

Experimental Comparison of Concurrent Training Protocols Incorporating Resistance with High-Intensity Interval Training or Sprint Interval Training Versus Resistance Training Alone on Some Physical Fitness and Body Composition in Sedentary Prepubescent Children

Concurrent Versus Resistance Training on Child Physical Fitness

Meysam Alipour-Raz¹, Nahid Bijeh², Mahtab Moazzami³

1. PhD Student, Department of Exercise Physiology, Faculty of Sport Sciences, Ferdowsi University of Mashhad, Mashhad, Iran. Email: maliour3@gmail.com, ORCID: <https://orcid.org/0000-0003-0823-9035>

2. Corresponding Author, Professor, Department of Exercise Physiology, Faculty of Sport Sciences, Ferdowsi University of Mashhad, Mashhad, Iran. Email: bijeh@um.ac.ir, ORCID: <https://orcid.org/0000-0003-3566-458X>

3. Associate Professor, Department of Exercise Physiology, Faculty of Sport Sciences, Ferdowsi University of Mashhad, Mashhad, Iran. Email: moazami@um.ac.ir, ORCID: <https://orcid.org/0000-0001-8354-2662>

Corresponding Author, Address: Ferdowsi University of Mashhad, Azadi Square, Mashhad, Razavi Khorasan Province, Iran. Email: bijeh@um.ac.ir, ORCID: <https://orcid.org/0000-0003-3566-458X>

Abstract

Background and Purpose: Speed, agility, and core muscular endurance are crucial in children's fitness. This study compared concurrent resistance-high-intensity interval training (RT+HIIT), concurrent resistance-sprint interval training (RT+SIT), and resistance training (RT) alone on speed, agility, abdominal endurance, and body composition in sedentary prepubescent children.

Materials and Methods: Forty-four sedentary children (11.43 ± 0.7 years; BMI: 17.13 ± 1.9 kg·m²) were randomly assigned to RT (n = 11), RT+HIIT (n = 11), RT+SIT (n = 11), or control (n = 11). Training lasted 12 weeks, three sessions weekly. Agility, speed, anthropometrics, and abdominal endurance (30-s sit-up) were assessed pre- and post-intervention. Within-group changes were analyzed using paired t-tests or Wilcoxon tests, while between-group differences were examined with ANCOVA and Bonferroni post hoc tests. Significance was set at $P < 0.05$.

Results: No significant between-group differences were observed in anthropometrics or agility. Within groups, agility improved in RT+SIT ($P = 0.002$), BMI increased in RT+HIIT ($P = 0.02$), and lean mass increased in RT+HIIT and RT+SIT ($P = 0.001$, $P = 0.02$). Speed improved only in RT+SIT compared to control ($P = 0.001$), and was significantly better than in RT and RT+HIIT ($P < 0.05$). Sit-up performance improved in all training groups versus control ($P < 0.05$), with no differences among training groups ($P > 0.05$).

Conclusions: Agility improved within RT+SIT, with no between-group differences. Body composition improved within some groups, without between-group differences. Abdominal endurance improved in all training groups (RT, RT+HIIT, RT+SIT), and running speed improved in RT+SIT.

Keywords: Physical Fitness, child, Motor Skills, High-Intensity Interval Training, Resistance Training

Introduction

Childhood physical fitness is a key health indicator and essential for healthy growth and development. It reflects the integrated function of musculoskeletal, cardiorespiratory, psychological, and metabolic systems (1, 2). Physical fitness is commonly divided into health-related components (e.g., muscular strength and endurance) and performance-related components (e.g., speed and agility). Although traditionally separated, many performance-related skills are now also recognized as important for health (3, 4). Muscular endurance, particularly core endurance, plays a vital role in injury prevention and daily functioning. However, recent evidence shows a decline in physical activity and fitness levels among children, with reduced muscular endurance often linked to sedentary lifestyles, obesity, and unfavorable body composition. This is concerning, as low endurance in childhood may persist into adulthood (5, 6).

