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Contextual application of integrative neuromuscular training: motor skill competence in rural primary school children aged 8–10 years

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Abstract

Background and Study Aim Motor skill competence is important for children's physical and social development. Regular physical education classes may not fully support the improvement of specific motor abilities. Although different training approaches are used in schools, their effectiveness in enhancing fundamental motor skills remains of practical interest. This study investigated the effects of a comprehensive integrative neuromuscular training (INT) program, implemented outside the standard physical education curriculum, on the gross motor skill abilities of children aged 8–10 years.

Material and Methods The study employed a true experimental design with a pre-test – post-test control group model. A total of 30 children (17 girls and 13 boys) aged 8–10 years voluntarily participated in the study. All participants were enrolled at Samanlı Primary School, located in the central district of Yalova, Türkiye, and had not previously engaged in structured physical activity programs. Based on a priori power analysis (effect size = 0.5, $\alpha = 0.05$, power = 0.80), a minimum sample size of 27 was determined. The final sample size met this requirement. Participants were randomly assigned to either the experimental group (n = 16) or the control group (n = 14). The experimental group received an INT program three times per week for eight weeks, while the control group did not participate in any additional training. Prior to and following the intervention, all participants were assessed using the Bruininks-Oseretsky Test of Motor Proficiency, Second Edition, Short Form (BOT-2 SF) to evaluate gross motor proficiency. Demographic characteristics such as age, height, and weight were presented. Data analysis was conducted using SPSS 25.

Results At baseline, no significant differences were found between the experimental and control groups in BOT-2 scores ($p > 0.05$), indicating homogeneity. Following the intervention, the experimental group demonstrated significant improvements in balance, speed–agility, strength, and BOT-2 total scores (all $p < 0.05$). Between-group comparisons at post-test revealed significantly higher scores in the experimental group for speed–agility ($p = 0.038$, $p = 0.005$), strength ($p = 0.002$), and BOT-2 total ($p = 0.003$). Effect size analyses indicated large to very large differences favoring the experimental group, with Cohen's d ranging from 0.79 (large) for SA-1 to 1.22 (very large) for S-2 and 1.18 (very large) for BOT-2 total. In contrast, the control group showed no significant changes in most subtests, except for a modest increase in BOT-2 total scores ($p = 0.024$).

Conclusions The findings demonstrate that an eight-week INT program effectively enhanced balance, speed–agility, strength, and overall motor proficiency in rural children aged 8–10 years. These improvements were confirmed through standardized assessments using the BOT-2 test, underscoring the program's potential as a practical approach to support motor development in young populations with limited access to structured physical activity opportunities.

Keywords: integrated neuromuscular training, motor skills, children, rural youth, physical education

Introduction

Motor skill competence represents a fundamental component of childhood development that influences health, movement efficiency, and engagement in physical activity throughout life. The process of acquiring and refining these skills depends on multiple factors, including neuromuscular coordination, physical fitness, and environmental opportunities for movement practice. In rural areas, where organized sport and structured activity programs are often limited, children may experience slower or uneven development of fundamental motor abilities. Therefore, strategies that integrate purposeful physical training into existing educational contexts are important for supporting balanced motor growth and functional competence in early school years.

In this context, early acquisition of fundamental movement skills has been shown to predict long-term physical activity participation and motor proficiency across adolescence and into adulthood [1, 2, 3]. As such, improving motor skill competence during childhood is crucial for fostering lifelong physical literacy and health-enhancing behaviors [4].

Integrative neuromuscular training (INT) is a comprehensive, multifaceted intervention model

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that combines general movement skills with targeted conditioning components such as strength, speed, balance, agility, plyometrics, and coordination. It has been proposed as both a preventive and performance-enhancing approach, particularly when implemented in school-based physical education settings [5]. Evidence also suggests that INT can be especially beneficial for populations with limited access to structured training opportunities, such as those in rural or resource-constrained environments [6, 7].

Motor performance in children develops through dynamic interactions among biological maturation, environmental exposure, and task-specific experience [8, 9, 10]. Research has shown that factors such as sex, growth rate, and opportunities for structured play may lead to observable differences in motor competence across childhood [8, 11, 12]. Warm-up and training programs focusing on proprioception, balance, and coordination have been found to enhance motor control and reduce injury risk in school-aged populations [11, 13]. Furthermore, studies integrating neuromuscular training principles into early physical activity programs demonstrated improvements in strength, agility, and coordination among both male and female children [12, 14]. These findings collectively support the pedagogical and physiological relevance of incorporating integrative neuromuscular training into primary school education as a means to enhance motor skill development and general movement proficiency.

