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## INDEXING

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# Motor skill development in schoolchildren with hearing impairments during physical education in general secondary schools

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

**Abstract**

| | |
|---|---|
| *Background and Study Aim* | Hearing impairment is a common childhood disorder that influences communication, learning and physical development. It is often associated with delays in motor skills and reduced functional capacity. Although physical education is widely applied in schools, its role in supporting children with hearing impairments remains a practical concern. The purpose of this study was to compare motor and functional indicators between schoolchildren with hearing impairments and their typically developing peers. |
| *Material and Methods* | A comparative cross-sectional study was conducted with 36 schoolchildren with hearing impairments (7–8 years old) and 50 typically developing peers. Functional development was assessed using anthropometric measurements, spirometry, the Ruffier test, the Stange test, and the Genchi test. Statistical analysis included descriptive statistics, tests of normality (Shapiro–Wilk), Student's $t$-test, and calculation of effect sizes (Cohen's $d$). Results are presented as mean ± standard error (SE), with significance set at $p < 0.05$. |
| *Results* | Children with hearing impairments demonstrated significantly lower lung vital capacity (1100–1250 ml vs. 1200–1300 ml in peers, $p < 0.05$) and a reduced vital index (approximately 41–43 ml/kg vs. 44 ml/kg, $p > 0.05$). The Ruffier test showed consistently higher scores (17–19 vs. 10–11, $p < 0.01$), reflecting poorer cardiovascular adaptation. The Stange test revealed markedly shorter breath-holding times (18–20 s vs. 34–40 s, $p < 0.001$), while the Genchi test confirmed limited hypoxic reserves (13–14 s vs. 16–18 s, $p < 0.01$). These patterns were consistent across both age groups and sexes. |
| *Conclusions* | Schoolchildren with hearing impairments exhibit marked functional limitations compared to their typically developing peers. These results underline the need for differentiated approaches in physical education and provide a scientific basis for the development of adapted programs focused on improving cardiorespiratory endurance, motor coordination, and overall physical fitness in this group. |
| **Keywords**: | motor development, hearing impairment, schoolchildren, physical education, Ruffier test, respiratory endurance |

## Introduction

The health and development of children with special educational needs represent a complex issue that extends beyond medical care and requires coordinated attention from educators, psychologists, and specialists in physical culture. Hearing impairment is one of the most widespread sensory disorders in childhood, influencing not only communication but also motor development, emotional well-being, and social integration. The multifactorial nature of this condition means that its impact is reflected in reduced physical activity, limitations in motor skills, and challenges in adapting to the demands of the school environment. The scale of the problem is illustrated by global and national statistics, which underline the significance of hearing impairment as a widespread health and educational challenge.

According to the World Health Organization (WHO), about 540 million people worldwide have hearing problems, including approximately 32 million children. In Ukraine, more than 1.5 million people live with hearing impairments, among them over 300,000 children. Around 100,000 adults and 11,000 children suffer from complete deafness. Moreover, the prevalence of hearing impairment continues to rise, reflecting a concerning trend in modern society

[1]. In this context, recent reviews provide valuable insights into how hearing loss influences motor development and highlights the importance of adapted approaches within physical education.

Vestibular dysfunction is strongly linked with delays in gross motor milestones among children with hearing loss, which has direct implications for physical education and motor training [2, 3, 4]. Systematic reviews further show that structured balance interventions of 8–16 weeks can significantly improve motor outcomes, reinforcing the feasibility of implementing such programs in PE curricula [5, 6, 7]. Together, these findings highlight the relevance of focusing on balance, coordination, and functional fitness in adapted PE. Building on this evidence, diagnostic and applied studies have explored specific manifestations of motor deficits and provided tools for assessing postural control in children with hearing impairments.

Observational evidence indicates that children with hearing impairments often demonstrate postural instability and higher sway during balance tasks [8, 9, 10]. The Geneva Balance Test provides a child-friendly instrument for identifying vestibular deficits in school settings [11, 12]. Additional research shows that BOT-2 balance tasks can reveal vestibular loss in students with sensorineural hearing loss, highlighting their potential use for screening within PE and school health programs [13, 14]. Long-term follow-ups also confirm persistent differences in vestibular and motor performance, which are relevant for monitoring progression across school years [15, 16]. Complementing these international findings, national studies provide region-specific evidence that reflects the educational and cultural context of Ukraine.

Regional investigations add further detail to the specific challenges of motor development in schoolchildren with hearing impairments. Research points to difficulties in balance and coordination during PE classes [17], the importance of activating sports and recreational activities for students with disabilities [18], and ongoing debates around the terminological framework of motor qualities [19]. Other studies emphasize the need for modern technologies of inclusive physical education [20] and the positive role of physical activity in supporting students' academic performance [21]. Collectively, these findings justify adapted PE strategies in Ukraine that align with global evidence. At the policy level, broader monitoring initiatives and population-based analyses further illustrate the significance of physical activity and health surveillance for children with hearing loss.

Large-scale analyses highlight associations between adherence to 24-hour movement guidelines and improved emotional, social, and academic functioning in children with hearing loss [22, 23]. School-based enhanced hearing screening combined with telehealth demonstrates scalable approaches that can be integrated with educational monitoring and PE observations [24]. In parallel with these organizational efforts, intervention studies focused on physical activity, recreation, and sport provide practical evidence of how targeted exercise programs can enhance balance, coordination, and overall motor performance in children with hearing impairments.

Exercise-based interventions show direct benefits for balance and motor performance. A randomized trial demonstrated that dance-sport activity improved vestibular function and balance in children with hearing impairments [5, 25]. Additional studies confirm that postural stability is influenced by physical activation and that exercise programs can be integrated into sport and recreation modules [26, 27]. Comparable findings were also reported for adolescents with intellectual disabilities, who show lower levels of cardiorespiratory fitness but maintain similar physical activity compared to typically developing peers [28]. These findings support embedding progressive balance and coordination exercises into PE curricula, recreational sport, and fitness programs.

The analysis of research results has shown that children with hearing impairments face consistent challenges in motor development, balance, and overall functional fitness. Authors emphasize the importance of integrating differentiated approaches into physical education and highlight the potential of targeted exercise programs to improve motor coordination, cardiorespiratory endurance, and postural stability. Researchers also underline that adapted educational strategies and the inclusion of recreational and sport activities can significantly enhance social participation and quality of life in this population. At the same time, there remains a need for continued investigation, as gaps in knowledge about the long-term effects of adapted physical education and the optimization of intervention models still hinder the full development of evidence-based practices.

The hypothesis of the study is that assessing the level of motor development in schoolchildren with hearing impairments is a necessary condition for designing modern programs and recommendations in physical education. Such an approach can significantly enhance motor activity and facilitate students' adaptation to the external environment.

The purpose of this study was to compare motor and functional indicators between schoolchildren with hearing impairments and their typically developing peers.

## Materials and Methods

### Participants

The study included 36 students with hearing impairments (HI) aged 7–8 years (17 aged 7 and 19

aged 8) and 50 typically developing peers without impairments (Control) (25 aged 7 and 25 aged 8). Participants with HI were recruited from specialized schools, while the Control group consisted of students from general education schools. Inclusion criteria were: an officially confirmed diagnosis of hearing impairment (for the HI group), regular attendance of physical education classes, and absence of severe comorbidities. Written informed consent was obtained from parents/guardians of all participants. Age, level of motor development, and general health of both groups were considered to ensure sample comparability. The study was conducted in accordance with the Declaration of Helsinki. Ethical approval was granted by the Ethics Committee of T.H. Shevchenko National University "Chernihiv Collegium."

*Study Design*

The applied approach allowed the formation of two representative and relatively homogeneous groups, ensuring the correct comparison of results and increasing the reliability of the research conclusions. This study was designed as a comparative cross-sectional investigation aimed at evaluating motor and functional development indicators in schoolchildren with hearing impairments compared to students without impairments.

Motor development was assessed using the Ruffier test [28], lung vital capacity, the vital index, and the Stange and Genchi tests [29, 30]. Data collection was carried out at Chernihiv Secondary School No. 1 and the Sosnytsky Educational and Rehabilitation Center. Students with hearing impairments were examined in the laboratory "Problems of the Formation of Motor Function of Persons Engaged in Physical Education and Sports" at the National University "Chernihiv Collegium" named after T. H. Shevchenko, while students without impairments were assessed in the general school setting.

The Ruffier test [28, 31] is a simple physiological assessment used to evaluate cardiac response to muscular exertion. It provides information about the functional capacity of the cardiovascular system under physical load. Detailed procedures and scoring criteria are presented in Table 1.

**Table 1.** Ruffier test scoring scale in conventional units

| Result | 7–8 years old |
|---|---|
| Poor | ⩾ 21 |
| Weak | 17–21 |
| Satisfactory | 12–16 |
| Good | 6.5–11 |
| Excellent | ⩽ 6 |

The Ruffier test is a standardized medical procedure used in Ukrainian schools to evaluate the functional state of the cardiovascular system.

The results are applied to determine the physical education group to which a child can be assigned, taking into account their motor capacity and health status. On the basis of the Ruffier test score, students receive an official certificate indicating the appropriate physical education group.

The Ruffier test is performed after five minutes of rest in a sitting position. The pulse is first recorded for 15 seconds (P1). The participant then performs 30 squats within 45 seconds. Immediately after completing the squats, the pulse is measured twice: during the first 15 seconds (P2) and during the last 15 seconds (P3) of the first minute of recovery.

The Ruffier index is calculated according to the following formula:

$$RI = \frac{(P1 + P2 + P3) - 200}{10}$$

where P1 = resting heart rate, P2 = post-exercise heart rate, P3 = recovery heart rate.

Vital capacity of the lungs is a key indicator of the functional state of the respiratory system. It depends on body size and age and correlates with both physical fitness and overall functional status [32]. To further characterize the development of the respiratory muscles and the efficiency of the respiratory organs, the vital index (ratio of vital capacity to body weight) was calculated according to established spirometry guidelines [33].

In addition, standardized hypoxic tests were applied to assess the body's oxygen supply during breath-holding. The Stange test (breath-holding after a deep inhalation) and the Genchi test (breath-holding after a deep exhalation) were performed using a stopwatch to record the duration [34].

*Testing procedure*

All participants were tested under similar environmental conditions (quiet indoor setting, temperature 20–22 °C). Each test was conducted in the morning, at least two hours after the last meal. Standardized instructions were provided, and each measurement was performed twice; the best result was recorded.

*Measurements and instruments*

1. Anthropometry: body height was measured using a stadiometer (accuracy ±0.1 cm), and body weight with mechanical scales (accuracy ±0.1 kg).
2. Spirometry: lung vital capacity was assessed using a portable spirometer. Calibration was performed before each testing session [35].
3. Vital index: calculated as lung vital capacity (ml) divided by body weight (kg), according to established spirometry guidelines [33].
4. Stange test: breath-holding duration after maximal inhalation, recorded with a stopwatch.
5. Genchi test: breath-holding duration after

maximal exhalation, recorded with a stopwatch.

*Statistical analysis*

Data were processed using Microsoft Excel 2010. Results are presented as mean ± standard error (SE). Between-group comparisons (children with and without hearing impairments) were performed using Student's t-test. Statistical significance was accepted at $p < 0.05$.

## Results

The analysis of anthropometric indicators showed no statistically significant differences in height between students with and without hearing impairments at either age group ($p > 0.05$). However, 8-year-old boys with hearing impairments had significantly higher body weight compared to their peers without impairments ($p < 0.01$).

Regarding functional tests, Ruffier index scores were significantly higher, indicating poorer cardiovascular adaptation, in children with hearing impairments. Among 7-year-old girls, the difference reached statistical significance ($p < 0.05$). Similarly, 7-year-old boys with hearing impairments scored significantly higher than their peers ($p < 0.01$). At the age of 8, this trend persisted, with both girls ($p < 0.01$) and boys ($p < 0.01$) showing less favorable results. The findings are summarized in Table 2.

Analysis of the results presented in Table 2 revealed a consistent tendency toward lower lung vital capacity in girls with hearing impairments compared to their peers without impairments. This difference was evident in both age groups and reached statistical significance. By contrast, the vital index showed only minor variations between groups and was not statistically significant. The breath-holding tests demonstrated clear differences: in both the Stange and Genchi tests, girls with hearing impairments achieved substantially shorter times, indicating reduced hypoxic tolerance and lower respiratory endurance.

The vital index (ml/kg) was consistently lower in children with hearing impairments, although the differences did not always reach statistical significance ($p > 0.05$). The results are summarized in Table 3.

Analysis of the results presented in Table 3 showed that boys with hearing impairments demonstrated a consistent disadvantage in breath-holding performance. In the Stange test, they had markedly shorter times compared to their peers without impairments, and the differences were highly significant across both age groups ($p < 0.001$). A similar pattern was observed in the Genchi test, where boys with hearing impairments consistently achieved lower values, with differences reaching statistical significance ($p < 0.01$). These findings indicate reduced hypoxic tolerance and lower respiratory endurance among children with hearing impairments.

The comparative results of the Ruffier, Stange,

**Table 2.** Results of motor skills indicators for girls aged 7–8 years (Mean ± SE)

| Test name | 7 years (HI, n=8) | 7 years (Control, n=12) | 8 years (HI, n=9) | 8 years (Control, n=11) |
|---|---|---|---|---|
| Body weight (kg) | 26.36 ± 2.45 | 26.65 ± 2.38 | 27.50 ± 2.56 | 28.32 ± 3.72 |
| Body height (cm) | 128.16 ± 2.89 | 129.78 ± 2.29 | 133.67 ± 3.18 | 134.39 ± 4.36 |
| Ruffier test (index) | 18.78 ± 3.61 | 11.87 ± 2.43 | 18.52 ± 2.04 | 10.67 ± 1.82 |
| Lung vital capacity (ml) | 1100.42 ± 139.78 | 1200.06 ± 169.21 | 1200.00 ± 122.12 | 1300.00 ± 149.31 |
| Vital index (ml/kg) | 41.9 ± 6.38 | 43.8 ± 7.05 | 42.8 ± 7.10 | 44.7 ± 7.40 |
| Stange test (s) | 18.5 ± 3.3 | 34.3 ± 4.6 | 19.3 ± 3.9 | 36.9 ± 4.9 |
| Genchi test (s) | 12.2 ± 2.18 | 14.6 ± 3.6 | 13.1 ± 3.8 | 15.7 ± 3.5 |

Note: HI = hearing impairments; Control = peers without impairments.