While numerous pediatric exercise studies have focused on cardiorespiratory fitness, less attention has been given to muscular strength, speed, and agility—despite their clear health relevance (4, 7, 8). For example, both resistance training (RT) and concurrent training (CT) have been shown to improve sprint performance in school-aged children (9-11), and high-intensity interval training (HIIT) protocols (running-based or bodyweight-based) also enhance speed (12). Similarly, agility has improved following RT, CT, and combined plyometric programs in different populations of children and adolescents (13-15). Importantly, body composition is closely related to both agility and sprint performance, underscoring the interdependence between muscular adaptations and physical performance in children (16, 17). Yet, these findings come from heterogeneous samples (e.g., obese adolescents, gymnasts) and training modalities, making it difficult to generalize outcomes. Moreover, limited studies have examined how CT affects abdominal muscular endurance, despite its strong links with activity levels and body composition (5, 6). Another important consideration is the potential “interference effect” of CT, whereby strength and power adaptations may be attenuated compared to RT alone (18, 19). This is notable because, in prepubescent children, RT mainly enhances muscle strength and power (20). Since speed and agility depend heavily on strength and power (16, 21, 22), the type of aerobic training combined with RT—such as HIIT or sprint interval training (SIT)—may differentially influence these outcomes in children.

Taken together, although previous studies have examined the effects of RT, CT, and high-intensity training protocols in children, no study has directly compared RT, RT+HIIT, and RT+SIT in sedentary prepubertal children within a single controlled design. Moreover, the potential interference effect of CT, which may influence strength- and power-related adaptations and consequently affect speed and agility, has not been fully investigated. The novelty of the present study lies in its direct comparison of these training methods in sedentary prepubertal children, while simultaneously evaluating their effects on speed, agility, abdominal muscular endurance, and body composition.

Methodology

Study design

Following recruitment through schools in Bojnord (North Khorasan, Iran), participants were chosen using purposive and convenience sampling methods based on the study’s eligibility criteria. The inclusion criteria for this study included: 1) boys aged between 10 and 12 years, 2) being at Tanner stages 1 or 2 of puberty as determined by self-assessment and self-report (23), and confirmed by parents 3) no involvement in organized or regular sports activities during the past six months, 4) absence of cardiovascular or metabolic disorders, 5) no musculoskeletal impairments, and 6) No use of supplements or special diet. Participants were excluded if they: 1) experienced acute illness or sports-related injuries, 2) attended less than 80% of the training sessions, or 3) engaged in other regular exercise programs outside of the study protocol. Information was collected through the completion of questionnaires covering personal, medical, and health information, as well as the International Physical Activity Questionnaire adapted for children (PAQ-C) (24, 25), with assistance from parents. After explaining the study procedures, the parents or legal guardians of the participants signed an informed consent form to confirm their agreement to participate in the study. This study was approved by the Bioethics Committee of Ferdowsi University of Mashhad (code: IR.UM.REC.1403.214). The sample size calculation was performed assuming a power of 0.8, a moderate effect size of 0.5, and an alpha level of 0.05, based on a design with four groups and two repeated measures, using G Power (version 3.1) software. A

minimum of 12 participants per group was required; however, to account for potential dropouts, the sample size was increased to at least 15 participants per group. Participants were randomly and equally assigned (using simple randomization) to three experimental groups (RT, RT+HIIT, RT+SIT), which participated in exercise interventions, and one control group (C) that received no intervention. The control group maintained their usual daily activities and routine. The characteristics of the participants are presented in Table 1.

Table 1. Baseline physical characteristics of participants (Mean $\pm$ SD).

	All (n=44)	C (n=11)	RT (n=11)	RT+HIIT (n=11)	RT+SIT (n=11)
Age (years)	11.43 $\pm$ 0.7	11.18 $\pm$ 0.75	11.81 $\pm$ 0.6	11.27 $\pm$ 0.9	11.45 $\pm$ 0.82
Height (cm)	144.27 $\pm$ 6.4	142.81 $\pm$ 5.06	148.5 $\pm$ 7.58	142.17 $\pm$ 6.28	143.59 $\pm$ 5.12
Weight (kg)	35.8 $\pm$ 5.6	34.52 $\pm$ 4.18	39.39 $\pm$ 6.93	33.57 $\pm$ 6.28	35.73 $\pm$ 3.48
BMI (kg.m²)	17.13 $\pm$ 1.9	16.89 $\pm$ 1.54	17.78 $\pm$ 2.43	16.49 $\pm$ 1.99	17.34 $\pm$ 1.62
PBF (%)	10.06 $\pm$ 5.2	10.78 $\pm$ 4.92	12.57 $\pm$ 6.95	7.48 $\pm$ 3.78	9.3 $\pm$ 3.91
LBM (kg)	32 $\pm$ 3.9	30.68 $\pm$ 3.32	34.11 $\pm$ 4.56	30.87 $\pm$ 4.64	32.33 $\pm$ 2.6
cm, centimeters; kg, kilograms; BMI, body mass index; C, control group; RT, resistant training; HIIT, high intensity interval training; SIT, sprint interval training; LBM, lean bod mass; BFP, body fat percentage.					