Analysis of research findings has shown that children's motor development is influenced by a complex interplay of biological, environmental, and sociocultural factors. Researchers emphasize the necessity of addressing variations in motor competence between rural and urban children, which are often linked to differences in access to structured physical activities, socioeconomic conditions, and opportunities for free play. While rural children may develop balance and agility through unstructured outdoor play, their progress in more complex motor skills can be limited by a lack of facilities and professional guidance. Conversely, urban children often benefit from organized programs but may experience reduced spontaneous movement due to sedentary lifestyles. These contrasting conditions indicate the necessity of developing and applying context-dependent training models that can address environmental disparities and provide equal opportunities for motor skill enhancement in diverse settings.

The aim of this study was to examine whether an eight-week INT program would improve gross motor skills in rural children aged 8–10 years. It was hypothesized that participants in the experimental group would demonstrate significantly greater improvements in BOT-2 outcomes compared with those in the control group.

Materials and Methods

Participants

A total of 30 students aged 8–10 years voluntarily participated in this study. All participants were enrolled at Samanlı Primary School, located in the central district of Yalova, Türkiye. Eligibility criteria required that the children had not previously taken part in any organized extracurricular sports or structured training programs. Children with diagnosed cognitive, motor, or medical conditions (e.g., neurological disorders, musculoskeletal injuries, or behavioral disorders) were excluded, and no such cases were identified among the participants. Based on a G*Power analysis with an effect size of 0.5, an alpha level of 0.05, and a statistical power of 0.80, the minimum required sample size was calculated as 27 participants. The final sample met this criterion. Participants were randomly assigned to either the experimental group (n = 16) or the control group (n = 14). Written informed consent was obtained from all parents or guardians prior to participation. This study was conducted in accordance with the principles of the Declaration of Helsinki. Ethical approval was granted by the İstanbul University-Cerrahpaşa Non-Interventional Clinical Research Ethics Committee (Approval No: 2022/87; Document No: E-74555795-050.01.04-594495; Date: 07.09.2022).

The demographic characteristics and gender distribution of the participants are summarized in Tables 1 and 2.

Research Design

This study employed a true experimental design, specifically a pretest–posttest control group model, following the recommendations of Büyüköztürk et al. [10]. Prior to the intervention, motor skill tests were administered to establish baseline measures. The experimental group received an integrative neuromuscular training (INT) program for eight weeks, while the control group continued with regular school activities without additional training.

To minimize the influence of confounding variables, only children who did not participate in any extracurricular sports programs were included. Additional potential confounders such as nutritional status, daily physical activity, and academic workload were evaluated using parent information forms and teacher interviews. Both groups were drawn from the same school environment, which helped reduce differences in daily routines and environmental exposure. These variables were monitored to confirm group comparability but were not included as covariates in the statistical analyses, as no systematic group differences were identified.

Warm-up Protocol

Before the start of the training sessions, all participants performed a warm-up protocol (Table 3) developed in accordance with recommendations

Table 1. Demographic Characteristics of Participants

Variables	Group	N	Min	Max	Mean	SD
Age (years)	Total	30	8.00	10.00	8.87	0.90
	Experimental	16	8.00	10.00	8.75	0.86
	Control	14	8.00	10.00	9.00	0.96
Height (cm)	Total	30	118.00	157.00	129.24	9.09
	Experimental	16	118.00	141.00	126.83	7.72
	Control	14	118.00	157.00	132.00	10.01
Weight (kg)	Total	30	19.20	46.70	28.02	7.11
	Experimental	16	19.20	38.50	26.57	6.05
	Control	14	21.00	46.70	29.67	8.05

Table 2. Percentage Distribution of Participants by Gender

Gender	Group	N	%
Female	Total	17	56.7
	Experimental	8	50.0
	Control	8	57.1
Male	Total	13	43.3
	Experimental	8	50.0
	Control	6	42.9
Total		30	100.0

Table 3. Warm-up Program

No.	Exercise	Duration / Repetitions
1	Active running	5 min
2	Neck exercise	10 repetitions
3	Hands in front movement	10 repetitions
4	Shoulder stretch	10 sec
5	Back arm (triceps) stretch	10 sec
6	Wrist stretch	10 sec
7	Front leg (quadriceps) stretch	10 sec
8	Foot (calves) stretch	10 sec
9	Inner leg stretch	10 sec
10	Waist stretch on the floor	10 sec

from the relevant literature [11, 12, 13]. A passive warm-up method was chosen to prepare the muscles for exercise, ensure adequate range of motion, and reduce the risk of early fatigue. The rationale for selecting this approach is outlined in the introductory section of the training program.

Integrative Neuromuscular Training Program

The INT program was implemented over an eight-week period and conducted three times per week for the experimental group (n = 16). The program content and exercises were introduced to the participants one week before the intervention. It was designed in accordance with recommendations from the established literature [14, 15, 16] and organized into two-week cycles featuring progressively varied exercises to promote motor diversity and engagement. Although the program did not include specific bilateral coordination tasks, most exercises were structured to involve both sides of the body, thereby indirectly supporting symmetrical motor development.