**Table 3.** Results of motor skills indicators for boys aged 7–8 years (Mean ± SE)

| Test name | 7 years (HI, n=8) | 7 years (Control, n=12) | 8 years (HI, n=9) | 8 years (Control, n=11) |
|---|---|---|---|---|
| Body weight (kg) | 33.9 ± 3.5 | 27.1 ± 2.96 | 36.1 ± 3.9 | 29.3 ± 2.7 |
| Body height (cm) | 131.57 ± 2.2 | 132.65 ± 3.1 | 134.6 ± 2.8 | 135.2 ± 3.3 |
| Ruffier test (index) | 18.06 ± 2.5 | 10.68 ± 2.4 | 17.1 ± 2.7 | 9.7 ± 2.9 |
| Lung vital capacity (ml) | 1200.0 ± 122 | 1250.1 ± 188 | 1250.0 ± 168 | 1300.0 ± 133.2 |
| Vital index (ml/kg) | 42.7 ± 7.4 | 43.5 ± 8.0 | 40.8 ± 7.6 | 41.3 ± 7.0 |
| Stange test (s) | 19.1 ± 3.7 | 36.8 ± 4.8 | 20.4 ± 5.3 | 39.7 ± 5.6 |
| Genchi test (s) | 13.9 ± 2.3 | 16.2 ± 2.6 | 14.3 ± 3.5 | 18.0 ± 4.2 |

Note: HI = hearing impairments; Control = peers without impairments.
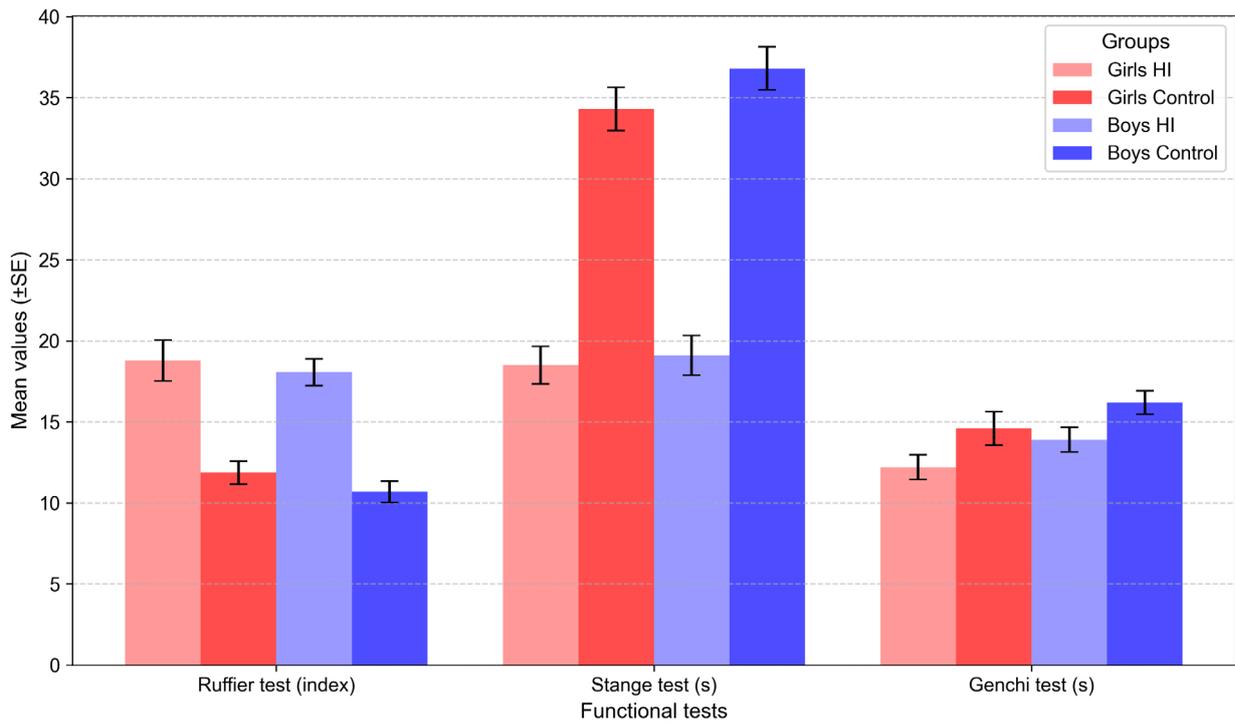
**Figure 1.** Comparison of Ruffier, Stange, and Genchi test results in 7-year-old students with and without hearing impairments. Values are shown as Mean ± SE. HI = hearing impairments; Control = typically developing peers.
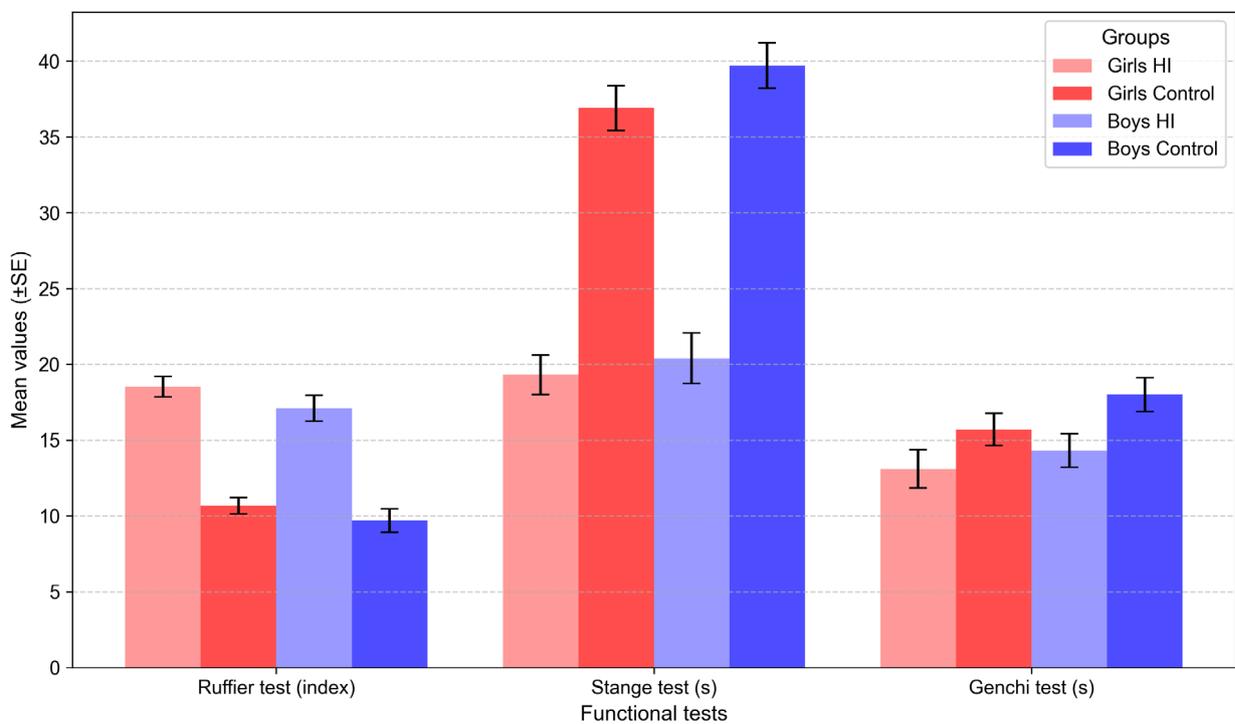


**Figure 2.** Comparison of Ruffier, Stange, and Genchi test results in 8-year-old students with and without hearing impairments. Values are shown as Mean ± SE. HI = hearing impairments; Control = typically developing peers.

and Genchi tests are presented in Figure 1 (7-year-olds) and Figure 2 (8-year-olds). These tests reflect cardiovascular adaptation and respiratory endurance, which were consistently reduced in the groups with hearing impairments.

In both age groups, girls with hearing impairments (Girls HI) and boys with hearing impairments (Boys HI) demonstrated significantly higher Ruffier index values and shorter Stange and Genchi test times compared to girls without impairments (Girls Control) and boys without impairments (Boys Control). These consistent patterns across sex and age indicate reduced cardiovascular adaptation and lower respiratory endurance in children with hearing impairments.

## Discussion

The purpose of this study was to compare motor and functional indicators between schoolchildren with hearing impairments and their typically developing peers. The results demonstrated reduced lung vital capacity, lower respiratory endurance in the Stange and Genchi tests, and higher Ruffier index values in the hearing-impaired group, indicating poorer cardiorespiratory adaptation. Height did not differ significantly between groups, although boys with hearing impairments showed higher body weight.

A comparative analysis with international research supports these findings. Children with hearing impairments are consistently reported to demonstrate lower levels of coordination, endurance, and speed–strength abilities than their peers [2, 36, 37]. Similar to our results, D'Anna et al. [37] described a decline in physical activity and motor development among youth in recent years, which corresponds to the lower motor test scores observed in this study. Singh et al. [2] and Zhou et al. [5] also confirmed that vestibular dysfunction and impaired balance are strongly associated with delayed motor milestones in children with hearing loss. Moreover, the strong relationship between auditory and motor systems, highlighted by Bernstein [36], may explain the observed limitations in motor development when auditory input is impaired. Comparable conclusions have been drawn in broader physical education contexts, where insufficient coordination and endurance were found to negatively affect respiratory and cardiovascular function [7, 28, 38, 39].

National studies further support these tendencies. Ukrainian researchers emphasize that reduced motor activity and coordination difficulties negatively influence functional health indicators in students with hearing impairments [17, 18, 40]. Other works have drawn attention to the terminological and methodological aspects of assessing motor qualities, highlighting the need for unified diagnostic criteria [19]. Studies in the field of adaptive and inclusive

physical education also underline the importance of technological and methodological innovations in promoting motor development among students with disabilities [20]. Furthermore, recent findings demonstrate the broader value of physical activity as a factor in supporting not only physical fitness but also academic performance and psycho-emotional well-being of Ukrainian students [21, 41]. Collectively, these results align with our data, confirming the need for early diagnostics and targeted interventions. At the same time, the literature indicates that these functional limitations are not solely biological but are also shaped by social and educational conditions, including reduced opportunities for active participation in physical education.

These national findings complement international evidence by demonstrating that functional and motor limitations in children with hearing impairments are consistently observed across diverse contexts. While global studies emphasize vestibular dysfunction, balance, and cardiorespiratory outcomes, Ukrainian research highlights pedagogical and educational dimensions, particularly the role of adapted teaching methods and activity promotion. Taken together, these perspectives reinforce the need for comprehensive assessment and form the basis for the novelty of the present study.

The novelty of this study lies in its integrated evaluation of motor and functional indicators in schoolchildren with hearing impairments at the early school age of 7–8 years. Unlike most international studies, which have focused primarily on vestibular dysfunction and balance [2, 3, 4], or national research, which has emphasized pedagogical and methodological aspects [17, 18, 19], the present work provides a comprehensive comparison with typically developing peers. Standardized functional tests (Ruffier, Stange, and Genchi), spirometry, and anthropometry were combined to assess both motor and cardiorespiratory performance. This multidimensional approach makes it possible to identify not only deficits in motor coordination and balance but also specific limitations of the cardiovascular and respiratory systems. The results extend current knowledge by demonstrating that functional impairments are evident at the onset of school education, thereby providing a timely rationale for the development of targeted adaptive physical education programs.

The reduced vital capacity and vital index found in this study suggest insufficient development of respiratory muscles and limited cardiorespiratory endurance. Lower Ruffier, Stange, and Genchi test results demonstrate decreased adaptability of the cardiovascular and respiratory systems to motor loads and hypoxic stress. These outcomes may be linked to reduced daily physical activity, impaired speech breathing, and limited practice of deep

breathing in communication. Similar associations between auditory deficits, vestibular dysfunction, and impaired postural or respiratory function have been described in international research [3, 8, 10]. Structural differences in motor control caused by auditory deficits may therefore explain not only slower motor reactions and poor balance but also the reduced hypoxic tolerance observed in this group.

The findings highlight the necessity of differentiated approaches in physical education for children with hearing impairments. Teachers should adapt lesson structures to provide clear instructions, integrate breathing and endurance exercises, and regularly monitor motor development using standardized tools. Evidence also suggests that targeted physical activity programs can improve functional outcomes in this population. For example, exercise interventions such as dance sports have been shown to enhance vestibular function and balance in children with sensorineural hearing loss [25], while research on cochlear implant users indicates measurable improvements in postural stability [26]. At the educational level, the integration of school-based screening and telehealth follow-up offers scalable approaches that can complement physical education monitoring [24]. Implementing adaptive physical education programs can therefore improve coordination, spatial orientation, and overall physical readiness. These recommendations are consistent with contemporary approaches to inclusive education and support both physical and social integration of students with hearing impairments [21, 42, 43].

The study demonstrated that schoolchildren with hearing impairments experience significant limitations in respiratory and cardiovascular adaptation, as well as in motor coordination and endurance, compared to their typically developing peers. These findings are consistent with both international and national evidence, reinforcing the understanding that motor and functional deficits in this group have multifactorial origins. The outcomes strengthen the evidence base for the importance of implementing adapted physical education programs in schools and highlight their role in supporting not only physical performance but also social integration of children with hearing impairments. At the same time, the present results provide a practical foundation for teachers and policymakers to design effective interventions and monitoring strategies, while also pointing to the need for continued research on long-term outcomes and innovative pedagogical approaches.

*Limitations*

This study has several limitations. First, the sample size was relatively small, which reduces the generalizability of the findings. Second, participants were recruited from specific educational institutions, limiting the applicability of the results to inclusive settings. Third, differences in the severity of hearing impairment and individual factors such as speech development and motivation could have influenced the outcomes. Fourth, the cross-sectional design of the study does not allow the tracking of long-term changes in motor or functional development. Fifth, while standardized tools such as the Ruffier, Stange, and Genchi tests are widely used, their interpretation in children with sensory impairments may have methodological constraints. Finally, although Student's t-test was applied, more advanced statistical methods (e.g., multivariate models) could provide deeper insights.

Future studies should address these limitations by expanding the sample to include students from different regions and educational settings (including inclusive schools) and by considering various levels of auditory impairment. It is also appropriate to investigate the long-term effects of motor development programs and their integration with other components, such as psycho-emotional support and speech therapy. A promising direction for further research is the study of individual trajectories of motor development and the use of digital technologies (virtual reality, interactive simulators) to enhance motor activity. Moreover, the relationship between motor development and social adaptation in schoolchildren with hearing impairments should be explored, as it may form the basis for comprehensive educational strategies.

## Recommendations

Based on the results of the study, the following recommendations are proposed for physical education teachers working with schoolchildren with hearing impairments:

1. Adaptation to the educational process. Lessons should be clearly structured to facilitate comprehension of instructions and to reduce anxiety. The use of visual aids and non-verbal cues may enhance understanding.
2. Individual approach. Prior assessment of motor fitness is recommended to avoid excessive workloads. Individual capabilities should be taken into account, and breathing exercises may be incorporated to compensate for the reduced vital capacity observed in this group.
3. Enhancing motor activity. Programs should include targeted breathing, coordination, balance, and spatial orientation exercises to address the functional limitations revealed in Ruffier, Stange, and Genchi tests.
4. Psychological and social support. A supportive classroom atmosphere should be maintained, with an emphasis on activities that promote peer interaction and social integration.
5. Systematic observation and control. Regular monitoring of motor activity is recommended,

including the use of standardized functional tests, with progress recorded in individual reports to guide load adjustment.

6. Use of modern technologies. Where feasible, digital tools such as interactive simulators, virtual reality, or mobile applications should be employed to enhance motivation and engagement.

7. Interdisciplinary cooperation. Collaboration with speech therapists, psychologists, and medical professionals is advisable in order to design comprehensive strategies that integrate physical, communicative, and psycho-emotional development.

These recommendations are relevant for teachers working with students with special educational needs, both in specialized institutions and in inclusive classrooms. They provide practical guidance for improving motor skills, facilitating adaptation to physical activity, and supporting broader educational and social integration of children with hearing impairments.

## Conclusions

A comparative analysis of physical and functional indicators in 7–8-year-old students with and without hearing impairments revealed consistent differences between groups. Children with hearing impairments showed lower lung vital capacity and vital index, suggesting insufficient development of respiratory muscles; higher Ruffier index values, indicating weaker cardiovascular adaptation to physical load; and poorer Stange and Genchi test results, reflecting reduced hypoxic resistance and respiratory endurance. These findings emphasize the need for individualized approaches in physical education, with training programs tailored to the functional characteristics of students with hearing impairments. The study provides a foundation for improving the effectiveness of adaptive physical education and for designing targeted measures to support motor and functional development in this population.