Exercise protocol

Before the start of the training program, a three-week familiarization phase was conducted, during which participants were introduced to the study protocol and exercise procedures, and baseline measurements of the study variables were taken during the first week of this familiarization phase. The training groups then completed exercises three times per week for 12 weeks. This 12-week training period was divided into four consecutive three-week phases. Each training session began with a five-minute warm-up consisting of light jogging and stretching, and ended with a five-minute cool-down with stretching exercises. The intensity of RT was controlled using the children's OMNI Resistance Exercise Scale (OMNI-RES), a validated rating of perceived exertion (RPE) scale (26). Heart rate was monitored during the training sessions using a wrist-based heart rate monitor (Xiaomi Mi Band 7, China). Maximum heart rate (HRmax) was calculated using the following formula (27): $HR_{max} = 208 - 0.7 \times \text{age}$. To regulate training variables such as duration and intensity, a trainer-to-participant ratio of 1:6 was maintained to ensure proper supervision of the training sessions.

RT protocol: Each session consisted of two sets of resistance exercises performed with minimal or no equipment, such as body weight, medicine balls, and resistance bands. During the initial six weeks, each set comprised six movements targeting the primary muscle groups of the upper body, lower body, and core. Each set lasted six minutes, with a concentric and eccentric phases ratio of 1:1. Exercises for the upper body, lower body, and core were alternated. A passive rest period of three minutes was allotted between sets. The training intensity during this phase was maintained between 5 and 7 on the children's OMNI-RES (0–10). In the subsequent six weeks, participants performed eight movements per set in an “all-out” mode (i.e., as hard as they could), corresponding to a rating of 9–10 on the children's OMNI-RES (0–10). The RT protocol was adapted from the study by Branco et al. (28). Details regarding the timing, intensity, duration, work-to-rest ratios, and periodization of the 12-week program are presented in Table 2.

Table 2. Exercise training information for the resistance group over 12 weeks

week	1 st - 3 rd	4 th – 6 th	7 th – 9 th	10 th – 12 th
Warm-up (min)	5	5	5	5
Resistance training				
Number of motions per set	6	6	8	8
Number of sets	2	2	2	2
Rest time between sets (min)	3	3	3	3
Rest type	Inactive	Inactive	Inactive	Inactive
Work intensity (OMNI-RES)	5 - 7	5 - 7	All-out	All-out
Work: Rest interval duration (seconds)	30:30	40:20	30:30	40:20
Work: Rest ratio	1:1	2:1	1:1	2:1
Time (min)	15	15	19	19
Cool-down (min)	5	5	5	5

Total time (min)	25	25	29	29
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RT+HIIT protocol: At the start of each session, following a warm-up, resistance training similar to that of the resistance training group was performed. After a 2-minute rest, participants engaged in HIIT, consisting of 2 to 4 bouts of 4-minute runs at 85–95% HR_{max}. Each bout was separated by three minutes of active recovery at 50–70% HR_{max}. The HIIT protocol was adapted from the study by Dias et al. (29). Detailed information on the 12-week HIIT protocol is presented in Table 3.

Table 3. Exercise training information for HIIT over 12 weeks.

week	1st- 3rd	4th – 6th	7th – 9th	10th – 12th
HIIT				
Number of intervals	2	2	3	4
Interval time (min)	4	4	4	4
Work intensity in intervals (%HR _{max})	85 - 95	85 - 95	85 - 95	85 - 95
Rest time between intervals (min)	3	3	3	3
Rest work intensity (%HR _{max})	50 - 70	50 - 70	50 - 70	50 - 70
Time (min)	11~	11~	18~	25~

RT+SIT protocol: After the warm-up, resistance training similar to the RT group protocol was performed at the beginning of each session. Following a 2-minute rest, running interval training was conducted, consisting of 3 to 6 30-second bouts performed at “all-out” mode or above 95% HR_{max}, with four minutes of passive rest between bouts. The SIT protocol was adapted from the study by Salus et al. (30). A summary of the SIT protocol is presented in Table 4.