For methodological transparency, the weekly structure of the INT program is presented in Table 4, which outlines the sequencing, duration, and targeted motor components across the eight-week period. A schematic overview of the intervention timeline is provided in Figure 1, illustrating the progression from baseline testing to the completion of the program.

Data Collection Tools

Bruininks Oseretsky Motor Competence Test-2 Short Form

Table 4. Applied Integrative Neuromuscular Training Program

Weeks	Exercise	Duration/ Repetitions	Skills Impacted
1–2	1. Broad jump stick landing	4 reps	Speed–Agility–Plyometrics
	2. Crossover hop stick	8 reps	
	3. 180° jump stick landing with ball catch	6 reps	Speed–Agility–Balance–Plyometrics
	4. BOSU double-leg perturbations	20 sec	Strength–Balance–Coordination
	5. BOSU both-knees deep hold with ball catch and release	6 reps	
3–4	1. Broad jump stick landing	6 reps	Speed–Agility–Plyometrics
	2. Crossover hop stick	12 reps	
	3. 180° jump stick landing with ball catch	6 reps	Speed–Agility–Balance
	4. BOSU double-leg pick	10 reps	Strength–Balance
	5. BOSU crunches	30 sec	
5–6	1. BOSU single-leg deep hold	30 sec	Strength–Dynamic Stabilization
	2. BOSU V-sit toe touches	10 reps	
	3. BOSU superman	20 reps	
	4. Balloon drop and catch (open/closed eyes)	2×6 reps	Balance–Coordination
	5. Get up and ball catch	6 reps	
7–8	1. Crossover hop stick	8 reps	Speed–Agility–Balance
	2. 180° jump stick landing with ball catch	6 reps	
	3. BOSU crunches	40 sec	Strength–Dynamic Stabilization
	4. BOSU V-sit toe touches	10 reps	
	5. BOSU superman	20 reps	

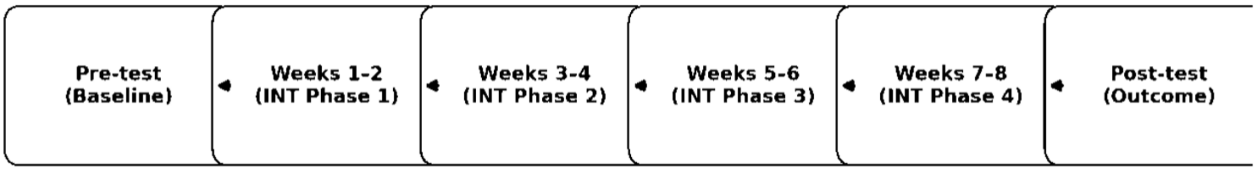

Figure 1. Timeline of the Study Design

Motor abilities of the children were assessed using the Bruininks–Oseretsky Test of Motor Proficiency, Second Edition Short Form (BOT-2 SF), following the instructions in the test manual. The BOT-2 is designed to measure both fine and gross motor skills in individuals aged 4 to 21 years [17]. In the present study, only four subtests from the BOT-2 SF that target gross motor skills were utilized. The subtests and items used are detailed in Table 5. Figures 2 and 3 illustrate sample images captured during the bilateral coordination test and the speed-agility test, respectively, as administered to participants.

Statistical Analysis

All statistical analyses were conducted using SPSS version 25. Descriptive statistics, including minimum, maximum, mean, and standard deviation values, were calculated. The normality of the data was assessed using skewness and kurtosis values. In line with established recommendations, values within ±2 for skewness and ±7 for kurtosis were considered acceptable for univariate normality [18, 19, 20]. Since these assumptions were satisfied, parametric tests were applied.

Independent-samples *t*-tests were used for between-group comparisons, and paired-samples *t*-tests were used for within-group comparisons. The selection of *t*-tests was justified by the confirmed normality, relatively balanced group sizes, and the robustness of these tests to minor deviations from normality [21]. Homogeneity of variances was verified using Levene's test. For most variables, this assumption was met; however, SA-1 and S-2 exhibited unequal variances ($p < .05$), and Welch-adjusted t values (equal variances not assumed) were therefore reported.

The level of statistical significance was set at $p < .05$. In addition, effect sizes (Cohen's d) were calculated to supplement significance testing, with thresholds of 0.20, 0.50, and 0.80 interpreted as small, medium, and large effects, respectively.