## Acknowledgment

## Conflict of Interest

The authors declare no conflict of interest.

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# Developing multiple intelligences, passing accuracy, and ball control skills through a differentiated learning strategy in female students

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**Abstract**

*Background and Study Aim*    In modern sports education, the development of both cognitive and motor skills is an important component of effective training. Multiple intelligences and futsal-specific abilities, such as passing accuracy and ball control, are key elements that support students' overall performance. Although differentiated learning strategies are applied in educational practice, their relative effectiveness in enhancing these domains remains a subject of practical interest. The aim of this study was to assess the effectiveness of a differentiated learning strategy in improving multiple intelligences and futsal-specific skills (passing accuracy and ball control) among female students.

*Material and Methods*    Forty students participated during the 2024–2025 academic year at Al-Qasim Green University, Iraq. Thirty students were randomly assigned to an experimental group (n = 15) and a control group (n = 15), while ten students took part in a pilot study. A structured 12-week training program (24 sessions, 90 minutes each, twice weekly) was designed based on differentiated instruction principles. Outcomes were assessed using the Multiple Intelligences Scale, the Ball Passing Accuracy Test, and the Ball Control Test.

*Results*    ANCOVA revealed significant group effects across all variables. The experimental group outperformed the control group in multiple intelligences (F = 112.788, p < 0.001, $\eta^2$ = 0.807), passing accuracy (F = 65.139, p < 0.001, $\eta^2$ = 0.707), and ball control (F = 105.828, p < 0.001, $\eta^2$ = 0.797). Estimated marginal means confirmed these findings, with higher post-test scores for the experimental group (MI = 147.8 vs. 142.7; PA = 11.5 vs. 9.5; BC = 6.2 vs. 4.6).

*Conclusions*    Differentiated learning strategies tailored to students' intelligence profiles proved highly effective in enhancing both cognitive (multiple intelligences) and motor (passing and ball control) domains. These findings highlight the pedagogical value of integrating adaptive instructional models into sports education curricula.

**Keywords**:    differentiated instruction, multiple intelligences, passing accuracy, ball control, sports science education

## Introduction

The integration of cognitive and motor development has become a central focus in contemporary approaches to physical education and sports training. In the context of team sports such as futsal, success depends not only on technical proficiency but also on the ability to process information, adapt to dynamic situations, and coordinate complex movements. Passing accuracy and ball control represent fundamental motor skills that determine both individual effectiveness and collective performance. At the same time, multiple intelligences provide a framework for understanding how diverse cognitive capacities influence learning, decision-making, and skill acquisition in sports education. Such an approach highlights the need to view sports training not only as physical practice but also as a process shaped by mental and social factors.

Within this context, the concept of multiple intelligences offers a valuable framework for linking cognitive development with motor skill acquisition. In recent years, sports education has increasingly emphasized holistic approaches that integrate cognitive, emotional, and physical development [1, 2, 3]. Central to this perspective is Gardner's theory of multiple intelligences, which expands the traditional concept of intelligence to include bodily-kinesthetic, interpersonal, intrapersonal, and visual-spatial domains [2, 4]. This framework is particularly relevant in sports science, where performance requires not only physical execution but also cognitive, social, and emotional engagement to achieve optimal outcomes [3, 5]. While numerous studies support the benefits of fostering multiple intelligences in education, conventional sports training programs often remain focused on physical abilities alone [4, 5, 6]. Such a narrow focus risks

neglecting individual learning preferences and cognitive strengths, potentially limiting both engagement and skill acquisition. In futsal, a technically demanding and fast-paced sport, skills such as passing and ball control require adaptive teaching methods that align with learners' cognitive profiles [7, 8, 9]. Mastery of these skills demands not only repetition but also individualized instructional approaches that cater to the diverse learning needs of students.

Building on this perspective, it becomes essential to consider how instructional methods can be adapted to align with the diverse profiles of learners. One approach that directly addresses this challenge is differentiated instruction.

Differentiated instruction has emerged as a promising pedagogical strategy to address diverse learner needs. Grounded in Gardner's theory, it adapts teaching methods and content according to students' dominant intelligences and learning styles [10, 11, 12]. For example, learners with strong bodily-kinesthetic intelligence benefit from hands-on demonstrations, while those with visual-spatial or interpersonal strengths respond better to video analysis or peer collaboration. This tailored approach enhances engagement, motivation, and skill acquisition. However, empirical evidence regarding its effectiveness in motor learning contexts remains mixed: some studies report positive effects on motivation and cognitive outcomes, whereas others note limited transfer to actual skill development [13, 14, 15]. Furthermore, female students, particularly those in their first year of higher education, are underrepresented in research on innovative instructional strategies [16].

Analysis of research findings has shown that differentiated instructional approaches can enhance both cognitive engagement and motor skill development in sports education. At the same time, the interplay between multiple intelligences and specific abilities illustrates the complexity of designing effective pedagogical models. Futsal, with its high cognitive-motor demands and technical complexity, represents a suitable context for examining how adaptive strategies may support skill development. These considerations underscore the necessity of exploring adaptive strategies within the field of sports education.

Therefore, the aim of this study is to examine the effectiveness of a differentiated learning strategy, grounded in the theory of multiple intelligences, on enhancing both cognitive (multiple intelligences) and motor (passing accuracy and ball control) outcomes among first-year female sports science students. It is hypothesized that students in the experimental group will demonstrate greater improvements in multiple intelligences (H1) and futsal passing and ball control skills (H2) compared to the control group, and that the combined impact across cognitive and motor domains will be stronger than with traditional teaching methods (H3)

## Materials and Methods

### Participants

The study included 40 first-year female students from the College of Physical Education and Sports Sciences, Al-Qasim Green University, Iraq, during the 2024–2025 academic year. Thirty students were randomly assigned to either the experimental group (n = 15) or the control group (n = 15). An additional ten students formed a pilot group to evaluate the instruments and refine intervention procedures.

Inclusion criteria required participants to: (1) be first-year students enrolled during the specified academic year; (2) be physically and mentally healthy, without chronic, neurological, or psychological conditions; (3) be able to fully participate in physical activities without medical restrictions; (4) maintain consistent attendance in both theoretical and practical sessions; and (5) provide written informed consent prior to participation.

Exclusion criteria ruled out students who: (1) had injuries or medical conditions preventing participation; (2) exhibited frequent absences; (3) participated in similar external training programs; (4) failed to comply with study procedures; or (5) voluntarily withdrew from the study.

All participants met the inclusion criteria and attended all sessions. No dropouts occurred during the 12-week intervention. The focus on first-year female students reflects the need to examine differentiated instruction at the early stages of higher education. All 30 participants were included in the final data analysis, ensuring the completeness and reliability of the results.

### Ethical Considerations

Written informed consent was obtained from all participants after the study objectives, procedures, and duration were thoroughly explained. Participation was voluntary, and students were free to withdraw at any time without academic or personal consequences. Confidentiality of all data was maintained, and information was used solely for research purposes. The Research Ethics Committee of the College of Physical Education and Sports Sciences, Al-Qasim Green University, approved the study (Administrative Order No. 1343, January 10, 2024).

### Research Design

A well-aligned research methodology is crucial for effectively addressing the research problem [16, 17]. An experimental design with two equivalent groups and pre- and post-tests was employed. Students were randomly assigned to the experimental or control group using a lottery system conducted by

an independent researcher who was not involved in data collection or instruction. This procedure ensured allocation concealment and minimized selection bias. Sealed opaque envelopes were used to preserve the randomness of group assignment. The experimental group received the differentiated instruction intervention, while the control group followed conventional futsal training methods. A pilot group (n = 10) was used to verify instrument reliability, session timing, group composition, and instructional materials. Adjustments were made prior to the main intervention.

*Instrumentation*

Three primary tools were used to measure the study variables: the Multiple Intelligences Scale [18], the Ball Passing Accuracy Test [19], and the Ball Control Test [20]. A summary of these instruments is provided in Table 1.

*Validity and Reliability*

1. *Content Validity.* The instruments' content validity was evaluated using expert panels and the Content Validity Ratio (CVR) based on the Lawshe method [21]. The Multiple Intelligences Scale and motor skills tests were selected for their methodological rigor and recommendations from previous intervention studies [2]. The Multiple Intelligences Scale had CVR values between 0.751 and 1.000. The Passing Accuracy Test achieved 1.000, and the Ball Control Test 0.857. All values exceeded the minimum acceptable CVR of 0.51, confirming high content validity.

2. *Reliability.* A pilot study with 10 female students assessed internal consistency and test–retest reliability. Cronbach's alpha for the Multiple Intelligences Scale was 0.92, indicating high internal consistency. Test–retest reliability for the Passing Accuracy and Ball Control Tests showed Pearson correlation coefficients of 0.89 and 0.90, respectively. All reliability results were statistically significant (p < 0.01).

3. *Cultural and Contextual Suitability.* The Multiple Intelligences Scale and skill-based tests (Ball Passing Accuracy Test and Ball Control Test) were evaluated for their appropriateness for first-year female students in Iraq. The items, instructions, and scoring procedures were reviewed by local experts in physical education and adapted where necessary to align with cultural norms, language comprehension, and sports experience of the participants. This followed recommendations for ensuring assessments are consistent with students' capabilities and experiences [4]. Pilot testing with 10 female students confirmed that the tasks were understandable, engaging, and representative of the targeted motor and cognitive skills. This process ensured valid and reliable assessment within the specific population.

*Procedures*

*Pre-Test.* Baseline measurements of multiple intelligences, passing accuracy, and ball control were collected for both groups using standardized protocols.

*Intervention.* A 12-week structured training program based on differentiated learning principles was implemented from December 1, 2024, to March 1, 2025. Sessions were held twice weekly (Mondays and Wednesdays), totaling 24 sessions of 90 minutes each. The program was designed to enhance futsal-specific motor skills while fostering educational outcomes aligned with multiple intelligences, particularly in the interpersonal, intrapersonal, and bodily-kinesthetic domains.

The intervention was explicitly guided by Vygotskian constructivist principles, emphasizing learner-centered pedagogy. Instructional strategies were intended to scaffold learning, promote active engagement, encourage collaboration and self-reflection, and provide flexible tasks tailored to individual differences in physical, cognitive, emotional, and social abilities. In this way, the program operationalized multiple intelligences in practice [12], as summarized in Tables 2 and 3.

*Post-Test.* The same instruments and procedures as in the pretest were applied to evaluate changes in multiple intelligences, passing accuracy, and ball control.

**Table 1.** Summary of the Study Tools

| Scale/Test | Purpose | Items/Attempts | Scoring Method | Notes |
|---|---|---|---|---|
| Multiple Intelligences Scale | Measure various types of intelligence | 43 items (5 domains) | 5-point Likert scale (1–5); total score 43–215 | Domains: physical (kinesthetic), emotional, intrapersonal, social, visual |
| Passing Accuracy Test | Assess accuracy in passing | 5 balls (one trial) | Small circle: 3 pts; Medium: 2 pts; Large: 1 pt; Outside: 0 pts (max 15, min 0) | Distance: 15 m; 3 concentric circles (1.5, 3, 4.5 m) |
| Ball Control Test | Measure accuracy in stopping the ball | 5 attempts | 2 pts for correct stop inside square (max 10, min 0) | Test area: 2 × 2 m; player reacts from 1 m behind coach's throw |

**Table 2.** Implementing a Differentiated Learning Strategy

| Type of Intelligence | Definition | Role of Differentiated Learning | Application in Futsal Skills |
|---|---|---|---|
| Physical (kinesthetic) | Use of the body to express, move, or solve problems | Content variation and physical activities adapted to different levels (simplification or complexity; movement games) | Using diverse physical drills, movement-based stations, and "learning by doing" activities |
| Emotional | Regulate emotions, self-motivate, overcome challenges | Creating a flexible and safe environment, offering options for different emotional states, and recognizing individual differences | Using engaging games to reduce stress, allowing downtime, and employing self-assessment to monitor progress |
| Intrapersonal (self) | Understanding self, strengths, limits, goals | Using self-assessment, providing opportunities for reflection, and offering choices aligned with personal preferences | Allowing students to select their preferred learning style, analyzing their own performance, and engaging in post-performance reflection |
| Social (interactive) | Effective interaction, leadership, teamwork | Adopting cooperative learning, grouping by skill level, and promoting communication and teamwork | Peer teaching, explaining skills to classmates, and working in small groups to practice and observe |
| Visual | Analyze visual and spatial information | Using videos, visual aids, diagrams, and imaginative role play | Visualizing passing angles and positioning, analyzing videos, and explaining skills through drawings or gestures |

**Table 3.** 12-Week Differentiated Learning Futsal Program

| Week | Session | Targeted Intelligence | Futsal Activity/Skill | Differentiated Learning Method |
|---|---|---|---|---|
| 1 | 1 | Physical/ Kinesthetic | Basic passing and ball control drills | Learning by doing, varied movement games, different difficulty levels |
| | 2 | Visual | Watching videos of passing and control techniques | Visual analysis, diagramming, skill demonstration |
| 2 | 1 | Emotional | Drills to improve focus and emotional control | Stress-reducing games, self-assessment of emotions during performance |
| | 2 | Social | Cooperative and team passing exercises | Cooperative learning, grouping by skill level, role rotation |
| 3 | 1 | Intrapersonal | Identifying strengths and weaknesses in passing and control | Self-performance analysis, evaluation, review |
| | 2 | Physical/ Kinesthetic | Tactical passing and control under pressure | Varied movement stations, progressive challenges |
| 4 | 1 | Visual | Planning passing angles and positioning | Mapping, movement visualization, instructional videos |
| | 2 | Emotional | Challenges for emotional control during competition | Relaxation strategies, stress-reducing games, confidence enhancement |
| 5 | 1 | Social | Group games to develop accurate passing and ball control | Group learning, cooperation, peer teaching |
| | 2 | Intrapersonal | Personal performance review and choosing drills | Self-assessment, activity selection based on personal interests |
| 6 | 1 | Physical/ Kinesthetic | Speed and ball response drills | Fast-paced movement exercises, multiple stations, tactical games |
| | 2 | Visual | Video analysis of correct techniques | Learning from video, comparing ideal vs. individual performance |
| 7 | 1 | Emotional | Pressure and competition challenges | Encouraging emotional control, boosting self-confidence |
| | 2 | Social | Group play with defined roles | Organizing teams, enhancing leadership and teamwork |

**Table 3.** (Continued)

| Week | Session | Targeted Intelligence | Futsal Activity/Skill | Differentiated Learning Method |
|------|---------|----------------------|----------------------|-------------------------------|
| 8 | 1 | Intrapersonal | Individual performance evaluation in passing/control | Self-performance analysis, goal setting for improvement |
| | 2 | Physical/ Kinesthetic | Advanced passing and control drills | Complex movement games, multi-level challenges |
| 9 | 1 | Visual | Designing game plans and passing strategies | Using diagrams, passing according to planned strategy |
| | 2 | Emotional | Developing patience and discipline during training | Emotional control drills, overcoming mistakes |
| 10 | 1 | Social | Group passing and tactical drills | Small group divisions, role rotation, peer teaching |
| | 2 | Intrapersonal | Analysis of strengths and weaknesses after 10 weeks | Self-assessment, progress review, improvement planning |
| 11 | 1 | Physical/ Kinesthetic | Simulated match to apply skills | Learning by doing, applying passing and control under pressure |
| | 2 | Visual | Video analysis of match | Performance evaluation, comparison to ideal standards |
| 12 | 1 | Emotional | Managing psychological pressure during competition | Realistic game situations, breathing techniques |
| | 2 | Social/ Intrapersonal | Final match with individual and group review | Cooperation, self-assessment, discussion of future improvements |

*Statistical Analysis*

The required statistical assumptions were tested prior to analysis. Normality of the dependent variables was examined using the Shapiro–Wilk test, and all distributions did not significantly deviate from normality ($p > 0.05$). Homogeneity of variances was assessed using Levene's test, which confirmed equality across groups ($p > 0.05$). Linearity between the covariates and dependent variables was verified through scatterplot inspection. The assumption of homogeneity of regression slopes was also met, with no significant interaction effects observed ($p > 0.05$).