Table 4. Exercise training information for SIT over 12 weeks.

week	1st- 3rd	4th – 6th	7th – 9th	10th – 12th
SIT				
Number of intervals	3	4	5	6
Interval time (seconds)	30	30	30	30
Work intensity in intervals (%HR _{max})	All-out or > 95	All-out or > 95	All-out or > 95	All-out or > 95
Rest time between intervals (min)	4	4	4	4
Rest type	Inactive	Inactive	Inactive	Inactive
Time (min)	10~	14~	19~	23~

Study measurements

Anthropometric Measurements: Body weight was measured using a digital scale (Seca, Germany) with an accuracy of 0.1 kg, while participants wore minimal clothing, were barefoot, and had an empty bladder. Height was measured using a stadiometer (Seca, Germany) with an accuracy of 0.1 cm, with participants standing barefoot, feet together, and heels and buttocks in contact with the wall. Body mass index (BMI) was calculated by dividing body weight by the square of height in meters. Skinfold thickness was measured at three sites (chest, thigh, and abdomen) using the Jackson and Pollock three-site method (31) with a Slim Guide caliper (manufactured in the USA). Body density was estimated using this method, and body fat percentage (PBF) was then calculated using the Siri equation (32), which converts body density into body fat percentage. Lean body mass (LBM) was obtained by subtracting fat mass from total body weight.

Agility Measurement: Participants’ agility was assessed using the 4 × 9-meter shuttle run test (14). Each participant started from a standing position with both feet behind the start line. To complete each 9-meter segment, participants were required to cross the designated start and finish lines with at least one foot. Timing commenced as the participant crossed the initial timing gate at the start line and stopped upon crossing the same timing gate after the final 9-meter segment. The best time out of two consecutive trials was recorded for statistical analysis. A two-minute

passive rest period was provided between trials. The time was recorded by the examiner using the stopwatch (Casio, Japan) with an accuracy of 0.01 seconds.

Speed Measurement: A 50-meter sprint test was used to assess speed (33). Upon the start signal, participants standing behind the starting line ran the 50-meter distance at maximum effort. The examiner recorded the time as soon as the participant crossed the finish line using a stopwatch (Casio, Japan) with an accuracy of 0.01 seconds.

Abdominal Muscle Endurance Measurement: Abdominal muscle endurance was assessed using a 30-second sit-up test (34). The participant lay on their back with knees bent and hands clasped behind the neck. Each repetition consisted of rising to a full sitting position and returning to the starting position, constituting one complete sit-up. The outcome measure was the number of correctly completed sit-ups within 30 seconds (12).

Statistical analysis

Data were expressed as means and standard deviations (SD) in text and tables. Normality and homogeneity of variances were assessed using the Shapiro–Wilk and Levene’s tests, respectively. Paired t-tests and Wilcoxon signed-rank tests were used for within-group analyses. Between-group comparisons were conducted using analysis of covariance (ANCOVA), with baseline measurements as covariates, followed by Bonferroni post hoc tests. Statistical analyses were performed using SPSS software version 26. A significance level of $p < 0.05$ was considered for all tests.

Results

In each group, three participants did not attend the baseline assessment and were therefore not included in the analysis. After baseline, one participant from each group withdrew due to a lack of cooperation. Finally, 11 participants in each group completed the study. Baseline characteristics of those who withdrew did not differ from those who remained.

Intra-group analysis of anthropometric indices revealed that body weight increased significantly in the control ($P = 0.007$), RT ($P = 0.003$), and RT+HIIT ($P = 0.003$) groups compared to baseline. A significant increase in BMI was observed only in the RT+HIIT group ($P = 0.02$) compared to baseline. LBM variable significantly increased in the RT+HIIT ($P = 0.001$) and RT+SIT ($P = 0.02$) groups compared to baseline. No significant changes in BFP were observed in any of the groups (C, $P = 0.4$; RT, $P = 0.8$; RT+HIIT, $P = 0.1$; RT+SIT, $P = 0.4$) compared to pre-intervention values. Inter-group comparison revealed no statistically significant differences among the study groups in height ($F = 0.06$, $P = 0.90$), body weight ($F = 1.5$, $P = 0.20$), BMI ($F = 0.9$, $P = 0.40$), LBM ($F = 2.1$, $P = 0.10$), and BFP ($F = 1.1$, $P = 0.30$).

Intra-group analysis revealed no significant change in agility time in the C ($P = 0.1$), RT ($P = 0.08$), and RT+HIIT ($P = 0.6$) groups compared to baseline. In contrast, a significant decrease was observed in the RT+SIT group ($P = 0.002$). Inter-group comparison revealed no significant differences in agility time among the study groups ($F = 1.8$, $P = 0.1$).