Results

Before presenting the statistical comparisons,

Table 5. Subtests and Items/Scoring Included in the Study from the BOT-2 SF Test Battery

BOT-2 Subtest	Item Code	Item Name / Scoring Description
Bilateral Coordination	BC-1	Touching the tip of the nose with the index finger – Arms extended to the sides, eyes closed; touch the tip of the nose with the index finger (4 touches). Scored from 0–4 points based on the best trial.
	BC-2	Jumping jacks (5 jumps) – Scored from 0–3 points based on the best trial.
Balance	B-1	Standing on a balance beam, heel-to-toe, eyes closed (10 sec) – Scored from 0–4 points based on the best performance.
	B-2	Standing on one leg, eyes closed (10 sec) – Scored from 0–4 points based on the best performance.
Speed–Agility	SA-1	One-legged stationary hop (15 sec) – Scored from 0–10 points based on the best performance.
	SA-2	Two-legged side hop (15 sec) – Scored from 0–10 points based on the best performance.
Strength	S-1	Sit-ups (30 sec) – Perform regular sit-ups for 30 seconds. The number of correctly performed sit-ups is scored from 0–10 points based on the best result.
	S-2	Knee push-ups (for girls) / Standard push-ups (for boys) (30 sec) – The number of correctly performed repetitions is scored from 0–10 points based on the best result.

Note. BC-1 – Bilateral Coordination-1; BC-2 – Bilateral Coordination-2; B-1 – Balance-1; B-2 – Balance-2; SA-1 – Speed–Agility-1; SA-2 – Speed–Agility-2; S-1 – Strength-1; S-2 – Strength-2.

Figure 2. Bilateral Coordination Test - Touching The Tip of The Nose with The Index finger- Eyes closed (4 touches)

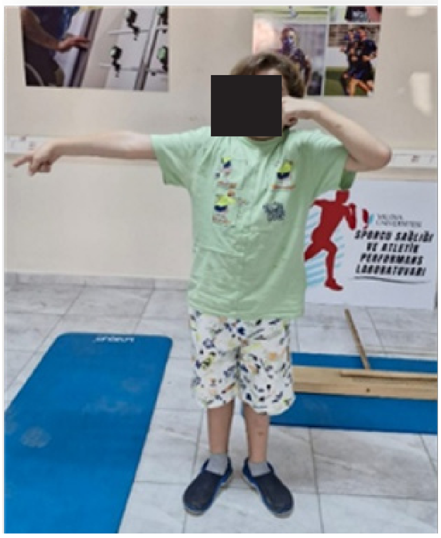

Figure 3. Speed and Agility Two-Legged Side Hop-15 sec

it is important to clarify the meaning of the BOT-2 subscales. The Bilateral Coordination (BC) subtests assess the ability to coordinate movements of both sides of the body simultaneously or sequentially, reflecting neuromuscular integration. The Balance (B) subtests measure static and dynamic postural control. The Speed and Agility (SA) subtests evaluate quickness, change of direction, and motor reaction capacity. The Strength (S) subtests capture muscular power and endurance in age-appropriate tasks. Finally, the BOT-2 Total score provides an overall index of gross motor proficiency. These dimensions collectively represent essential components of children's motor competence.

Pre-test BOT-2 comparisons between groups are reported in Table 6, and post-test comparisons are presented in Table 7.

Results

Pre-test comparisons of BOT-2 scores between the experimental and control groups are presented in Table 6. No statistically significant differences were found between groups in any of the measured variables at baseline ($p > .05$), indicating that the groups were homogeneous before the intervention.

When the pre-test BOT-2 values of the groups were compared, no significant differences were found between the experimental and control groups ($p > .05$) (Table 6). This result indicates that the groups were homogeneous in terms of their BOT-

Table 6. Comparison of Pre-Test BOT-2 Score Values Between Groups

Variables	Groups	N	Mean	SD	t	df	p
Height (cm)	Experimental	16	126.83	7.72	1.597	28	0.121
	Control	14	132.00	10.01			
Weight (kg)	Experimental	16	26.57	6.05	1.202	28	0.239
	Control	14	29.67	8.05			
Bilateral Coordination (BC-1)	Experimental	16	3.81	0.40	−0.149	28	0.883
	Control	14	3.79	0.58			
Bilateral Coordination (BC-2)	Experimental	16	2.44	1.09	1.629	21.03	0.118
	Control	14	2.93	0.47			
Balance (B-1)	Experimental	16	3.75	0.58	−0.541	28	0.593
	Control	14	3.64	0.50			
Balance (B-2)	Experimental	16	2.94	1.12	1.857	28	0.074
	Control	14	3.57	0.65			
Speed–Agility (SA-1)	Experimental	16	6.81	2.23	0.547	28	0.589
	Control	14	7.21	1.72			
Speed–Agility (SA-2)	Experimental	16	5.69	2.06	0.041	28	0.967
	Control	14	5.71	1.38			
Strength (S-1)	Experimental	16	4.13	1.41	−1.086	28	0.287
	Control	14	3.50	1.74			
Strength (S-2)	Experimental	16	3.50	1.71	−0.807	28	0.426
	Control	14	3.07	1.07			
BOT-2 Total (Score)	Experimental	16	32.94	7.77	0.216	28	0.831
	Control	14	33.43	3.72			