Independent-samples t-tests were conducted to assess baseline equivalence between groups. Post-intervention differences were analyzed using ANCOVA, with pretest scores entered as covariates. All analyses were performed using SPSS version 28 (IBM Corp., Armonk, NY, USA) at a 95% confidence level ($\alpha = 0.05$).

## Results

Prior to the intervention, baseline measurements were collected to ensure equivalence between the experimental and control groups. Table 4 presents the pretest comparison of multiple intelligences, passing accuracy, and ball control.

As shown in Table 4, no significant differences were observed between the experimental and control groups for any variable at baseline ($p > 0.05$). The 95% confidence intervals included zero, confirming that the groups were equivalent prior to the intervention, as further illustrated in Figure 1.

Following the intervention, posttest measurements were collected to evaluate the effectiveness of the differentiated learning strategy. Table 5 presents the posttest comparison of multiple intelligences, passing accuracy, and ball control.

As shown in Table 5, the experimental group scored higher than the control group on all measured variables. Significant differences were observed in multiple intelligences (MD = 5.163, $p < 0.001$), passing accuracy (MD = 2.076, $p < 0.001$), and ball control (MD = 1.522, $p < 0.001$). The 95% confidence intervals for all differences did not include zero, confirming the reliability of these effects.

These results indicate that the differentiated learning strategy had a substantial positive impact on students' multiple intelligences, passing accuracy, and ball control. The findings support the effectiveness of individualized instruction in enhancing both cognitive and motor skills in the context of the study, as illustrated in Figure 2.

To assess the effect of the 12-week differentiated learning program while controlling for pretest scores, ANCOVA was conducted. Table 6 summarizes the results.

As shown in Table 6, the ANCOVA results indicate that the experimental group significantly outperformed the control group across all measured variables. This demonstrates the effectiveness of the differentiated learning strategy. In multiple intelligences (MI), the experimental group showed a substantial improvement compared to the control group (F = 112.788, $p < 0.001$, $\eta^2 = 0.807$), reflecting enhanced cognitive abilities among female students. In passing accuracy (PA), the experimental

**Table 4.** Pretest Comparison of Study Variables Between Groups

| Variable | Control Group (Mean ± SD) | Experimental Group (Mean ± SD) | t | p | 95% CI of Difference |
|---|---|---|---|---|---|
| Multiple Intelligences | 140.53 ± 3.93 | 141.20 ± 3.49 | 0.492 | 0.627 | −2.11 to 3.44 |
| Passing Accuracy | 8.99 ± 0.14 | 8.92 ± 0.09 | 0.031 | 0.975 | −0.088 to 0.086 |
| Ball Control | 4.14 ± 0.15 | 4.21 ± 0.23 | 0.945 | 0.353 | −0.078 to 0.211 |

**Table 5.** Posttest Comparison of Study Variables Between Groups

| Variable | Control Group (Mean ± SD) | Experimental Group (Mean ± SD) | MD | t | p | 95% CI of Difference |
|---|---|---|---|---|---|---|
| Multiple Intelligences | 142.68 ± 1.63 | 147.84 ± 1.57 | 5.163 | 9.075 | <0.001 | 4.145 to 6.182 |
| Passing Accuracy | 9.45 ± 0.77 | 11.53 ± 0.70 | 2.076 | 7.679 | <0.001 | 1.540 to 2.612 |
| Ball Control | 4.64 ± 0.42 | 6.16 ± 0.38 | 1.522 | 10.676 | <0.001 | 1.215 to 1.828 |
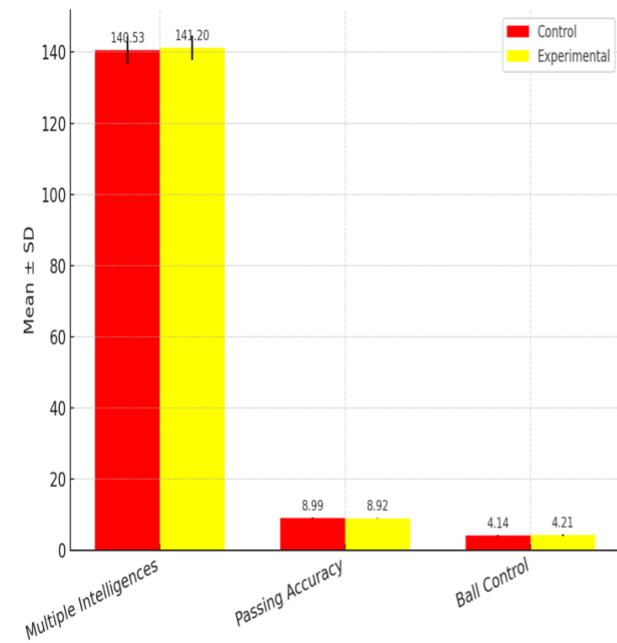


**Figure 1.** Bar chart of pretest comparisons between experimental and control groups.
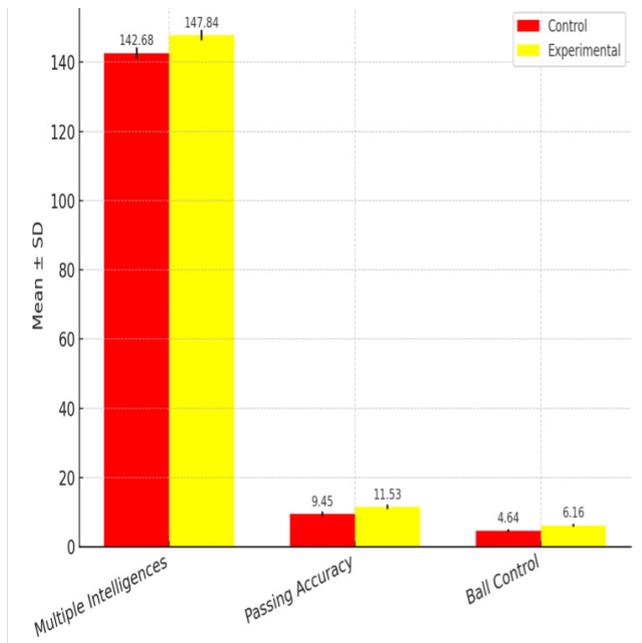


**Figure 2.** Bar chart of posttest comparisons between experimental and control groups.

**Table 6.** ANCOVA Results for Differentiated Learning Strategy Effects

| Variable | Source | df | F | p | Partial Eta Squared |
|---|---|---|---|---|---|
| Multiple Intelligences (MI) | Pre_MI | 1 | 14.266 | 0.002 | 0.346 |
| | Group | 1 | 112.788 | <0.001 | 0.807 |
| | Corrected Model | 2 | 67.819 | <0.001 | 0.834 |
| | Group × Pre_MI | 1 | 0.003 | 0.953 | 0.000 |
| Passing Accuracy (PA) | Pre_PA | 1 | 3.844 | 0.060 | 0.125 |
| | Group | 1 | 65.139 | <0.001 | 0.707 |
| | Corrected Model | 2 | 34.399 | <0.001 | 0.718 |
| | Group × Pre_PA | 1 | 0.302 | 0.587 | 0.011 |
| Ball Control (BC) | Pre_BC | 1 | 0.430 | 0.517 | 0.016 |
| | Group | 1 | 105.828 | <0.001 | 0.797 |
| | Corrected Model | 2 | 56.048 | <0.001 | 0.806 |
| | Group × Pre_BC | 1 | 1.291 | 0.266 | 0.047 |

group achieved higher scores (F = 65.139, p < 0.001, $\eta^2$ = 0.707), indicating meaningful gains in motor performance. In ball control (BC), the experimental group also performed better (F = 105.828, p < 0.001, $\eta^2$ = 0.797), demonstrating improvements in coordination and control.

Although some pretest scores (Pre_MI, Pre_PA, Pre_BC) contributed to posttest variance, interactions with group were non-significant. This finding shows that the benefits of the intervention were consistent across initial skill levels. Overall, the corrected models explained between 71% and 83% of variance across variables. These results confirm both the robustness and the educational relevance of the differentiated learning strategy.

## Discussion

The aim of this study was to examine the effectiveness of a differentiated learning strategy, grounded in the theory of multiple intelligences, on enhancing both cognitive and motor outcomes among female sports science students. The results demonstrated that the intervention produced substantial positive effects, with effect sizes exceeding the conventional threshold of 0.8. ANCOVA confirmed significant improvements in all measured variables even after adjusting for pretest scores.

The improvement in multiple intelligences (MI) can be interpreted through Self-Determination Theory (SDT). The intervention fostered autonomy, competence, and relatedness, which enhanced intrinsic motivation and encouraged students to engage deeply with cognitive tasks [5]. This motivational climate likely contributed to the development of individual cognitive profiles, as reflected in the higher MI scores [8, 22].

Gains in ball control and passing accuracy can be explained using Motor Learning Theory and the principles of differential learning. Variable practice conditions encouraged adaptive problem-solving, reinforced motor representations, and enhanced skill transfer [3, 6]. These improvements also align with Vygotsky's Zone of Proximal Development (ZPD). Scaffolded and individualized feedback enabled learners to exceed their baseline competencies, supporting both technical execution and skill progression [12, 23].

These findings are consistent with prior research. Targeted interventions have been shown to enhance multiple intelligences, supporting the MI improvements observed in this study [2, 24]. Personalized learning structures also increase cognitive engagement, which mirrors the present results [12]. For motor performance, adaptive decision-making training in futsal improved technical execution [15, 25]. Enriched practice conditions have additionally been shown to support talent development [23, 26]. Further evidence

suggests that structured and adaptive physical education programs contribute to sustainable student engagement and the development of both cognitive and motor skills [1].

Integrating differentiated learning into physical education curricula can create inclusive environments that support both cognitive and motor development. Teacher involvement in curriculum adaptation improves learning outcomes [10]. Adaptive, technology-assisted systems further enhance engagement and achievement [7]. These results highlight the importance of curriculum redesign that incorporates adaptive methods, ongoing assessment, and individualized feedback.

To implement such strategies effectively, curriculum developers and PE instructors should design skill units with varied difficulty levels and align activities with multiple intelligences, such as bodily-kinesthetic, interpersonal, and intrapersonal. Flexible task options tailored to individual abilities should also be provided. Adaptive assessment methods, including self-assessment, peer feedback, and instructor evaluation, are recommended to guide learning. Scaffolded and individualized feedback promotes active engagement, problem-solving, and reflection. This approach ensures that all students benefit from a structured and inclusive learning environment while maximizing both cognitive and motor outcomes.

### Limitations

While this study provides valuable insights, several methodological limitations must be acknowledged. The small, homogeneous sample of 40 female students from a single institution limits generalizability to other populations, such as male students, athletes from different sports, or learners from diverse educational and cultural backgrounds, as noted in prior work on population variability [2, 3]. The lack of blinding and reliance on self-reported MI measures may have introduced reporting bias, an issue highlighted in studies addressing self-assessment in education [5, 16]. Long-term follow-up assessments were not conducted, which restricts evaluation of the durability of improvements in MI and motor skills, a limitation also reported in earlier intervention studies [11, 15]. Potential confounding factors, including prior futsal experience, intrinsic motivation, and individual learning preferences, were not fully controlled, though these have been shown to influence learning outcomes [4, 14]. Finally, the absence of qualitative data, such as student reflections, teacher observations, or interviews, constrains understanding of the mechanisms driving the success of differentiated learning strategies, as suggested in research emphasizing mixed-methods approaches [7, 13].

### Future Research

To build upon these findings, future studies should

conduct longitudinal follow-ups comparing male and female students using the same differentiated learning framework to examine whether gender influences responsiveness to individualized instruction, as proposed in gender-focused research on pedagogy [3, 23]. Studies that combine quantitative assessments with qualitative data, such as reflections and observations, could provide insight into the psychological and instructional mechanisms through which differentiated learning enhances multiple intelligences and motor skills, as recommended in recent educational research [4, 7]. Additionally, incorporating objective assessments of cognitive abilities and motor skills, along with blinded evaluators, would reduce measurement bias and improve internal validity. This approach is consistent with best practices for strengthening evidence in intervention studies [16, 26].

## Conclusions

The findings of this study indicate that differentiated learning strategies can effectively enhance both cognitive and motor outcomes among first-year female sports science students. The experimental group showed significant improvements in multiple intelligences, supporting H1, as well as in futsal passing and ball control skills, confirming H2. The combined effect on cognitive and motor domains was greater in the experimental group than in the control group, consistent with H3. These results demonstrate the integrated benefits of adaptive, student-centered instruction.

Implementing differentiated learning in physical education may support intellectual development and motor skill acquisition while providing a structured and inclusive learning environment. The findings also offer practical guidance for curriculum development. Incorporating adaptive and individualized strategies can strengthen both cognitive and motor learning outcomes in physical education and sports training programs.

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# Development of a game-based physical training model to improve motivation and smashing ability in volleyball athletes aged 15-18 years

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## Abstract

| | |
|---|---|
| *Background and Study Aim* | Game-based training has become an important approach in modern volleyball, as it combines physical development with engaging and sport-specific activities. These models are widely used to enhance coordination, technical execution, and motivation among young players. Although different game-based strategies are applied in practice, their relative effectiveness in improving motivation and smashing ability among volleyball athletes aged 15–18 years remains a matter of practical interest. The aim of this study was to develop a structured and scientifically validated game-based physical training model specifically designed for volleyball athletes aged 15–18 years, with a focus on motivation and smashing ability. |
| *Material and Methods* | This study is Research and Development (R&D) using the ADDIE model. The sample consisted of 60 students aged 15–18 years (30 male and 30 female) from senior high schools in Indragiri Hilir Regency, Riau Province, Indonesia. They were students who participated in volleyball extracurricular activities at their schools. Motivation was measured using an instrument adapted and modified from previous research, while smashing ability was assessed using the Spike Accuracy Test. Data analysis involved product validation and effectiveness testing over an 8-week period (24 sessions) using the Game-Based Physical Training Model. Results were analyzed with t-tests ($p < 0.05$). |
| *Results* | This study developed and validated a Game-Based Physical Training Model consisting of four training objectives: improving coordination and motivation (weeks 1–2), improving smashing technique and accuracy (weeks 3–4), increasing intensity and strength (weeks 5–6), and conducting match simulations and evaluations (weeks 7–8). The validation results indicated several aspects: suitability of the training model for improving motivation and smashing ability in volleyball players aged 15–18 years, practicality, safety, and feasibility of implementation, with Aiken's V validity > 0.7. The effectiveness test through pretest–posttest showed $p = 0.000 < 0.05$ for both motivation and smashing ability variables. |
| *Conclusions* | This study produced a Game-Based Physical Training Model to improve motivation and smashing ability in 15–18-year-old volleyball athletes. In practice, this model provides a structured and adaptable program framework that can be used by coaches with adjustments tailored to athletes' profiles, playing positions, and available facilities and equipment. Future studies are expected to include the design of developmental research using a pre-experimental design with elements such as a control group, advanced objective measurements, and detailed statistical reporting. |
| **Keywords**: | volleyball, game-based training, youth athletes, motivation, smashing ability |

## Introduction

Volleyball is a dynamic team sport that requires a combination of physical fitness, technical skills, and tactical awareness. Among the different components of performance, motivation influences athletes' commitment to training, while the smashing technique is one of the central skills contributing to competitive success. The development of these aspects has specific relevance during adolescence, as athletes aged 15–18 years are in a phase of physical growth, skill acquisition, and psychological adaptation. In this context, designing training approaches that integrate physical preparation with game-like situations is a complex and necessary process for supporting both performance outcomes and long-term athletic development.