Intra-group analysis revealed no significant change in speed time in the C ($P = 0.3$), RT ($P = 0.1$), and RT+HIIT ($P = 0.6$) groups compared to baseline. In contrast, a significant decrease was observed in the RT+SIT group ($P = 0.003$). Inter-group comparison revealed a significant difference in speed time among the study groups ($F = 6.7$, $P = 0.001$). Post-hoc Bonferroni tests indicated that speed time in the RT+SIT group was significantly lower than in the C ($P = 0.001$), RT ($P = 0.03$), and RT+HIIT ($P = 0.005$) groups.

Intra-group analysis revealed that sit-up scores significantly increased in the RT ($P = 0.001$), RT+HIIT ($P = 0.001$), and RT+SIT ($P = 0.001$) groups compared to baseline. Inter-group comparison revealed a significant difference in sit-up scores among the study groups ($F = 8.9$, $P = 0.001$). Post-hoc Bonferroni analysis indicated that sit-up scores in the RT ($P = 0.04$), RT+HIIT ($P = 0.04$), and RT+SIT ($P = 0.001$) groups were significantly higher than in the control group. The detailed variable values in the study groups are presented in Table 5.

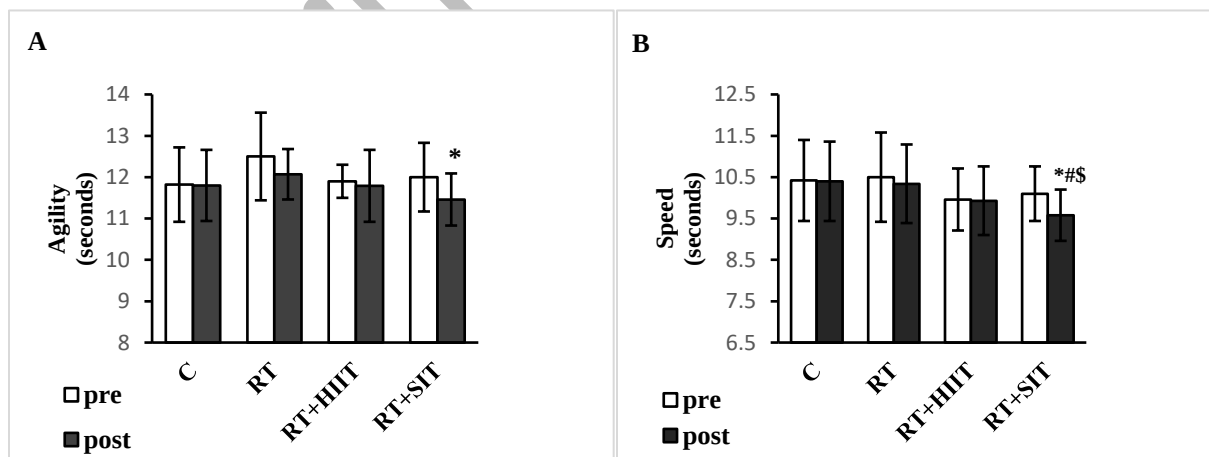
Table 5. Descriptive statistics and analysis of study variables across groups (Mean $\pm$ SD).

Variables	Group	Pre	Post	Change (%)	ANCOVA	
					f	p-value
Height (cm)	C	142.81 $\pm$ 5.06	143.27 $\pm$ 4.91*	0.31	0.06	0.9
	RT	148.5 $\pm$ 7.58	149.1 $\pm$ 8.01*	0.42		
	RT+HIIT	142.17 $\pm$ 6.28	142.68 $\pm$ 6.45*	0.35		