Note: BC-1 – Bilateral Coordination-1; BC-2 – Bilateral Coordination-2; B-1 – Balance-1; B-2 – Balance-2; SA-1 – Speed–Agility-1; SA-2 – Speed–Agility-2; S-1 – Strength-1; S-2 – Strength-2; BOT-2 Total – Bruininks–Oseretsky Test of Motor Proficiency Total Score.

Table 7. Comparison of Post-Test BOT-2 Score Values Between Groups

Variables	Groups	N	Mean.	SD.	t	df	p
Bilateral Coordination/BC-1	Experimental	16	3.88	0.34	0.473	28	0.640
	Control	14	3.93	0.27			
Bilateral Coordination/BC-2	Experimental	16	2.81	0.54	1.379	28	0.179
	Control	14	3.07	0.47			
Balance/B-1	Experimental	16	3.94	0.25	-0.714	28	0.481
	Control	14	3.86	0.36			
Balance/B-2	Experimental	16	3.81	0.40	-1.379	19.187	0.184
	Control	14	3.50	0.76			
Speed-Agility/SA-1	Experimental	16	8.81	1.33	-2.178	28	**0.038****
	Control	14	7.57	1.79			
Speed-Agility/SA-2	Experimental	16	8.38	1.59	-3.049	28	**0.005****
	Control	14	6.43	1.91			
Strength/S-1	Experimental	16	5.00	1.41	-1.723	28	0.096
	Control	14	4.14	1.29			
Strength/S-2	Experimental	16	5.06	2.02	-3.493	22.532	**0.002****
	Control	14	3.07	1.00			
BOT-2 Total (Score)	Experimental	16	41.81	6.02	-3.220	28	**0.003****
	Control	14	35.43	4.62			

**p<0.01, p<0.05- BC-1: Bilateral coordination-1, BC-2: Bilateral coordination-2, B-1: Balance-1, B-2: Balance-2, SA-1: Speed-Agility-1, SA-2: Speed-Agility-2, S-1: Strength-1, S-2: Strength-2, BOT-2 Total: Bruininks-Oseretsky Test of Motor Proficiency Total Score

2 scores. At baseline, no significant differences were observed between the groups across the bilateral coordination, balance, speed–agility, strength subtests, and total BOT-2 score (*all p* > .05), confirming group equivalence prior to the intervention.

Post-test comparisons of BOT-2 scores between the experimental and control groups are summarized in Table 7. When the post-test BOT-2 values were compared, significant differences were found in Speed–Agility 1, Speed–Agility 2, Strength 2, and the total BOT-2 score (p = 0.038, 0.005, 0.002, and 0.003, respectively), with higher values in the experimental group. In contrast, bilateral coordination and balance measures did not differ significantly between groups (*all p* > .05), indicating stability in these domains despite improvements in other motor components.

Within-group pre- and post-test comparisons of BOT-2 scores for both the experimental and control groups are summarized in Table 8. The experimental group demonstrated significant improvements from pre-test to post-test in balance (B-2, p = 0.004), speed–agility (SA-1, p = 0.004; SA-2, $p < 0.001$), strength (S-1, $p < 0.001$; S-2, p = 0.001), and overall BOT-2 total scores ($p < 0.001$). No significant changes were observed in bilateral coordination (BC-1, BC-2) or static balance (B-1) (*all p* > 0.05). In contrast, the control group showed no significant changes in most subscales, except for a modest increase in BOT-2 total scores (p = 0.024). These results indicate that the INT program produced broad improvements across several domains of motor competence, whereas the control group remained largely stable.

Effect size values (Cohen's d) for post-test comparisons are presented in Table 9, showing that the observed improvements were not only statistically significant but also practically meaningful. In addition to p-values, the effect size analysis revealed large to very large between-group differences in favor of the experimental group (SA-1: d = 0.79; SA-2: d = 1.12; S-2: d = 1.22; BOT-2 Total: d = 1.18) (Table 9).

Discussion

This study aimed to examine how integrative neuromuscular training influences the neuromuscular system and improves gross motor skills in children. The BOT-2 Short Form was used to assess children's gross motor proficiency.