Motivation plays a crucial role in volleyball. Without strong motivation, an athlete will find it difficult to maintain commitment to an intense training schedule, face challenges during matches, or bounce back from defeat [1]. High motivation serves as the primary foundation for a champion mindset developing in the competitive environment of volleyball [2]. Therefore, maintaining and enhancing athletes' motivation is the key to achieving peak performance and sustaining a successful career as a

volleyball athlete [3].

Strong motivation tends to lead to greater discipline in adhering to a regular physical training program [4], which in turn improves performance. This improvement in performance, among other things, significantly enhances smash ability in volleyball. The smash is one of the fundamental attacking techniques that requires a combination of muscle strength, precise coordination, and reaction speed [5]. Athletes with high motivation are more likely to attempt varied smash techniques, be more persistent in correcting mistakes, and more self-confident in executing smashes during matches [6]. This directly contributes to the effectiveness of team attacks and the likelihood of scoring points [7].

Motivation and smash ability are crucial to develop at a young age, particularly between 15 and 18 years [8, 9]. During this age range, athletes undergo an important stage of talent development [10]. Additionally, the rapid physical growth and motor development during this period [11] make it an optimal time to intensify physical training and technical skill development. At the same time, athletes require consistent motivational support to continue progressing [12]. Enhancing motivation and smash ability provides them with a solid foundation for transitioning to higher levels of competition and prepares them to become accomplished senior athletes [13].

Improving motivation and smash ability in volleyball athletes aged 15–18 years requires an innovative and relevant training approach tailored to their developmental characteristics. One promising approach is the use of a game-based physical training model [14]. Game-based physical training has been shown to enhance aerobic capacity and change of direction in basketball [15]. In handball, the combination of match simulation training with games influences sprint performance and jumping ability [16]. Furthermore, physical training using the game model, combined with small-sided games and technical drills, can enhance passing skills in volleyball [17, 18]. Research in volleyball indicates that the Game-Based Training Group method is more effective in improving performance in male athletes compared to the Traditional Training Group method [19]. Therefore, based on previous research findings, game-based methods have been shown to enhance athletic performance.

Analysis of research findings has shown that game-based training contributes to the improvement of physical, technical, and motivational components across different sports. Researchers emphasize that for volleyball athletes, motivation and smashing ability are central elements that influence both individual performance and team success. At the same time, the complexity of adolescence as a developmental stage highlights the importance of training approaches that are adaptable, engaging,

and effective for athletes aged 15–18 years. This ongoing challenge continues to limit the full integration of structured game-based physical training models specifically tailored to volleyball.

However, to date, there has been no structured and scientifically tested physical training model specifically designed for volleyball athletes aged 15–18 years with a focus on motivation and smash ability. Furthermore, many existing training programs tend to be general in nature and do not explicitly integrate game elements for the simultaneous development of motivation and smash ability. Therefore, this study aims to develop a game-based physical training model that is expected to provide a concrete solution for enhancing motivation and smash ability in volleyball athletes aged 15–18 years. With this model, it is expected that coaches will have a systematic and innovative guide to optimize the potential of young athletes.

## Materials and Methods

### Participants

The population in this study consisted of all students from senior high schools in Indragiri Hilir Regency, Riau Province, Indonesia. The sample was selected using total sampling based on the extracurricular volleyball program at the schools, resulting in a sample size of 60 students (30 male and 30 female). The characteristics of the male participants were as follows: age 15–18 years, mean ± SD = 16.5 ± 0.6 years, height 169.1 ± 1.7 cm, weight 63.6 ± 2.2 kg, and training experience 2.8 ± 0.7 years. The characteristics of the female participants were: age 15–18 years, mean ± SD = 16.1 ± 0.5 years, height 167.0 ± 1.5 cm, weight 54.2 ± 1.2 kg, and training experience 2.5 ± 0.5 years. Additional inclusion criteria required participants to be free from illness or injury. Participants were also required to have engaged in regular volleyball training (minimum twice per week) over the past six months, and be physically cleared for high-intensity activity by a school physician. Students with chronic illness, orthopedic limitations, or whose legal guardians did not provide consent were excluded.

This study obtained a research permit from the university (B/1067/UN34.16/PT.01.03/2025) and ethical approval. The study was approved by the Research Ethics Committee of Yogyakarta State University and conducted in accordance with the Declaration of Helsinki. Approval was also obtained from the school principals and physical education teachers. Prior to participation, written informed consent was obtained from the parents or legal guardians of all student participants. To ensure proper implementation and monitoring, the research was conducted at the volleyball court of Indragiri University.

*Research Design*

This study employed a development research design oriented toward the creation, testing, and refinement of a specific product or model aimed at achieving defined objectives. The development process adopted the ADDIE (Analysis, Design, Development, Implementation, and Evaluation) model. The advantages of using ADDIE include providing a systematic and comprehensive framework from needs analysis to final evaluation, ensuring that each stage of development is carefully planned [20, 21, 22].

The first stage is analysis, which aims to identify problems based on a literature review, training needs, target characteristics, available resources, and expected constraints. The second stage is design, which aims to develop a detailed plan for the product or model to be produced. The third stage is development, which aims to transform the design into a tangible product or model that is ready for testing. The fourth stage is implementation, which aims to apply the developed model or product on a larger scale or in real-world conditions to collect data on its effectiveness and practicality. The fifth stage is evaluation, which aims to assess the effectiveness, efficiency, and appeal of the developed product or model, as well as to identify areas for further improvement. This stage takes place not only at the end but is also integrated into each stage (formative evaluation) and at the conclusion of the process (summative evaluation).

The study followed a single-group pretest–posttest design without a control group. While this design limits causal inferences, it allows for initial validation and pilot-level assessment of the training model's effectiveness. To strengthen internal validity, consistent intervention delivery, participant supervision, and environmental conditions were maintained throughout the 8-week period.

Each phase of the ADDIE model was operationalized in alignment with sport pedagogy: the analysis stage incorporated field interviews with coaches and athletes; the design phase involved structuring a week-by-week training schedule with specific physical and technical objectives; the development phase produced visual training diagrams and activity protocols; implementation included 24 guided sessions supervised by certified trainers; and evaluation utilized both expert validation and statistical testing of outcome variables.

Although the core procedures were described narratively, a schematic representation of the 8-week intervention schedule was also developed to ensure clarity, standardization, and replicability of the training structure.

The instruments used in this study for the motivation variable were adapted and modified based on the results of previous studies [23, 24, 25], which have been shown to be effective for measuring athletes from junior to senior levels and across different sports. The motivation variable consisted of six factors: (1) Approach-Success, (2) Avoidance-Failure, (3) Approach-Success in Competition, (4) Approach-Success in Training, (5) Avoidance-Failure in Competition, and (6) Avoidance-Failure in Training. The instrument for measuring smash ability was adapted and modified from the Spike Accuracy Test. The main strength of this test is its ability to assess an athlete's accuracy in directing a smash to specified target areas [26, 27, 28, 29]. The procedure involves placing targets in different areas of the opponent's court (e.g., corners, open zones) and counting the number of successful smashes that land within the target from a predetermined number of attempts.

*Statistical Analysis*

The first stage of this research analysis was the validity test of the game-based physical training product, using the Aiken's V validity test. This validity test was evaluated by experts, including lecturers with volleyball coaching experience and a minimum doctoral qualification, as well as coaches with at least a national license. The expert panel consisted of nine individuals: three doctoral-level university lecturers specializing in volleyball coaching, three national-level coaches with A licenses, and three with B licenses. All experts independently assessed the draft training model using a structured Likert-scale questionnaire.

The second stage of this research analysis was the effectiveness test. The effectiveness test in this study used a paired t-test by comparing pretest and posttest scores ($p < 0.05$). This test was selected to evaluate within-subject changes in motivation and smash ability following the intervention. Prior to conducting the t-test, assumptions of normality (Shapiro-Wilk test) and homogeneity of variance (Levene's test) were verified. The use of a paired t-test is appropriate given the single-group pre–post design; however, the absence of a control group limits the generalizability of findings. No covariates were included in the model.

Sample size justification was based on previous literature indicating moderate to large effect sizes for similar game-based training interventions. Although no formal power analysis was performed, a sample of 60 participants is generally sufficient to detect moderate effects with adequate statistical power ($\geq 0.80$) in within-subject designs.

The formula for Aiken's V is:

$$V = \frac{\sum s}{n(c-1)}$$

where: $s = r - l0$; $r$ = rating given by an expert; $l0$ = lowest score on the rating scale; $n$ = number of experts; $c$ = number of categories on the rating scale.

## Results

The first stage in this analysis involved reviewing scientific literature from previous studies, as well as conducting interviews with coaches and athletes to formulate the research problem. The objectives of this stage were: (1) to identify problems based on field observations, (2) to determine whether these problems could be addressed through previous research findings, (3) to provide solutions by developing the product using scientific procedures, (4) to produce an original product accompanied by publication in a Scopus-indexed journal, and (5) to avoid plagiarism in all aspects, including the product, training program, research variables, and research samples.

The results of the analysis phase included: (1) identifying why motivation and smash skills need to be improved and why a game-based training model is relevant, (2) understanding the characteristics of 15–18-year-old volleyball players, including their initial knowledge, training style, motivation, and physical and psychological abilities, (3) determining the skills or content that need to be taught or developed, and (4) identifying available resources (facilities, equipment, coaches) as well as research limitations.

The second stage, Design, produced the following outcomes: (1) determining the type of physical training, (2) determining the type of games, (3) selecting the tools and materials to be used in the product, (4) designing the flow and components of the training model, including the sequence of activities, duration, and methods of assessment, and (5) determining how the success of the model would be measured, including pretest and posttest instruments, questionnaires, and evaluations.

The third stage, Development, aimed to produce an initial draft of a game-based physical training product. This draft was based on Table 1 and contained information about the training period in weeks, training objectives, game names, activity descriptions, physical focus, and corresponding movement illustrations.

**Table 1.** Game-based physical training model for improving motivation and smash ability in volleyball athletes aged 15–18 years

| Week | Training Objectives | Game Name | Activity Description | Physical Focus | Movement Diagram |
|---|---|---|---|---|---|
| 1–2 | Improving coordination and motivation | Volley Target Hunt | Students are divided into groups and perform smashes to hit targets in different zones of the court. | Coordination, interest, smash technique |  |
| | | Jump and Catch | Vertical jumps to catch a balloon or ball suspended in the air. | Vertical jump, explosiveness |  |
| 3–4 | Improving smash technique and accuracy | Smash Zone Challenge | Players perform smashes into the opponent's court according to designated value zones. | Smash technique, accuracy, competitive motivation |  |
| | | Jump Volley Race | Team competition: vertical jump followed by passing the ball to the net after landing. | Jumping, leg muscle stability |  |
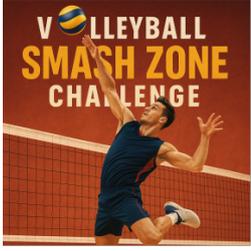
**Table 1.** (Continued)

| Week | Training Objectives | Game Name | Activity Description | Physical Focus | Movement Diagram |
|------|---------------------|-----------|---------------------|----------------|------------------|
| 5 | Increasing intensity and strength | Obstacle Smash Game | Smashes performed after overcoming light obstacles (zig-zag running, small hurdles). | Power, concentration, muscle endurance |  |
| | | Explosive Square Drill | Four-point jump combined with receiving and hitting the ball from different directions. | Vertical jump, explosiveness |  |
| 7–8 | Game simulation and evaluation | Mini Volleyball Game | 3 vs. 3 or 4 vs. 4 with modified rules, requiring attacks to be completed with a smash. | Application of techniques, motivation |  |
| | | Smash Point Rally | Points awarded only if the smash hits the target in the high-value zone. | Accuracy, power, endurance |  |

The results of the draft, as shown in Table 1, indicate that the game-based physical training program spans 8 weeks and is divided into four training objectives, each lasting 2 weeks. This draft then underwent product validation by experts, consisting of three doctoral-level lecturers with expertise in volleyball coaching, three volleyball coaches with A licenses, and three volleyball coaches with B licenses.

The results of this product validation are presented in Table 2, which contains a questionnaire covering four aspects: items 1–5 assess the suitability of the training model for improving motivation and smashing ability in volleyball players aged 15–18 years; items 6–9 assess practicality; items 10–12 assess safety; and items 13–15 assess ease of implementation.

Based on the results of Table 2, the validation results show that all statement items have a validity value > 0.7, so this development product is considered valid because each item is greater than 0.6 [30, 31]. After the product development was deemed valid, the next step was to implement the product through an effectiveness test via an experiment. Therefore,

a pretest and posttest were required to assess the effectiveness of this product.

In the fourth stage, Implementation, data related to the athletes' motivation and smash ability before and after the implementation of the model were collected, as well as feedback from athletes and coaches regarding the practicality and effectiveness of the model. Volleyball players aged 15–18 then applied the model for 24 sessions. The evaluation of this model used a paired t-test. However, prior to this, normality and homogeneity tests were required. The results of the normality test are presented in Table 3.

Based on the results in Table 3, the residual-based normality test showed significance values for the motivation and smash ability variables greater than 0.05 ($p > 0.05$). These results indicate that the residuals did not deviate from normality. After confirming normality, we proceeded to a homogeneity test. The homogeneity test results are presented in Table 4.