	RT+SIT	143.59 ± 5.12	144.04 ± 5.4*	0.31		
Weight (kg)	C	34.52 ± 4.18	35 ± 4.31*	1.36	1.5	0.2
	RT	39.39 ± 6.93	39.83 ± 7.01*	1.09		
	RT+HIIT	33.57 ± 6.28	34.27 ± 6.57*	2.05		
	RT+SIT	35.73 ± 3.48	36.04 ± 3.56	0.83		
BMI (Kg.m²)	C	16.89 ± 1.54	17.02 ± 1.64	0.7	0.9	0.4
	RT	17.78 ± 2.43	17.83 ± 2.45	0.2		
	RT+HIIT	16.49 ± 1.99	16.7 ± 1.98*	1.2		
	RT+SIT	17.34 ± 1.62	17.38 ± 1.62	0.2		
LBM (Kg)	C	30.68 ± 3.32	30.94 ± 3.04	0.8	2.1	0.1
	RT	34.11 ± 4.56	34.44 ± 4.7	0.9		
	RT+HIIT	30.87 ± 4.64	31.65 ± 4.99 *	2.5		
	RT+SIT	32.33 ± 2.6	32.71 ± 2.7 *	1.1		
BFP (%)	C	10.87 ± 4.92	11.25 ± 4.88	3.4	1.1	0.3
	RT	12.57 ± 6.95	12.52 ± 6.84	0.3		
	RT+HIIT	7.48 ± 3.78	7.09 ± 3.78	5.2		
	RT+SIT	9.3 ± 3.91	9.03 ± 3.93	2.9		
Agility (second)	C	11.82 ± 0.9	11.8 ± 0.86	-0.1	1.8	0.1
	RT	12.5 ± 1.06	12.07 ± 0.61	-3.2		
	RT+HIIT	11.9 ± 0.4	11.97 ± 0.87	0.9		
	RT+SIT	12 ± 0.83	11.46 ± 0.63 *	-4.4		
Speed (second)	C	10.42 ± 0.98	10.4 ± 0.96	-0.1	6.7	0.001
	RT	10.5 ± 1.08	10.34 ± 0.95	-1.5		
	RT+HIIT	9.96 ± 0.75	9.93 ± 0.83	-0.3		
	RT+SIT	10.1 ± 0.66	9.58 ± 0.62 *#S	-5.04		
Sit-up (number)	C	15.27 ± 3.66	16.09 ± 3.38	5.3	8.9	0.001
	RT	15 ± 4.12	18.27 ± 4.07 *#	21.8		
	RT+HIIT	15.81 ± 2.71	19 ± 2.86 *#	20.1		
	RT+SIT	15.63 ± 3.77	20.81 ± 3.84 *#	33.1		

In ANCOVA, the baseline value of each variable was used as a covariate.
cm, centimeters; kg, kilograms; BMI, body mass index; C, control group; RT, resistant training; HIIT, high intensity interval training; SIT, sprint interval training; LBM, lean bod mass; BFP, body fat percentage.
*Significant difference from pre to post (p < 0.05)
#Significantly different from C (p < 0.05)
\$Significantly different from RT and RT+HIIT (p < 0.05)

The results related to agility, speed, sit-ups, LBM, and BMI are presented in Figure 1 (A-E).