Analysis of BOT-2 results revealed significant between-group differences in Speed–Agility 1, Speed–Agility 2, Strength 2, and total BOT-2 scores, with higher post-test values observed in the experimental group. Within-group comparisons further showed that post-test scores of the experimental group were significantly higher than pre-test scores in Balance 2, Speed–Agility 1, Speed–Agility 2, Strength 1, Strength 2, and total BOT-2 variables ($p < 0.05$). No statistically significant changes were found in the other variables ($p > 0.05$). In contrast, the control group demonstrated no significant differences across most variables, except for a modest improvement in total BOT-2 scores.

In the present study, bilateral coordination, a component of the BOT-2 test battery, was evaluated through two subtests: "Touching Nose with Index Fingers – Closed Eyes (BC-1)" and "Jumping Jack (BC-2)." Previous research has emphasized that bilateral coordination reflects the ability to use both sides of the body simultaneously, and that individuals with higher levels of this ability demonstrate greater interhemispheric synergy [22, 23]. A review of the relevant literature showed that [24] reported no statistically significant differences in BOT-2 upper extremity coordination outcomes between 9-year-old children who participated in sports and those who did not. This finding aligns with the results of the present study, in which no between-group differences were observed in bilateral coordination performance.

Another study [25] reported a significant improvement in the bilateral coordination values of the experimental group after eight weeks of sports school practice for preschool children in the Jumping Jack test, while no significant change was observed in the "Touching the Tip of the Nose with the Index Finger – Eyes Closed" test. Similarly, Stanković et al. [26] found that a 12-week aerobic exercise program for children aged 5–6 years led to increases in all bilateral coordination test values of the BOT-2 battery in the experimental group. However, no significant difference was detected in the "Touching the Tip of the Nose with the Index Finger – Eyes Closed" test. These studies show partial similarity to the findings of the present research.

In the current study, it was hypothesized that the absence of differences in BC-1 and BC-2 values between the experimental and control groups could be attributed to the fact that the bilateral coordination tasks used in the BOT-2 test are relatively simple and can be successfully performed even by children without active sports participation, provided they have no health problems. Some studies have emphasized that the bilateral coordination subtests of the BOT-2 battery should not be overly complex for children with well-developed motor skills [27, 28, 29]. These tests are typically performed successfully by children from preschool age through later developmental stages.

In the present study, participants' speed and agility were evaluated using two subtests of the BOT-2 test battery: the Single-Leg Fixed Jump (15 seconds) and the Double-Leg Right–Left Jump (15 seconds). Faigenbaum et al. [29] reported that an INT program applied twice a week for approximately 15 minutes produced positive effects on speed and agility, which closely aligns with the findings

Table 8. Comparison of Pre and Post Test BOT-2 Score Values within Groups

Groups	Variables	N	Mean	Sd.	t	df	p
Experimental	BC-1 Pre-test	16	3.81	0.40	1.000	15	0.333
	BC-1 Post-test	16	3.88	0.34			
	BC-2 Pre-test	16	2.44	1.09	-1.464	15	0.164
	BC-2 Post-test	16	2.81	0.54			
	B-1 Pre-test	16	3.75	0.58	-1.379	15	0.188
	B-1 Post-test	16	3.94	0.25			
	B-2 Pre-test	16	2.94	1.12	-3.416	15	**0.004****
	B-2 Post-test	16	3.81	0.40			
	SA-1 Pre-test	16	6.81	2.23	-3.381	15	**0.004****
	SA-1 Post-test	16	8.81	1.33			
	SA-2 Pre-test	16	5.69	2.06	-5.400	15	**0.000****
	SA-2 Post-test	16	8.38	1.59			
	S-1 Pre-test	16	4.13	1.41	-4.869	15	**0.000****
	S-1 Post-test	16	5.00	1.41			
	S-2 Pre-test	16	3.50	1.71	-4.038	15	**0.001****
	S-2 Post-test	16	5.06	2.02			
	BOT-2 Total Pre-test	16	32.94	7.77	-5.532	15	**0.000****
	BOT-2 Total Post-test	16	41.81	6.02			
Control	BC-1 Pre-test	14	3.79	0.58	-1.472	13	0.165
	BC-1 Post-test	14	3.93	0.27			
	BC-2 Pre-test	14	2.93	0.47	-1.472	13	0.165
	BC-2 Post-test	14	3.07	0.47			
	B-1 Pre-test	14	3.64	0.50	-1.385	13	0.189
	B-1 Post-test	14	3.86	0.36			
	B-2 Pre-test	14	3.57	0.65	0.366	13	0.720
	B-2 Post-test	14	3.50	0.76			
	SA-1 Pre-test	14	7.21	1.72	-1.161	13	0.266
	SA-1 Post-test	14	7.57	1.79			
	SA-2 Pre-test	14	5.71	1.38	-1.933	13	0.075
	SA-2 Post-test	14	6.43	1.91			
	S-1 Pre-test	14	3.50	1.74	-1.979	13	0.069
	S-1 Post-test	14	4.14	1.29			
	S-2 Pre-test	14	3.07	1.07	0.000	13	1.000
	S-2 Post-test	14	3.07	1.00			
	BOT-2 Total Pre-test	14	33.43	3.72	-2.550	13	**0.024****
	BOT-2 Total Post-test	14	35.43	4.62			