Based on the results in Table 4, the research data for both the motivation variable and the smash ability variable showed significance values greater than 0.05 ($p > 0.05$), indicating that the sample

**Table 2.** Expert Validation Results [n(c−1) = 3]

| No. | Statement Item | ΣS | Aiken V | Description |
|---|---|---|---|---|
| 1 | The training model developed is in accordance with the principles of physical training in volleyball. | 27 | 0.750 | Valid |
| 2 | The game-based training model developed is relevant for improving the motivation of extracurricular participants. | 28 | 0.778 | Valid |
| 3 | The training model developed is effective in improving participants' smash skills. | 26 | 0.722 | Valid |
| 4 | The training model developed is effective in improving participants' jump height. | 28 | 0.778 | Valid |
| 5 | The developed training model introduces an innovative approach to volleyball coaching in schools. | 27 | 0.750 | Valid |
| 6 | The training model developed is easy to understand by coaches and participants. | 28 | 0.778 | Valid |
| 7 | The training model developed can be implemented with equipment available at schools. | 28 | 0.778 | Valid |
| 8 | The duration of the training is consistent with the school's extracurricular schedule. | 28 | 0.778 | Valid |
| 9 | The training model developed can be applied by coaches without the need for additional complex training. | 27 | 0.750 | Valid |
| 10 | The training model developed is safe for participants in extracurricular activities. | 28 | 0.778 | Valid |
| 11 | The risk of injury in this training model has been minimized effectively. | 27 | 0.750 | Valid |
| 12 | This model complies with safety standards for physical training and volleyball. | 28 | 0.778 | Valid |
| 13 | This training model can be implemented by schools with existing resources. | 27 | 0.750 | Valid |
| 14 | This training model can be applied by participants with different levels of ability. | 28 | 0.778 | Valid |
| 15 | This training model can be combined with other training methods without difficulty. | 27 | 0.750 | Valid |

**Table 3.** Results of the normality test for pretest–posttest data

| Variable | Kolmogorov–Smirnov | | | Shapiro–Wilk | | |
|---|---|---|---|---|---|---|
| | Statistic | df | Sig. | Statistic | df | Sig. |
| Unstandardized Residual – Motivation | 0.079 | 60 | .200* | 0.969 | 60 | 0.126 |
| Unstandardized Residual – Smash Ability | 0.111 | 60 | 0.072 | 0.970 | 60 | 0.142 |

**Table 4.** Results of the homogeneity test of the data

| Variable | Test Type | Levene Statistic | df1 | df2 | Sig. |
|---|---|---|---|---|---|
| Motivation | Based on Mean | 0.120 | 1 | 118 | 0.727 |
| | Based on Median | 0.118 | 1 | 118 | 0.732 |
| Smash Ability | Based on Mean | 0.650 | 1 | 118 | 0.420 |
| | Based on Median | 0.693 | 1 | 118 | 0.407 |

data came from a similar population group. After the research data were found to be normal and homogeneous, the paired t-test could be conducted. The paired t-test was used to analyze the differences before and after the volleyball players completed the game-based physical training program that had been developed.

Based on the results in Table 5, the implementation of the developed game-based physical training product showed a significant effect on the motivation variable (p = 0.000, two-tailed) and on the smash ability variable (p = 0.000, two-tailed). Therefore, this product demonstrated a high level of effectiveness when tested on volleyball players aged 15–18 years.

The fifth stage, Evaluation, consisted of both formative and summative evaluations. The formative evaluation was carried out throughout the

**Table 5.** Results of the pretest–posttest effectiveness test

| Variable | Mean | Std. Dev | Std. Error Mean | t | df | Sig. (two-tailed) |
|---|---|---|---|---|---|---|
| Pretest Motivation – Posttest Motivation | -14.850 | 3.901 | 0.504 | -29.490 | 59 | 0.000 |
| Pretest Smash Ability – Posttest Smash Ability | -13.317 | 3.587 | 0.463 | -28.759 | 59 | 0.000 |

research and development process (after analysis, design, and development) to ensure that each phase was conducted according to plan and that the products produced met expectations. No evaluation was conducted after the analysis stage, as this stage was implemented through a focus group discussion (FGD). In the design stage, the results indicated that the quality of the images needed improvement. In the development stage, the results were reviewed during expert validation testing, which highlighted that the objectives of the training and the focus areas required more detailed explanation.

The summative evaluation was conducted after the implementation stage through effectiveness testing, involving statistical analysis and interpretation of findings. The results of this summative evaluation showed no revisions or product suggestions from the users who tested the product. Nevertheless, the researchers will continue to review the product, even though it has been successfully developed and published. The goal is for this product to serve as a scientific foundation for future development, particularly in relation to training programs and expanded variables.

## Discussion

The aim of this study was to develop a game-based physical training model designed to improve motivation and smash ability in volleyball athletes aged 15–18 years. The results demonstrated that the model met the criteria of validity, practicality, safety, and ease of implementation, as confirmed through expert validation. Furthermore, the effectiveness test showed significant improvements in both motivation and smash ability after athletes completed the 8-week training program.

Development of the eight-week game-based physical training model is consistent with evidence that game-based approaches effectively enhance technical learning and athlete engagement. Previous research indicates that varying basic volleyball techniques through a game-based approach makes learning more engaging and contextual, particularly for the smash as one of the core techniques [32]. Pedagogically, these findings are in line with the Teaching Games for Understanding (TGfU) framework, especially in relation to the overhead pass technique, which has been validated through expert-reviewed game-based training models and recognized as suitable for practical application [17].

Taken together, this supports the present study's training product, which emphasizes games as a medium to facilitate the transfer of smash skills into real-game situations.

The step-by-step structure of the development program—coordination and motivation in weeks 1–2, technique and accuracy in weeks 3–4, intensity and strength in weeks 5–6, and match simulations in weeks 7–8—aligns with the principles of periodization and progressive overload. A similar "combined impact" approach applied in the preparation macrocycle has been shown to significantly improve specific readiness and the quality of game techniques, particularly when training tasks replicate the spatio-temporal and dynamic characteristics of core skills [33]. With regard to physical abilities supporting the smash, a 6-week program emphasizing speed and agility drills for junior players demonstrated significant improvements in motor skill indicators [34]. This finding corresponds to weeks 5–6 of the present model, which combine increases in intensity and strength with coordinative demands. Overall, the layered design implemented here is grounded in both periodization theory and empirical evidence from studies on adolescent athletes.

The effectiveness of the model yielded statistically significant improvements in motivation and smash ability, consistent with the literature on the development of smash training devices and media. Subagio et al. successfully developed a smash training model using rubber tires, which was found to be valid and accepted in a pilot test [35]. In a subsequent study, the same authors reported that a smash training aid demonstrated high feasibility in expert testing and effectiveness in both small and large group trials [36]. These findings confirm that specific, validated, and engaging training devices or designs directly contribute to improvements in smash performance. In the context of the present study, the integration of game elements functions as a pedagogical tool that simulates pressure, timing, and real-time decision-making, ensuring that performance gains result not only from physical training but also from the alignment of training conditions with the demands of the game.

From a motivational perspective, game-based approaches are underpinned by psychological mechanisms aligned with Self-Determination Theory (SDT). Research on elite young volleyball

athletes applying SDT has shown that task orientation significantly predicts relative autonomy, while ego orientation does not [37]. Game-based practices that provide clear goals, rapid feedback, and opportunities for strategic exploration foster competence, autonomy, and connectedness, thereby enhancing motivation in volleyball players aged 15–18 years within the developed product. Evidence from younger age groups also supports these findings: for example, game-based methods for athletes aged 10–12 years effectively improved speed skills and increased training motivation [38], while mobile-based learning media for volleyball content received "very good" validation and positive responses from students [39]. Collectively, these studies reinforce the role of innovation and enjoyable learning experiences in sustaining athlete engagement, as reflected during weeks 1–2 of the present development program.

The key physical components determining the quality of smashes, speed, agility, and leg power, are also emphasized in previous literature. Studies on junior players highlight the need for a high level of both general and specific motor skills [40], and cross-country comparisons reveal room for improvement in agility and leg power in some populations. Therefore, the focus on intensity, strength, and accuracy in phases 3–6 of this development model is performance-relevant. By incorporating game constraints such as target zones, touch rules, and scoring, the program directs athletes' attention to external cues, enriches variations in smash execution, and reduces anxiety during technique application. Findings from Boichuk et al. further support these results, showing that training tools and formats resembling core technical characteristics improve intermuscular coordination and enhance the transfer of skills to match-like situations [33], which corresponds to weeks 7–8 of the present development program.

Overall, the developed game-based physical training model has substantial theoretical and empirical support. This is evidenced by valid results regarding both the content of the game model and its implementation, which effectively enhanced motivation and smash ability, while also aligning with the literature on applied periodization and the development of performance-related physical capacities. With further refinement of evaluation tools and impact reporting, this model appears suitable for wider adoption in the training of volleyball players aged 15–18 years.

*Limitations*

This study has several limitations. First, the research design did not employ the strongest experimental framework, which requires caution when making causal inferences. Second, the measurement instruments may not fully capture objective and comprehensive outcomes. Third, the program lacked personalization based on playing position, gender, and maturation status, and there was insufficient systematic monitoring of workload and safety. Therefore, future studies are encouraged to use developmental research designs that incorporate experimental elements, such as control groups, advanced objective measurement tools, and detailed statistical reporting, to generate more reliable evidence.

## Conclusions

This study successfully developed a Game-Based Physical Training Model to improve motivation and smash ability in 15–18-year-old volleyball athletes. The model was structured into four stages over eight weeks: weeks 1–2 focused on coordination and motivation, weeks 3–4 on smash technique and accuracy, weeks 5–6 on intensity and strength, and weeks 7–8 on match simulation and evaluation. Effectiveness testing showed statistically significant improvements in both motivation and smash ability ($p = 0.000$), confirming that the game-based approach can integrate physical strengthening, technical refinement, and match context. Practically, this model provides a structured, engaging, and adaptable program framework that coaches can adopt with adjustments based on athletes' profiles, playing positions, and available facilities. Thus, the research objectives of developing, validating, and testing the effectiveness of a game-based physical training model have been achieved, and the model is recommended as a guideline for interventions aimed at enhancing motivation and smash ability in 15–18-year-old volleyball athletes.

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## Conflict of Interest

The researcher declares no conflict of interest.

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# The impact of part-whole passing training on passing accuracy in volleyball athletes aged 10–14 years

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

## Abstract

| | |
|---|---|
| *Background and Study Aim* | Passing is one of the fundamental techniques for improving accuracy in young volleyball players. However, training methods that combine part and whole approaches are still understudied in the scientific literature. This study aimed to examine the effect of passing training using a combination of partial and full methods on passing accuracy in volleyball athletes aged 10–14 years, with respect to gender differences. |
| *Material and Methods* | This quasi-experimental study employed a pretest–posttest design. The sample was selected using total sampling and included all volleyball athletes aged 10–14 years in Sleman Regency, Indonesia, with a total of 60 athletes. The characteristics (mean±SD) of 30 male athletes were: age 11.9±1.0 years, height 150.1±6.7 cm, weight 44.4±4.9 kg. For 30 female athletes, the characteristics were: age 11.7±0.9 years, height 149.9±7.2 cm, weight 42.5±5.4 kg. Participants were randomly distributed into three groups: passing training with the part and whole method (Group 1), passing training without this method (Group 2), and a control group (Group 3). The intervention lasted 6 weeks (18 sessions). The Brady Volleyball Test was used to measure accuracy in both pretest and posttest. |
| *Results* | Paired t-test analysis revealed that passing training improved accuracy in all groups and in both genders (p<0.05). Independent t-test results showed that Group 1 had no significant gender differences in accuracy (p=0.524>0.05). In contrast, Groups 2 and 3 displayed substantial differences. One-Way ANOVA results (p=0.000<0.05), followed by LSD Post Hoc tests, confirmed that Group 1 achieved the highest passing accuracy. Group 2 ranked second, followed by the control group (Group 3). |
| *Conclusions* | The part and whole training method significantly enhances passing accuracy in volleyball athletes aged 10–14 years. Moreover, gender differences did not influence the outcomes when this method was applied. These findings have important implications for designing effective and inclusive volleyball training programs, particularly for young athletes in the foundational stages of skill development. |
| **Keywords**: | volleyball training, passing accuracy, part-whole method, youth athletes |

## Introduction

Volleyball is a team sport that requires the integration of technical, tactical, and physical abilities for effective performance. Passing has a central role in initiating offensive actions and maintaining the consistency of team play. Accuracy in passing is important at the early stages of athletic development, as it provides the foundation for skill progression and tactical execution. For young athletes, mastering passing is both a technical task and a factor that influences confidence, cooperation within the team, and continued participation in the sport.

Volleyball is among the most widely practiced sports worldwide, particularly among adolescents and adults. Success in this sport depends heavily on fundamental technical skills, with passing regarded as one of the most critical elements [1]. Accurate passing forms the basis for constructing effective attacks and maintaining control of the game [2]. Consequently, structured training programs designed to enhance passing performance are essential for junior athletes who are still in the early stages of skill development [3]. Despite the common use of passing training by coaches, its scientific investigation remains limited, particularly regarding the effectiveness of the part–whole training method [4, 5].

Proper passing technique directly contributes to improved accuracy in volleyball [6]. Accuracy is especially important for athletes aged 10–14 years, a developmental stage characterized by motor skill acquisition [7, 8]. Enhancing accuracy supports the development of control and coordination [9]. This, in turn, provides the foundation for mastering more complex skills in the future. Accurate passing and other fundamental techniques also enable young players to contribute more effectively to team performance. At the same time, they foster motivation and self-confidence, which directly

influence decision-making [10]. Improved accuracy helps reduce errors during matches and enhances both competitive outcomes and the learning experience [11]. Developing accuracy from an early age therefore prepares athletes for higher levels of competition, where precision and consistency are important for success.

Athletic success is also influenced by structured and systematic training programs. A training approach that combines part and whole methods has been widely applied in volleyball to improve athletes' technical abilities. The part–whole method involves learning a skill by breaking it into smaller components (part) and then reintegrating them into the complete movement (whole) [12]. This approach allows athletes to focus on specific details and correct technical errors more effectively. It also supports gradual learning that strengthens skill comprehension [5]. In contrast, general passing training emphasizes holistic execution from the outset, without separating skills into smaller parts [13]. In this method, athletes practice skills directly in a game context, which helps them understand their application in competitive situations [9]. General passing training also relies on intuition and adaptability, which can contribute to the development of decision-making and quick responses [6]. The choice of training method depends on both program objectives and athletes' specific needs.

Published scientific literature reviews have demonstrated the effectiveness of the part–whole method in improving volleyball skills. For example, this method improved forearm passing ability by 14.41% in 15 athletes aged 12–14 years [13]. It also had a positive influence on smash ability among novice players aged 11–12 years [5]. By contrast, the mini-game method was reported to be more effective than part–whole training for enhancing forearm passing [4]. Improvements in passing accuracy have also been observed with alternative approaches. These include target-based training with the net [6], the drill-based method [9], and pair training with teammates [14, 15]. Given evidence that manipulative movement skills in adolescents may vary by gender [16, 17], it is important to examine whether the effectiveness of training methods differs between male and female athletes.

Analysis of research findings has shown that different training approaches, including the part–whole method, mini-game exercises, and drill-based techniques, contribute to the development of technical skills in young volleyball players. Researchers emphasize that accuracy in passing is closely linked to overall performance, influencing both individual progress and team effectiveness. They also highlight that manipulative movement skills in adolescents may vary by gender, which adds complexity to the training process. At the same time,

certain aspects of applying structured methods to passing accuracy in athletes aged 10–14 years remain insufficiently clarified, which continues to limit the optimization of training strategies. These considerations form the basis for the present investigation. This study aimed to examine the effect of passing training using a combination of partial and full methods on passing accuracy in volleyball athletes aged 10–14 years, with respect to gender differences.

## Material and Methods

### Participants

The study population consisted of volleyball athletes in Sleman Regency, Indonesia. Total sampling was employed, including all athletes aged 10–14 years, with an average training experience of 1.6±0.4 years. A total of 60 athletes participated. They were divided equally between males (n=30; age 11.9±1.0 years; height 150.1±6.7 cm; weight 44.4±4.9 kg) and females (n=30; age 11.7±0.9 years; height 149.9±7.2 cm; weight 42.5±5.4 kg).

