0 (6.6)	4.7 ± 3.7 (**.04**)[e]	0.59[c]
90° Push-Ups, repetitions	9.9 (4.5)	7.9 (4.6)	1.3 ± 1.9 (.26)	0.25	9.8 (4.9)	7.9 (5.0)	0.99 ± 1.7 (.33)	0.25
Modified Pull-Ups, repetitions	7.7 (2.9)	4.6 (3.0)	8.1 ± 4.9 (**.01**)[e]	0.54[c]	7.8 (2.9)	4.6 (3.0)	6.8 ± 5.7 (**.02**)[e]	0.54[c]
Plank, s	44.4 (17.7)	39.1 (17.9)	0.59 ± 1.3 (.45)	0.30	44.7 (18.6)	38.5 (18.9)	0.7 ± 2.1 (.41)	0.30
Standing long jump, m	1.45 (0.16)	1.47 (0.17)	0.04 ± 0.34 (.84)	0.47	1.46 (1.53)	1.45 (0.17)	0.04 ± 0.36 (.85)	0.47
Shuttle run, s	12.8 (0.8)	11.8 (0.9)	5.8 ± 4.1 (**.02**)[f]	0.21	12.6 (0.8)	12.0 (1.0)	2.5 ± 2.7 (.12)	0.21
Overall FMS, score	18.7 (1.6)	14.4 (2.0)	35 ± 11 (**.0001**)[g]	1.89[d]	18.5 (1.6)	14.7 (2.0)	27 ± 8.6 (**.0001**)[g]	1.89[d]

Note. Bold values indicate statistically significant *P* value (<.05).
Abbreviations: ANCOVA, analyses of covariance; BMI, body mass index; CL, confidence limit; CON, control group; FMS, Functional Movement Screen; INT, intervention group.
[a]Adjusted for baseline score only.
[b]Adjusted for baseline score and BMI percentile.
[c]Moderate effect size.
[d]Large effect size.
[e]Very likely beneficial.
[f]Very likely harmful.
[g]Most likely beneficial.

and curl-up performance (17). The intervention group participated in this program for the first 15 minutes of physical education class, twice a week. In an 8-week study conducted in fourth graders using a similar program, significant increases in push-up and sit and reach flexibility scores were observed in the intervention group compared with the controls (21).

In addition to pushing and pulling, core strength and stability were also primary focus of some lessons and are incorporated into most of the suspension training movements. No statistical difference in isometric prone plank performance between groups was observed (intervention: 11.8% increase vs control: 6.5% increase), likely due to high variability and our relatively small sample size. Allen et al (2) observed significant improvements in core muscular endurance tests, including a similar prone plank test that was used in our study. Allen et al (2) also conducted their study for 6 weeks, but with only one 15-minute lesson each week. However, Allen et al (2) did not include a control group, so it is possible that some of the reported gains could be attributed to a learning effect and their intervention targeted muscles of the core, whereas the intervention in the current study had a multijoint, full body exercise focus. After a 4-week fundamental movement training program consisting of four 30-minute weekly sessions by Wright et al (48), young adolescents (aged 11–15 y) assigned to the intervention group experienced a "very likely small beneficial effect" for follow-up plank scores, compared with a control group. The lower session frequency of our intervention compared with that used by Wright et al may have potentially contributed to the lack of statistical effect that we observed for the isometric prone plank.

The assessment of functional movement skills in children is a relatively new area of research; therefore, all but one study (48) are observational (1,3,14,33). Observational studies set out to establish preliminary normative values for the FMS in children (1,30,33). In a sample of 77 Moldavian children (aged 8–11 y), Mitchell et al (33) observed a total FMS score of 14.9 (1.9). In a separate sample of 1005 children in India, aged 10–17 years, Abraham et al (1) reported a mean composite score of 14.59 (95% CI, 14.43–14.75) with no observable difference in scores for those with a previous injury. In our study, the overall FMS score at baseline was 14.89 (2.79), consistent with the current literature (1,33). Lloyd et al (30) reported that variations in physical performance observed in UK male soccer players, aged 11–16 years, could be explained by a combination of FMS scores ($r^2 = 47\%$ for FMS in-line lunge) and maturation ($r^2 = 46\%$). A study by Paszkewicz et al (38) also supports the influence of maturity on FMS scores, with postpubescent youth scoring higher than preadolescent and early pubescent youth. Although we did not assess stage of maturation in this study, the effect of the intervention on FMS improvements remained significant when we adjusted for age. To our knowledge, the 4-week fundamental movement intervention by Wright et al (48) is the only experimental study that has examined changes in FMS scores in children. Unlike with our study, Wright et al did not observe significant improvements in FMS. This could be attributed to the shorter length of intervention (ie, 4 wk) in the study by Wright et al and the use of an active control group (ie, "multisport activities"). The significant improvements and large effect size observed for the composite FMS score in our intervention group could be considered practically meaningful, as there was a mean increase in score of 4.06 (on a scale of 0–21) indicating that functional movement greatly increased. Our findings surpass the threshold of 1.0 arbitrary units proposed by Wright et al as a clinically relevant change in FMS score. Furthermore, our findings were classified as a practically most likely beneficial effect (with a probability of 100% for both models) (27). Still, due to the small sample size, caution is warranted when interpreting these results. With the exception of shoulder mobility, our intervention group experienced significantly greater gains in all individual movements of the FMS as well (mean score changes ranged from 0.53 to 0.76 with *SD*s ranging from 0.51 to 0.75). Although Portas et al (39) reported that the FMS stability movements (ie, the trunk stability push-up and rotary stability) appear more challenging for younger children, our findings seem to indicate that these skills can be taught and improved upon in preadolescents. Although the intervention used by Wright et al (48) was designed to target fundamental movements, the focus on movement quality and activation on posterior chain muscles incorporated in suspension training (31) may be more effective in eliciting changes in the FMS.