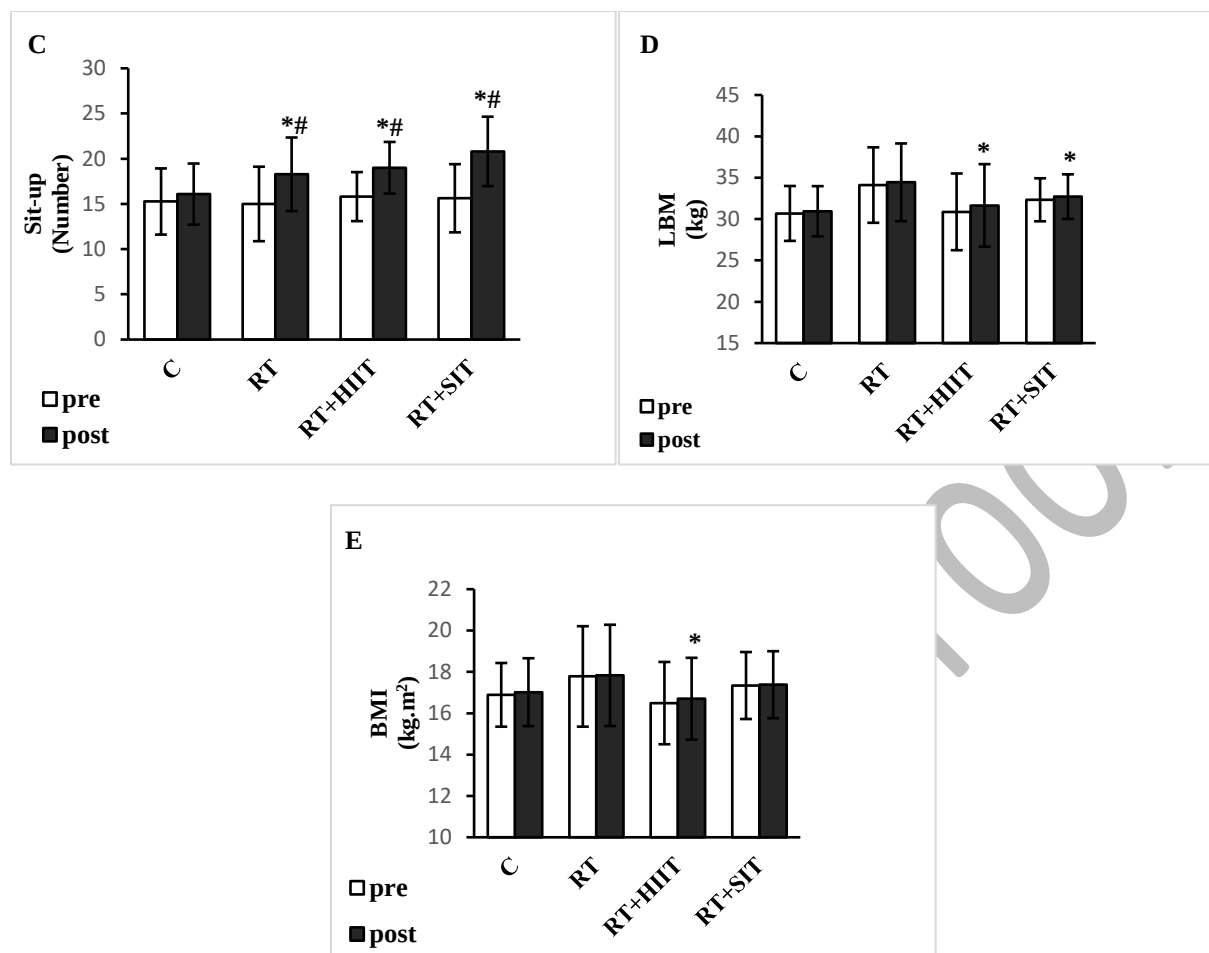


Figure 1. Within-group and between-group comparisons of the intervention effect on: (A) Agility, (B) Speed, (C) Sit-ups, (D) Lean body mass (LBM), and (E) Body mass index (BMI). *Significant difference from pre to post. #Significantly different from C.^s Significantly different from RT and RT+HIIT. ($p < 0.05$)

Discussion

This study compared the effects of RT and concurrent training models (RT+HIIT and RT+SIT) on selected fitness and anthropometric variables in prepubescent children. Overall, no significant between-group differences were found in anthropometric measures or agility. In contrast, speed improved only in the RT+SIT group, while abdominal muscle endurance increased across all training groups compared with the control.

In the present study, some within-group changes were observed in anthropometric variables (height, weight, BMI, LBM); however, these changes are most likely explained by natural growth and maturation during prepubescence rather than the training protocols. No significant differences were found between the training groups and the control group. Consistent with our results, a previous study on normal-weight children reported no significant effects of 12 weeks of circuit training on body weight, BMI, and LBM (34). In contrast, studies involving obese adolescents have shown significant reductions in weight, body fat percentage, and fat mass following CT, HIIT, or RT interventions (14, 28). These discrepancies can be attributed to differences in baseline characteristics, as training-induced changes in body composition are more pronounced in overweight or obese children compared to those of normal weight (35). Therefore, the lack of significant changes in our study may be explained by the participants' normal weight status and the overshadowing influence of natural growth and maturation.

In the present study, agility improved only in the RT+SIT group compared to baseline, whereas no significant differences were observed between the training groups or relative to the control group. The SIT component of the

RT+SIT intervention included high-intensity speed exercises. The observed improvement in this group, along with the increase in speed, highlights the link between speed and agility. However, agility also requires cognitive-perceptual skills and specific motor practice beyond mere speed (21), which may explain why between-group differences were not significant. Studies involving obese adolescents or trained children reported greater agility improvements following HIIT, RT, or a combined plyometric and RT program (13-15). Lower body fat has been linked to better agility, and increases in lean mass can enhance performance (16, 17). Comparisons with previous studies should be interpreted cautiously due to differences in participant characteristics. Baseline differences in body composition, age, and prior training experience likely contributed to the discrepancies with our findings. Developmental and physiological mechanisms further explain the results. Agility depends on both change-of-direction speed and cognitive-perceptual processes, including environmental scanning, stimulus detection, and timely motor responses. Improvements in prepubertal children are associated with maturation of the central and peripheral nervous systems, enhanced intra- and intermuscular coordination, and refined sensorimotor integration and motor control (21, 36). While RT+SIT improved both speed and agility, Duan et al. (2024) indicate that agility-specific exercises are required to optimally enhance agility (37). These findings suggest that, to effectively enhance agility in normal-weight, sedentary children, training programs should incorporate specific agility-focused exercises alongside resistance or high-intensity interval training.