Participants were recruited from local volleyball clubs and schools affiliated with youth sports programs in Sleman Regency. Inclusion criteria included being aged between 10 and 14 years, actively participating in volleyball training at least twice per week, and having no injuries or medical conditions limiting physical activity. Exclusion criteria involved any recent musculoskeletal injury within the past six months or non-compliance with the training schedule.

Ethical approval for the study was obtained under letter number B/1935/UN34.16/PT.01.10/2024. Informed consent was obtained from all participants and their legal guardians prior to participation, in accordance with institutional ethical standards and the Declaration of Helsinki.

No participants dropped out during the intervention, and all 60 completed the pretest and posttest assessments. Random allocation into three groups was performed after recruitment, and descriptive analysis confirmed that there were no significant baseline differences in demographic characteristics between groups (p > 0.05).

### Research Design

This study employed a quasi-experimental design, which allows the evaluation of interventions under natural conditions [18]. A pretest–posttest approach was applied, where passing accuracy was measured before and after the intervention. Participants were randomly distributed into three groups to reduce bias (Figure 1). Group 1 received passing training using the part–whole method. Group 2 received passing training without the part–whole method. Group 3 served as the control group and did not receive a specific training intervention. Passing accuracy was assessed using

the Brady Volleyball Test, which has demonstrated strong validity (0.862–0.904) and reliability (0.797–0.879) [19]. This instrument has also been used in volleyball-related studies to evaluate passing accuracy [20, 21].

The intervention lasted six weeks and consisted of 18 sessions conducted three times per week. Each session lasted approximately 90 minutes and included structured warm-up, targeted technical training, and cool-down phases. Training intensity was standardized across all groups at 60%–85% of perceived exertion, with 10–15 repetitions per drill, 3–5 sets per session, 30–60 seconds of rest between sets, and 1–2 minutes between exercise blocks.

Randomization was performed using block allocation stratified by gender to ensure balanced group composition. Although the trainers and participants were not blinded due to the nature of the intervention, performance assessment was conducted by evaluators blinded to group allocation to reduce potential observer bias. All training and assessments were conducted on indoor courts under similar environmental and scheduling conditions to ensure consistency and minimize confounding variables.
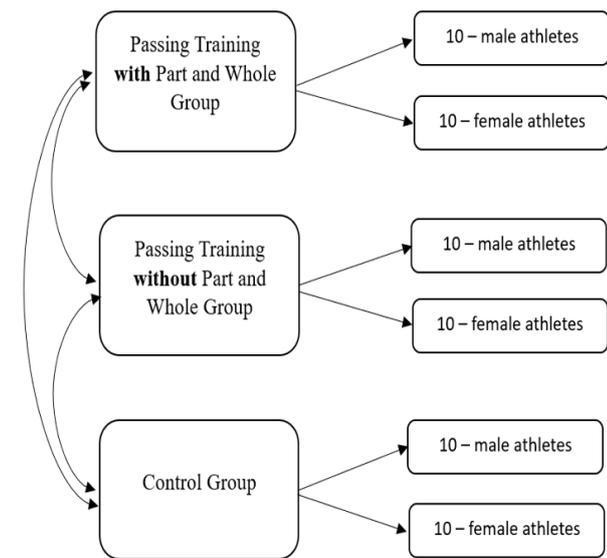


**Figure 1.** Research Design

*Training Program*

The passing training program that applied the part–whole method (Group 1) consisted of structured exercises performed both with and without the ball, in collaboration with teammates. This approach integrated two components: non-ball exercises and ball-based exercises.

The non-ball (part-training) model emphasized fundamental movement patterns. These included stepping forward, stepping sideways while touching the floor with the fingers, stepping backward with fingers reaching the ground, arm-swing drills, and repeated forward steps.

The whole-training model provided more integrated tasks. These included underhand passing followed by catching the ball individually, repeated underhand passing practice, underhand passing combined with forward movement, and underhand passing combined with sideways movement. Additional non-ball activities included pushing the arms followed by straight leg swings, forward stepping with arm extension, sideways stepping with straight arm pushes, pushing the arms upward with leg extension, and combinations of forward or sideways steps with simultaneous extension of the arms and legs.

The ball-oriented part and whole exercises involved tossing and catching, catching and tossing while moving forward, sideways, or backward, stepping forward with hands positioned above the head, pushing the arms upward with simultaneous leg extension, and combinations of forward or sideways steps with catching and pushing the ball upward. These drills also included overhead passing combined with forward and sideways steps.

For comparison, Group 2 completed free passing practices with teammates without applying the part–whole method. In contrast, the control group (Group 3) engaged in unstructured practice sessions directly supervised by the researcher.

The intervention for all three groups lasted six weeks, with 18 training sessions conducted three times a week in the afternoon. Training intensity across groups was standardized at 60%–85%, with three to five sets, recovery periods of 30–60 seconds, intervals of one to two minutes, 10–15 repetitions, and a session duration of approximately 90 minutes.

*Statistical Analysis*

Data were analysed using paired t-tests and one-way ANOVA to evaluate differences between pretest and posttest results. Statistical significance was set at $p < 0.05$. Tests of normality and homogeneity were conducted beforehand to confirm that statistical assumptions were met ($p > 0.05$). All analyses were performed using SPSS version 27, which is widely applied in research for accurate and efficient data processing [22].

Normality of the data was tested using the Shapiro–Wilk test, as group sizes were below 50. Homogeneity of variances across groups was assessed using Levene's test before conducting ANOVA. When significant group differences were found, post hoc analysis was carried out using the Least Significant Difference (LSD) method to identify specific intergroup differences.

Independent samples t-tests were used to assess differences in post-intervention performance between male and female participants within each group. Effect sizes were not reported, which limits the interpretation of practical significance despite statistical differences.

## Results

The results of data collection through the pretest–posttest design for volleyball athletes aged 10–14 years are presented below. The first analysis tested data distribution using the Shapiro–Wilk test, as each gender group consisted of 10 athletes. The results are summarized in Table 1.

As shown in Table 1, all groups (male and female, across Groups 1–3) yielded significance values of $p > 0.05$. Thus, the data were normally distributed. This confirmed that the assumptions for parametric testing were satisfied. Therefore, the paired t-test was applied to assess pretest–posttest differences in passing accuracy.

The paired t-test was used to evaluate pretest–posttest differences in passing accuracy for each group. The results are presented in Table 2.

As shown in Table 2, significant improvements were observed in all groups. For Group 1 (part–whole method), both male ($p = 0.000$) and female athletes ($p = 0.000$) demonstrated significant improvements in passing accuracy. In Group 2 (training without the part–whole method), male athletes ($p = 0.001$) and female athletes ($p = 0.000$) also improved,

though the gains were smaller compared with Group 1. In the control group (Group 3), male ($p = 0.010$) and female athletes ($p = 0.013$) showed only minor improvements, but the results remained statistically significant.

The third analysis tested gender differences in passing accuracy among volleyball athletes aged 10–14 years in each group, using an independent t-test. The results are presented in Table 3.

As shown in Table 3, Levene's Test values in all three groups were >0.05, confirming that the samples were homogeneous and that the independent t-test assumptions were met. In Group 1, the p-value was 0.524 (>0.05), indicating no significant difference in passing accuracy between male and female athletes when the part–whole training method was applied. In Group 2, the p-value was 0.001 (<0.05), showing a significant gender difference in passing accuracy. In Group 3, the p-value was 0.000 (<0.05), also indicating a significant difference between male and female athletes in the control group.

The fourth analysis used a One-Way ANOVA test to compare differences among the three groups. In SPSS, the researcher selected the One-Way ANOVA

**Table 1.** Normality test results

| Group | Kolmogorov–Smirnov | | | Shapiro–Wilk | | |
|---|---|---|---|---|---|---|
| | Statistic | df | Sig. | Statistic | df | Sig. |
| Group 1 (Male) – Pretest | 0.153 | 10 | 0.200* | 0.932 | 10 | 0.473 |
| Group 1 (Male) – Posttest | 0.132 | 10 | 0.200* | 0.965 | 10 | 0.841 |
| Group 1 (Female) – Pretest | 0.168 | 10 | 0.200* | 0.908 | 10 | 0.268 |
| Group 1 (Female) – Posttest | 0.146 | 10 | 0.200* | 0.948 | 10 | 0.646 |
| Group 2 (Male) – Pretest | 0.172 | 10 | 0.200* | 0.944 | 10 | 0.596 |
| Group 2 (Male) – Posttest | 0.134 | 10 | 0.200* | 0.952 | 10 | 0.690 |
| Group 2 (Female) – Pretest | 0.168 | 10 | 0.200* | 0.908 | 10 | 0.268 |
| Group 2 (Female) – Posttest | 0.159 | 10 | 0.200* | 0.936 | 10 | 0.508 |
| Group 3 (Male) – Pretest | 0.202 | 10 | 0.200* | 0.938 | 10 | 0.532 |
| Group 3 (Male) – Posttest | 0.153 | 10 | 0.200* | 0.969 | 10 | 0.882 |
| Group 3 (Female) – Pretest | 0.160 | 10 | 0.200* | 0.942 | 10 | 0.575 |
| Group 3 (Female) – Posttest | 0.143 | 10 | 0.200* | 0.934 | 10 | 0.487 |

Note. *$p < 0.05$

**Table 2.** Pretest–posttest results after treatment

| Group | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|
| | | | | Lower | Upper | | | |
| Group 1 (Male) | –21.800 | 1.229 | 0.389 | –22.679 | –20.921 | –56.080 | 9 | 0.000 |
| Group 1 (Female) | –25.500 | 1.434 | 0.453 | –26.526 | –24.474 | –56.244 | 9 | 0.000 |
| Group 2 (Male) | –5.700 | 3.529 | 1.116 | –8.225 | –3.175 | –5.107 | 9 | 0.001 |
| Group 2 (Female) | –4.800 | 2.860 | 0.904 | –6.846 | –2.754 | –5.308 | 9 | 0.000 |
| Group 3 (Male) | –2.200 | 2.150 | 0.680 | –3.738 | –0.662 | –3.236 | 9 | 0.010 |
| Group 3 (Female) | –1.400 | 1.430 | 0.452 | –2.423 | –0.377 | –3.096 | 9 | 0.013 |

procedure with the option for a homogeneity of variance test. The LSD (Least Significant Difference) Post Hoc test was also applied to examine pairwise group differences.

For clarity, the homogeneity test table is not presented here. However, the results showed a homogeneity value of 0.083 (>0.05), indicating that the data across the groups were homogeneous and came from the same population. The results of the One-Way ANOVA test are presented in Table 4.

As shown in Table 4, the significance value was 0.000 (<0.05), confirming that there were significant differences among the three groups. Therefore, Post Hoc test results were used for further analysis.

The Post Hoc analysis was performed using the LSD test to identify pairwise differences among the three groups. The results are presented in Table 5.

As shown in Table 5, the mean difference between Group 1 and Group 2 was 18.850 (p = 0.000), indicating a statistically significant advantage for Group 1. The difference between Group 1 and Group

3 was 22.350 (p = 0.000), confirming a significant advantage for Group 1 as well. Between Group 2 and Group 3, the mean difference was 3.500 (p = 0.000), showing that Group 2 outperformed Group 3.

Overall, the LSD Post Hoc test demonstrated statistically significant differences in passing accuracy among the three groups. The group trained with the part–whole method (Group 1) achieved the highest passing accuracy, followed by Group 2 (training without the part–whole method), while the control group (Group 3) had the lowest passing accuracy.

## Discussion

This study aimed to examine the effect of passing training using a combination of partial and full methods on passing accuracy in volleyball athletes aged 10–14 years, with respect to gender differences. The findings revealed significant improvements in passing accuracy across all groups (Group 1,

**Table 3.** Differences in training methods by gender

| Group | | Levene's Test for Equality of Variances | | t-test for Equality of Means | | | | |
|---|---|---|---|---|---|---|---|---|
| | | F | Sig. | t | df | Sig. (2-tailed) | Mean Difference | Std. Error Difference |
| Group 1 | Equal variances assumed | 0.035 | 0.853 | 0.650 | 18 | 0.524 | 0.500 | 0.770 |
| Group 2 | Equal variances assumed | 0.480 | 0.497 | 3.785 | 18 | 0.001 | 4.200 | 1.110 |
| Group 3 | Equal variances assumed | 0.171 | 0.684 | 4.516 | 18 | 0.000 | 3.600 | 0.797 |

**Table 4.** One-Way ANOVA test based on three groups

| Accuracy Ability | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 5780.633 | 2 | 2890.317 | 438.685 | 0.000 |
| Within Groups | 375.550 | 57 | 6.589 | | |
| Total | 6156.183 | 59 | | | |

**Table 5.** Post Hoc Test on One-Way ANOVA

**Dependent Variable: Accuracy Ability**

| (I) Group | | | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|---|
| | | | | | | Lower Bound | Upper Bound |
| LSD | Group 1 | Group 2 | 18.850* | 0.812 | 0.000 | 17.22 | 20.48 |
| | | Group 3 | 22.350* | 0.812 | 0.000 | 20.72 | 23.98 |
| | Group 2 | Group 1 | -18.850* | 0.812 | 0.000 | -20.48 | -17.22 |
| | | Group 3 | 3.500* | 0.812 | 0.000 | 1.87 | 5.13 |
| | Group 3 | Group 1 | -22.350* | 0.812 | 0.000 | -23.98 | -20.72 |
| | | Group 2 | -3.500* | 0.812 | 0.000 | -5.13 | -1.87 |

Note. *p < 0.05 (LSD Post Hoc Test).

Group 2, and Group 3) for both male and female athletes. These results suggest that structured and systematic training, including appropriate duration, sets, volume, and intensity, positively contributes to accuracy development regardless of the method employed, which is consistent with previous recommendations [9]. The most substantial improvement, however, was observed in Group 1, which applied the part–whole method. This confirms earlier findings that the technique is effective in enhancing technical skills, as it enables athletes to focus on individual skill components separately before integrating them into complete movements [5].

Further analysis demonstrated that within Group 1, there were no significant gender-based differences in the effectiveness of the training method. This suggests that the part–whole approach can be applied effectively to both male and female athletes. By contrast, significant mean differences were found in Group 2 and Group 3. These differences may be related to biological and psychological variations between male and female athletes, which influence their responses to more general training methods [16]. Previous studies confirm that children aged 10–14 undergo rapid physical growth and marked hormonal changes [23]. Boys and girls progress through different stages of physical maturity, which affects their strength, coordination, balance, and flexibility [24]. Physical capacities such as muscle strength, endurance, and agility also vary, shaping how they respond to training intensity and type [25].

Psychological factors also play an important role in athletes' responses to training. Differences in motivation and interest, often shaped by social environments, may influence the extent of children's engagement in sports [26]. Individual learning styles, such as visual, auditory, or kinesthetic, affect how young athletes absorb new instructions and techniques [3]. Other psychological aspects, including self-efficacy and self-confidence, further determine their willingness to attempt new techniques and adapt to changes in training [27, 28]. Within the context of volleyball training for athletes aged 10–14 years, acknowledging these biological and psychological differences is essential for designing effective and inclusive programs [7]. Coaches should consider variations in physical growth and learning preferences to optimize skill development, particularly in improving passing accuracy [13]. By tailoring training methods to individual needs, coaches can support young athletes in developing both technical and mental capacities required for success in volleyball.