For speed (shuttle run) and power (standing long jump), we did not observe significant benefits of the intervention, relative to the control group. Although the postshuttle run performance was actually faster in the control group, when the model was adjusted for BMI percentile, this difference was no longer significant. In a 12-week study, Chaouachi et al (10) randomized 10- to 12-year-olds to 1 of 4 groups; Olympic style weight lifting, plyometrics, traditional resistance training, or control group. All 3 training groups had significantly greater improvements in speed and power measurements than the control group. Faigenbaum et al (17) reported improvements in long jump, single leg hop, and half mile run performance in their 8-week training program study in second graders. However, in a fourth-grade physical education intervention, completed by the same research group, no improvements in long jump were observed (21). These differences in long jump scores could be attributed to the differences in age between the 2 samples (second vs fourth graders). In our sample, the participants' ages more closely reflect that of fourth graders, which would suggest our finding of no significant improvement between treatment groups is similar to previous research in that age group (21).

It is also worth noting that during the study period, the control group appeared to decrease in performance in some variables. Although unexpected, this could potentially be related to the lack of school- and community-offered structured physical activity opportunities that many children experience during the summer season, which appears to be a period of increased time in sedentary behaviors, such as television viewing (47). A study by Carrel et al (7) reported that after a 9-month fitness intervention held during the academic year, middle-school students experienced a decrease in cardiorespiratory fitness during the following summer months. It is possible that the dosage of structured physical activity offered from athletic practices and events in our control group was not sufficient to counterbalance the performance detriments in some outcomes. Anecdotally, several of the control group participants mentioned attending only one organized sport or activity session per week during the time of the study. To examine this, future studies would need to collect more detailed information regarding the volume of physical activity and training received from athletic programs, beyond the planned intervention.

Our intervention length of 6 weeks was similar to that used in some other youth resistance training interventions (2,48). A greater dose (eg, frequency of sessions, duration of training program) or greater intensity during the sessions could potentially amplify the current training effects (29). A longer training duration would provide the opportunity to implement and complete more of the possible progressions in the suspension-training movements. One of the key progressions in the TRX Training for Schools program involves decreasing stability by creating a smaller base of support and changing the participant's body position to shift his or her center of gravity.

The results of this randomized controlled trial demonstrate partial support for the efficacy of a suspension-training movement program in youth sports participants. Despite conducting the current study during the summer months, popular times for summer camps and family vacations, the average attendance rate was 71.7%, and the study had good retention; only one control participant was lost to follow-up. No adverse outcomes or injuries were reported during this study in either treatment group or study site. As with any other youth resistance training program, suspension training requires supervision by qualified instructors and coaches. Participants in the intervention group of our study were able to adjust the units by themselves, perform the exercises correctly with appropriate modifications, and transition safely and efficiently from one training movement to the next. Strengths of this study include the use of randomization and high retention of the participants. This study was designed as an efficacy pilot study, so data from this trial may be used to power future suspension-training intervention studies looking to improve muscular endurance and functional movement in children.

It is important to acknowledge a few limitations in this study. First, this study lacked comprehensive process evaluation and fidelity assessments of intervention lessons. Although we received positive verbal feedback for the suspension-training program, a postintervention participant questionnaire and/or interview would provide qualitative information on how well the program and individual lessons were received and accepted by the children. Control group monitoring during the intervention period would also provide helpful information, such as the amount and intensity of physical activity of control participants. Also, this study incorporated 2 sites for intervention implementation, and therefore, it is possible that the program was delivered slightly differently at each site. Although personal weekly communication between the primary investigator and intervention leaders at both sites provided anecdotal support that any site-specific modifications to the training program were minor, more frequent fidelity assessments would have more accurately evaluated compliance to the intervention protocols. Second, although our research assistants compared FMS scoring results during training, it would be prudent of future researchers to report interreliability and intrareliability of all assessments to ensure consistency of the measurements. Third, there was also a small threat of bias in this study as some participants' parents had suspension trainers at home. It is possible that some control participants used them at home during the course of the study. However, these children did not have access to the specific training program that was used in the intervention, and it is unlikely that the dose of training was very strong. This potential confounder should be considered in the analysis of future intervention studies using the suspension-training modality in youth. Fourth, given the small sample size, randomizing a greater proportion of the participants into the intervention group (mainly related to siblings being randomized together) may have diminished some of the benefits of randomization. Despite the potential decrease in power due to unequal randomization, we were still able to observe statistical and meaningful differences in several outcomes. Finally, due to time, we did not offer a familiarization session for participants to learn and practice the movements involved in the outcome assessments. However, most of the children were familiar with many of the assessments through physical education class and sports practices.

Future studies incorporating suspension training should include a larger sample size in a more diverse group of youth. This could provide valuable information on many differences that could not be accounted for simultaneously in the present study (ie, sex, age, physical fitness at baseline, and weight status). Outcome measures could be extended to be more comprehensive and include body composition, muscular strength, and cardiorespiratory endurance. An additional process evaluation measure incorporating an assessment of intensity during the training sessions would be beneficial as well.

Findings from this pilot study provide some initial evidence that a program consisting of mainly suspension-training movements can be described as a feasible method of resistance training for youth. Suspension training is a nontraditional modality that can be incorporated into a variety of community-based youth athletic and physical activity programs and potentially in school-based settings. The potential to improve FMS scores may be beneficial for overweight and obese children, particularly because they are at a higher risk of having poor functional movement. The acceptable participation and retention indicate the acceptability of this training modality in children. To build upon the findings of this pilot study, future research in community- or school-based settings is warranted.

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