**$p<0.01$, $p<0.05$- BC-1: Bilateral coordination-1, BC-2: Bilateral coordination-2, B-1: Balance-1, B-2: Balance-2, SA-1: Speed-Agility-1, SA-2: Speed-Agility-2, S-1: Strength-1, S-2: Strength-2, BOT-2 Total: Bruininks-Oseretsky Test of Motor Proficiency Total Score

Table 9. Cohen's d Effect Sizes for Post-Test Comparisons Between Groups

Variable	Experimental (M ± SD)	Control (M ± SD)	d	Interpretation
Speed–Agility 1 (SA-1)	8.81 ± 1.33	7.57 ± 1.79	0.79	Large
Speed–Agility 2 (SA-2)	8.38 ± 1.59	6.43 ± 1.91	1.12	Very large
Strength 2 (S-2)	5.06 ± 2.02	3.07 ± 1.00	1.22	Very large
BOT-2 Total	41.81 ± 6.02	35.43 ± 4.62	1.18	Very large

of the present study. Similarly, Özsaydi et al. [30] identified significant differences in speed–agility values between children who regularly participated in basketball activities and those leading a sedentary lifestyle. In another study with a different methodological design, Hopper et al. [31] observed significant improvements in the 20-m sprint times of netball players after six weeks of neuromuscular training.

The existing literature contains relatively few studies comparable to the present one [8, 32]. A review of available research indicates that the speed–agility component, as a sub-parameter of motor skills, has rarely been evaluated following integrative neuromuscular training interventions. Nevertheless, the literature describes speed–agility as a key element of INT programs [33]. To further develop this component, future INT studies should include agility-based exercises that emphasize acceleration with directional changes [34] and integrate cutting movements of varying difficulty, recognizing that many sports disciplines require rapid and multidirectional movement patterns.

The findings of this study indicate that the INT program had a positive effect on motor skill performance, particularly in the domains of speed and agility. These results suggest that the intervention was both effective and adequate. Although existing evidence supports the efficacy of INT programs in improving speed and agility, there remains a limited number of studies focusing on school-aged children. Future research should further explore the development of not only speed and agility parameters but also other components of INT programs implemented in this population.

In this study, the strength parameter, which is one of the subtests of the BOT-2 test battery, was evaluated using two subtests: "Push-up (30 seconds)" and "Sit-up (30 seconds)." Faigenbaum et al. [5] reported a significant increase in upper extremity and abdominal strength among children in the experimental group after eight weeks of INT. Similarly, Sinđić et al. [35] found significant improvements in core and upper body strength in girls following a comparable intervention. Faigenbaum et al. [5] also emphasized that the experimental group achieved greater gains in the abdominal curl-up test than the control group after participating in an eight-week INT program integrated into physical education classes. Duncan et al. [36] used the medicine ball throw test to assess upper extremity strength in children aged 7 to 10 years following a 10-week INT program and reported higher post-test values in the experimental group compared with the control group.

These findings are consistent with the significant differences observed in the Strength 2 (shuttle) subtest of the BOT-2 battery in the present study. However, there is still a limited number of studies examining the effects of INT programs on school-aged children. Among those that exist, the following are particularly noteworthy: [7, 14, 33, 35, 36].

The positive effects of the INT program on children's motor competence can be understood from both theoretical and empirical perspectives. According to dynamic systems theory, motor development arises through continuous interaction among the individual, the task, and the environment, rather than being solely determined by maturation. Structured and progressively challenging activities, such as those included in the INT intervention, may therefore provide opportunities for self-organization and the emergence of more efficient movement strategies [37].

Furthermore, motor learning principles suggest that repeated and variable practice promotes neural adaptations, including improved motor unit recruitment, intermuscular coordination, and proprioceptive control. Recent evidence indicates that variability in practice and initial motor variability is associated with greater adaptability and skill consolidation [38]. Empirical findings support these mechanisms, as systematic reviews and meta-analyses consistently report that INT improves sprint performance, jumping ability, balance, agility, and overall physical fitness in school-aged populations [39, 40, 41]. These results are consistent with earlier theoretical and applied recommendations emphasizing the role of integrative neuromuscular training in promoting safe and effective performance gains in youth [42].

Taken together, these findings suggest that the improvements observed in BOT-2 outcomes, particularly in agility, balance, and strength, reflect neuromuscular adaptations and enriched practice conditions that foster the development of fundamental motor skills in children living in rural areas [43, 44].