Our study demonstrated significant improvements in sprint speed in the RT+SIT group, both compared to baseline and the control and other training groups. The RT and RT+HIIT groups did not show meaningful changes in speed, highlighting that targeted sprint exercises within the RT+SIT protocol were critical for enhancing short-distance sprint performance. These findings underscore the importance of incorporating speed-specific training rather than relying solely on resistance or HIIT exercises. Previous studies have reported that eight weeks of RT and CT improved 20-meter sprint performance in children aged 10 to 12 years (9, 11). Both studies included two to three sets of 20-meter sprint runs. Another study indicated that boys with a mean age of 10.4 years improved their 30-meter sprint speed after 12 weeks of combined resistance and plyometric training, which also included sprint runs (38). While these findings are broadly consistent with the potential benefits of combined training, our results differ in that improvements were observed exclusively in the RT+SIT group, emphasizing the necessity of dedicated sprint exercises. Differences in study populations may partly explain discrepancies: the prior studies included both boys and girls, whereas our study focused only on boys. Variations in the timing of pubertal onset and developmental stages may influence responsiveness to training interventions. The improvement in sprint speed observed only in the RT+SIT group can be explained by the greater recruitment of type II fibers and neuromuscular adaptations rather than hypertrophy, as growth-related anabolic hormones are still low in prepubertal children (39). In contrast, RT or HIIT provides fewer specific stimuli for sprint development, since RT mainly enhances strength, and HIIT often involves near-maximal but not supramaximal intensity (40, 41). The mechanisms underlying the observed improvements in the RT+SIT group likely involve enhanced neuromuscular development, inter- and intramuscular coordination, and repeated exposure to short, high-intensity sprint stimuli (22). This combination appears to specifically optimize neural activation patterns and force production required for sprint performance. In contrast, the RT and RT+HIIT groups, lacking sprint-specific exercises, did not exhibit similar gains.

All three training protocols enhanced abdominal muscle endurance, with no significant differences observed between the groups. This indicates that the resistance training component in each program was sufficient to stimulate improvements in core musculature, regardless of whether it was combined with SIT or HIIT. Previous studies support this finding, showing that resistance-based training—whether combined with HIIT or functional exercises—consistently improves sit-up performance (10, 12, 28, 42). While these studies included different age groups and both sexes, the consistent outcomes suggest that the resistance component is the key factor driving improvements in abdominal endurance. Mechanistically, repeated resistance loading enhances muscular strength, endurance, and neuromuscular efficiency of the abdominal muscles, increasing fatigue resistance during performance. The absence of significant differences between groups indicates that once core-targeted resistance exercises are included, variations in the concurrent training mode exert minimal additional effect. Overall, these results highlight that incorporating

resistance exercises—alone or within concurrent training programs—is sufficient to improve abdominal muscle endurance in prepubertal children.

Study limitations

This study has several limitations. The sample size was relatively small (11 per group), and participants were recruited using convenience sampling, which may limit generalizability. Some participants were excluded during the intervention, and external factors such as diet, sleep, and physical activity outside the study were not controlled. The training protocols differed in total training volume, which may have influenced the results. Standardized specific agility exercises were not included in the training protocols, and pubertal stage was self-reported using the Tanner scale, which may introduce measurement error.

Practical implications

The findings of this study provide practical guidance for coaches, educators, and parents. Sprint-specific exercises are particularly important for enhancing short-distance sprint performance in prepubertal children. Additionally, incorporating resistance exercises, either alone or combined with SIT or HIIT, can effectively improve abdominal muscle endurance. These results can help design efficient training programs tailored to children's developmental needs and physical capabilities.

Conclusion

A 12-week training intervention improved selected physical performance measures in prepubertal children. RT+SIT enhanced sprint speed, while all three protocols—RT, RT+HIIT, and RT+SIT—improved abdominal muscle endurance. These findings highlight the importance of sprint-specific exercises for speed and resistance training for core strength. Future studies should examine longer interventions, include standardized agility exercises, test different populations such as children with overweight or obesity, and investigate protocols with equal training volumes to better understand the effects of concurrent training.

Conflict of Interest

The authors declare no conflict of interest.

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