In addition to the studies referenced in the previous sections, several other investigations have examined strength parameters that are only partially or not directly comparable to the measurement methods used in the present study. A few of these studies are highlighted below. For example, Xiong et al. [45] employed the One Repetition Maximum (1RM) test to assess strength after eight weeks of an INT program and reported positive results in the experimental group. Similarly, Panagoulis et al. [46] used the one repetition maximum leg test to evaluate strength following an INT program conducted with football players and found favorable outcomes for the INT group.

Strength is widely recognized as one of the key components of INT programs. In addition to the present findings, the inclusion of INT interventions that can be adapted to different anatomical regions in future studies may enhance understanding of strength development following such programs and clarify how these effects manifest across various muscle groups.

In our study, significant differences were found in the total BOT-2 post-test values in both the control and experimental groups. Additionally, a significant between-group difference in total BOT-2 scores was identified in favor of the experimental group. A previously cited study [32] also reported a significant difference in BOT-2 motor skill results favoring the experimental group and suggested that the INT program used was effective in improving children's overall fitness performance. Similarly, another study [47] emphasized that neuromuscular training produced positive effects on motor coordination and general fitness levels in children, although the data collection methods differed from those in our study.

Font-Lladó et al. [48] conducted a study in which integrative neuromuscular training was implemented as an additional warm-up protocol during physical education classes. They found that children in the experimental group achieved significant improvements in motor competence and fundamental motor skills. In a study by Duncan et al. [36], a 10-week INT program was incorporated into a school's physical education curriculum. Children in the experimental group participated in the program, while those in the control group attended standard physical education lessons. The results indicated that the INT program led to positive changes in the fundamental movement skills of children aged six to seven years. Similarly, Mülazımoğlu Ballı [49] reported that the experimental group outperformed the control group in balance, bilateral coordination, strength, and total gross motor composite scores on the BOT-2 motor competence test after gymnastics training.

A review of the relevant literature indicates that INT and similar resistance-based training programs generally have a positive impact on motor skill performance. The results of the present study are consistent with these findings. The significant within-group improvement observed in the control group may be attributed to the beneficial effects of games and physical activities conducted by teachers during free play and physical education classes.

The results of the present study are consistent with the findings of Gökşin et al. [50], who reported higher levels of speed–agility, strength, and overall motor competence in children regularly participating in sports activities. In contrast to their cross-sectional research, our experimental intervention demonstrates that a specifically designed integrative neuromuscular training (INT) program can elicit these improvements, thereby supporting a causal interpretation of the observed differences.

Limitations and Directions for Future Research

In interpreting these findings, several limitations should be acknowledged. The relatively small sample size (N = 30), the short intervention period of eight weeks, and the focus on a single rural primary school limit the generalizability of the results. Furthermore, the exclusive use of the BOT-2 may not fully capture broader dimensions of motor competence, such as motivational or affective aspects, while potential confounding factors (e.g., extracurricular activities, nutrition) were screened but not statistically controlled. Future research should therefore include larger and more diverse samples, extend the duration of the intervention, and incorporate multidimensional assessments of physical literacy. In addition, comparative studies involving rural and urban populations are recommended to better understand the moderating role of environmental factors and to clarify the long-term sustainability of INT-related improvements.

Practical Implications

The results of this study offer practical guidance for physical education teachers and school administrators. INT programs can be incorporated into regular physical education lessons without requiring specialized facilities or expensive equipment, making them particularly suitable for rural schools with limited resources. Teachers may implement brief INT modules (approximately 15–20 minutes, twice per week) to supplement the standard curriculum. These practices can enhance children's motor competence while promoting engagement, enjoyment, and long-term participation in physical activity. At the policy level, education authorities could consider integrating INT-based modules into national physical education standards to ensure that all children, regardless of geographic location, have access to structured opportunities for motor skill development.

Conclusions

This study demonstrated that an eight-week integrative neuromuscular training (INT) program significantly improved balance, speed, agility, strength, and overall motor skill competence in rural schoolchildren aged 8 to 10 years. Since both the experimental and control groups participated in the same physical education classes, the observed performance improvements can be attributed to the INT intervention rather than to differences in instructional exposure. Although the specific mechanisms underlying these improvements were not directly assessed, they are likely related to neuromuscular adaptations such as enhanced motor unit activation, coordination, and proprioceptive control.

The findings indicate that INT is a cost-effective and feasible approach for improving motor competence in primary school settings.

Incorporating structured INT modules into physical education curricula, particularly in resource-limited rural areas, may help promote children's lifelong participation in physical activity and contribute to their overall health and well-being.

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Conflict of Interest

The authors declare no conflict of interest.

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