The analysis confirmed that athletes in Group 1, who trained using the part–whole method, achieved the greatest improvement in passing accuracy compared with Groups 2 and 3. By breaking down complex skills into smaller components, athletes were able to understand and master each element before applying them in game contexts. Previous studies have reported that children aged 10–14 often prefer training methods that divide skills into smaller steps [29]. As this age represents a critical phase of cognitive and motor development, athletes can more easily comprehend and master complex skills when they are simplified into sequential components [30, 31]. Segmenting skills into smaller parts enables them to focus on each element independently, reduces cognitive overload, and increases self-confidence as they recognize progress in mastering each stage [32, 33].

In volleyball, particularly in passing training, the part–whole method appears to be highly effective. By decomposing passing techniques into smaller elements, such as hand positioning, footwork, and timing, children can identify weaknesses more easily and make targeted corrections [5]. Once each component is mastered, they can reintegrate them into the complete movement with greater confidence and efficiency [12]. This method not only improves technical execution but also supports tactical understanding, which is important for overall performance in volleyball [34, 35]. In contrast, Group 2, which trained without the part–whole approach, showed only moderate improvement, while the control group (Group 3) demonstrated the lowest progress. These findings emphasize the value of structured training interventions.

The present findings provide evidence that systematic and well-structured training plays a central role in developing passing accuracy among young volleyball athletes. The part–whole method demonstrated particular effectiveness, as it not only improved technical execution but also supported confidence and tactical awareness. At the same time, the observed gender-related differences in other groups highlight the importance of considering biological and psychological factors when designing training strategies.

*Limitations and Practical Implications*

Despite its contributions, this study is not without limitations. The geographical scope was limited to Sleman Regency, meaning the results may not fully represent a broader population. In addition, the quasi-experimental design did not allow complete control over external variables that may have influenced outcomes, and measurements of passing accuracy were conducted under controlled conditions that may not entirely replicate competitive match environments.

Nevertheless, the study provides meaningful implications for the development of volleyball training programs. The part–whole training method proved effective in improving passing accuracy and

can be adopted by coaches seeking to enhance the technical skills of young athletes. Furthermore, the observed gender-based differences in Groups 2 and 3 highlight the importance of designing inclusive and individualized training programs. These findings also open opportunities for future studies to examine the effectiveness of the part–whole method across diverse populations and contexts.

## Conclusions

This study demonstrates that the part–whole training method significantly enhances passing accuracy among volleyball athletes aged 10–14 years. The technique was equally effective for both male and female athletes, indicating that gender differences did not affect training outcomes when this structured approach was applied. In contrast, athletes who trained without the part–whole method, as well as those in the control group, showed only moderate improvements, underscoring the value of structured and systematic training. The findings highlight the importance of considering both biological and psychological differences when designing training programs for young athletes. By breaking down skills into smaller, manageable components, coaches can help athletes master techniques more effectively, build confidence, and foster long-term development. Although this study was limited by its geographical scope and quasi-experimental design, the results provide valuable implications for volleyball training programs and demonstrate the potential of the part–whole method to support inclusive and effective athlete development. Future research should expand the investigation to broader populations and competitive contexts to strengthen the generalizability of these findings.

## Acknowledgement

## Conflict of Interest

The author declares no conflict of interest.

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# Inclusive education and interdisciplinary approaches to the environment, pedagogical support, and social development: a systematic review

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

## Abstract

| | |
|---|---|
| *Background and Study Aim* | Inclusive education is increasingly regarded as a priority for ensuring equal opportunities for learning and development among all participants in the educational process. Despite growing attention, inclusive education still lacks interdisciplinary integration, particularly in spatial and pedagogical dimensions. The aim of this study is to systematize the thematic structure of contemporary literature on inclusive education using Latent Dirichlet Allocation (LDA) modeling. |
| *Material and Methods* | The Web of Science database was used in this study. The search covered the past five years and included only English-language articles. An initial keyword search yielded 791 publications, from which 661 were extracted. The PRISMA 2020 methodology and LDA modeling were applied to these 661 publications to identify thematic clusters (topics). The optimal LDA model featured the following parameters: coherence score = 0.4467, perplexity = −7.0425. Data processing of the extracted documents was carried out in the PyCharm environment using custom Python scripts. |
| *Results* | It was identified terms typical for environmental design (n = 62), inclusive and educational environments (n = 85). It was excluded terms used in non-relevant contexts (n = 10). Based on the extracted terms and 661 documents, a set of single words (n = 50) and word pairs (n = 225) with their respective weights was created. Using the WeightedPairCount metric, 29 of the most relevant publications were selected. Pedagogical support was the most frequently discussed topic (41.4% of the sample), followed by environmental design (27.6%), emotional development (17.2%), and assessment tools (13.8%). For each area, current challenges, barriers, and promising approaches were identified. |
| *Conclusions* | The systematization of current research on inclusive education enables the structuring of accumulated academic knowledge and highlights existing gaps. Future studies should prioritize interdisciplinary approaches that integrate pedagogical, environmental, and technological components. |
| **Keywords**: | educational environment, universal design, environmental design, sensory adaptation, digital visualization, inclusive culture, social integration, school climate, inclusion. |

## Glossary

*Inclusive education* – education that takes into account the needs of all learners, including children with disabilities.

*Inclusive design (universal design)* – design of environments to be accessible and usable by everyone without the need for additional adaptation.

*Pedagogical support* – methods, strategies, and conditions that facilitate successful learning for all student groups.

*Emotional integration* – creating a classroom atmosphere of acceptance, safety, and psychological comfort.

*Topics* – stable semantic groups in academic texts, automatically identified using topic modeling.

*LDA (Latent Dirichlet Allocation)* – a text analysis method that identifies topics based on word usage statistics.

*Coherence score* – a numerical measure of topic

quality; higher values indicate more clearly defined semantic clusters.

*Perplexity* – a measure of model complexity; used to assess its accuracy.

*PyCharm* – a programming environment used to run analysis scripts (e.g., in Python).

*WeightedPairCount* – the sum of word pair weights in a topic; used to assess its importance within the text.

## Introduction

Inclusion in education is regarded as a multifaceted phenomenon encompassing pedagogical practices, social interactions, and physical and digital environment of the educational process. Particular emphasis is placed on environmental solutions aimed at creating accessible, flexible, and supportive climate. Such environments take into account the diverse sensory, cognitive, and behavioral characteristics of learners. Despite a growing theoretical and practical foundation, the implementation of these solutions remains challenged by factors such as the resource-intensive nature of adaptations and the insufficient coherence of interdisciplinary approaches. The diversity of research directions highlights the need to identify evidence-based and context-sensitive solutions.

In this context, particular attention is given to studies that reveal the foundational principles of inclusive education. For example, the work of Ioannidi and Malafantis highlights the importance of incorporating diversity into the content and forms of assessment as a basis for equal access to learning [1]. The study by Jardinez and Natividad emphasizes the role of Universal Design for Learning and the need for teacher training to effectively implement inclusive approaches [2]. Florian and Beaton propose the concept of inclusive pedagogy as a systemic approach aimed at the active participation of all learners, rather than merely adapting to the needs of specific groups [3]. Additionally, the study by Lawrie et al. underscores the importance of institutional support, the rethinking of curricula, and assessment methods as essential components of a sustainable inclusive environment [4]. Furthermore, the inclusive pedagogy model proposed by Florian and Beaton [3] aligns with the need for a systemic rather than compensatory review of existing practices. Ultimately, these studies provide a theoretical foundation for analyzing the key areas covered in the present review.

*Theme 1: Inclusive Education and Pedagogical Support*

Pedagogical support in inclusive education is regarded as an essential component that ensures the active participation of all learners. In particular, the concept of inclusive pedagogy emphasizes the need to shift from individual adaptation strategies toward creating a shared learning environment that includes all children without exception [5]. Loreman's study draws attention to the importance of teachers' positive attitudes, their professional training, and adequate institutional support as key factors for successful inclusion [6]. Similarly, the work of Walton and Rusznyak highlights the significance of pedagogical reflection and justice in decision-making processes aimed at fostering the inclusive potential of educational practice [7]. These studies provide a scholarly foundation for analyzing the strategies, barriers, and prospects of pedagogical support in inclusive environments.

At the same time, researchers emphasize the development of co-teaching strategies, differentiated instruction, and professional support for educators. Studies highlight the importance of fostering an inclusive climate and implementing digital solutions to adapt the learning process [8]. However, challenges are also noted, including insufficient teacher preparation and a superficial understanding of the concept of inclusion [9, 10]. Key recommendations include revising curricula, developing professional communities, and integrating digital tools [11]. Thus, the conceptualization of inclusive education requires a comprehensive and interdisciplinary approach that integrates pedagogical, psychological, and administrative dimensions.

*Theme 2: Spatial Organization of Inclusive Environments and Interior Design*

Issues of spatial organization in inclusive environments are attracting increasing attention from researchers aiming to create educational spaces that support equal participation for all. According to Imrie, the physical environment has a direct impact on inclusion and therefore must be adapted not only to physiological needs but also to the sensory and emotional characteristics of learners [12]. Additionally, the studies by Woolner and Clark emphasize the importance of involving users – students and teachers – in the design process of inclusive spaces, which fosters a sense of belonging and support [13]. A significant contribution is also made by the study of Byers and Imms [14], who present empirical data on the impact of flexible architecture and furniture on the engagement and learning behavior of children with diverse needs. Collectively, these publications lay the groundwork for rethinking inclusive design as an interdisciplinary endeavor integrating pedagogy, architecture, and social justice.

An analysis of other studies highlights the growing development of approaches to designing inclusive spaces with attention to multisensory experience, ergonomics, and digital technologies [15]. Several works emphasize the importance of personalized environments and interdisciplinary collaboration between architects, educators, and sensory

integration specialists [16]. The use of VR tools and automated planning algorithms such as EDU-AI is expanding access to inclusive environments under limited resource conditions [8, 17].

Thus, spatial inclusion is viewed as a vital component of the educational process, requiring a shift from formal accessibility requirements toward the creation of flexible, adaptive, and empathetic learning spaces.

*Theme 3: Emotional and Social Development of Students in Inclusion*

Studies on the emotional and social development of students in inclusive environments emphasize that their well-being is closely linked to a supportive classroom atmosphere. One of the most frequently cited works in this field is the study by Schwab, which demonstrated that perceived social inclusion of students with disabilities is significantly influenced by a positive classroom climate and the level of teacher engagement [18]. Similar findings are presented in the research by Avramidis and Norwich [19], who highlight the role of teacher attitudes and competencies in ensuring emotional safety and social integration of students with special educational needs. Additionally, the study by De Boer et al. shows that positive peer perception among students with special needs significantly affects their participation in joint activities and their self-esteem [20]. The authors emphasize that teacher support acts as a mediator of this effect.

Emotional well-being and a sense of belonging are recognized as crucial conditions for successful inclusion. Schwab's research confirmed that perceived social inclusion is directly associated with a supportive classroom climate and teacher involvement [18]. Another study highlights the importance of developing teachers' interpersonal competencies and cultural sensitivity within inclusive settings [21]. The potential for co-developing inclusive norms with students' participation is also noted as a tool for overcoming social hierarchy [22].

Thus, the analysis of these studies underscores the significance of the psycho-emotional dimension of inclusive education. It also highlights the role of the teacher as a mediator of social relationships and reveals the importance of cultural and age-specific contexts in designing inclusive strategies.

*Theme 4: Analytical Tools and Systematic Reviews of Inclusive Practice*

Contemporary research emphasizes the importance of applying systematic and reproducible approaches to the analysis of inclusive educational practices. For example, the work of Mitchell summarizes evidence-based strategies for inclusive teaching [23], highlighting the integration of empirical data in the development of effective pedagogical approaches. In a systematic review,

Sharma et al. [24] demonstrate the need for teacher training and structured assessment of institutional readiness for inclusion, including the evaluation of attitudes, resources, and administrative support. In turn, Black-Hawkins [25] introduces the concept of "inclusiveness indicators," enabling researchers and practitioners to apply universal criteria when monitoring inclusive initiatives in educational institutions. Such approaches form a foundation for comparative analysis, support the transformation of educational policy, and enhance interdisciplinary connections in the field of inclusive education.

Other studies reflect researchers' efforts toward comprehensive evaluation of inclusion effectiveness through systemic frameworks and international experience [26, 27]. Special attention is given to the adaptation of strategies to cultural and organizational contexts [28, 29]. Some publications underscore the importance of institutional readiness to implement inclusive technologies even under crisis conditions, including remote and telemedical solutions [30].

In general, the analysis of research findings shows that inclusive education is regarded as a multidimensional phenomenon. This approach encompasses pedagogical strategies, spatial organization of learning environments, emotional development, and institutional support mechanisms. The reviewed authors emphasize the importance of rethinking the teacher's role, enhancing professional preparation, and developing flexible architectural and digital solutions. The studies also point to the significant influence of a positive climate and social engagement on student well-being. Although previous research has explored inclusive pedagogy, few studies have systematized the interdisciplinary spatial-pedagogical themes in empirical literature. In this context, there is a clear need to eliminate fragmentation in addressing spatial, emotional, and institutional aspects of inclusion across different disciplines.

Based on the conducted theoretical and contextual analysis, the following research questions were formulated:

– What dominant thematic clusters are represented in contemporary publications on inclusive education?

– How spatial, pedagogical, and emotional aspects are interconnected in the reviewed sources?

*Research Aim.* To identify and analyze the key thematic directions in contemporary academic literature on inclusive education using Latent Dirichlet Allocation (LDA) topic modeling, with a focus on pedagogical, spatial, and emotional components.

## Methodology

The structure of the systematic review adheres to the core criteria of PRISMA 2020, ensuring

transparency and reproducibility of the results (Figure 1).

*Information Sources*

Publications from the Web of Science (WoS) database were used as the information source. The search covered the last five years and included only articles in English. The initial search was based on two categories of keywords:

1. First category – Object-related terms: "resource room" OR "learning resource room" OR "inclusive classroom" OR "special education classroom" OR "support classroom" OR "sensory room" OR "resource center". Search result: 791 documents.
2. Second category – Synonyms and related terms for development, design, and creation: design* OR redesign* OR "co-design*" OR "pre-design*" OR "post-design*" OR develop* OR creat* OR construct* OR implement* OR plann* OR architect* OR model* OR prototyp* OR concept* OR structur* OR schem*. Search result: 661 documents.

All 661 documents identified during the search were exported into a text file with all associated keys.

*Research Methods*

To enhance the transparency of the analysis, the research methods were structured as follows:

(1) extraction of publications based on keyword search;

(2) manual and automated filtering according to relevance criteria;

(3) semantic analysis using the LDA algorithm and visualization of term graphs.

*Study Design*

*Procedure for Selecting the Most Relevant Publications*

The selection of relevant documents was performed automatically in accordance with the recommendations by Yermakova [31, 32].

The text file containing 661 documents was cleaned of irrelevant information and converted into a more analysis-friendly format (CSV). The resulting table contained two columns: "Identifier" and "Combined Data" (title, abstract, and keywords).

For further analysis, keyword (term) tables were generated. The keyword groups were developed based on the spatial, pedagogical, and institutional aspects of inclusion.

The table 1 included terms (n = 62) that reflected design and construction activities typical of environmental design topics. It included words with the root "design" and its derivatives, as well as lexemes related to development, creation, architectural modeling, and structural planning (e.g., develop, create, construct, implement, plan, architect, model, prototype, concept, structure, scheme).

The table 2 included terms (n = 85) denoting types of rooms and spaces typical for inclusive and educational environments (e.g., resource room, inclusive classroom, sensory room, etc.). These expressions reflect the specifics of architectural and spatial organization in the context of inclusive and special education.
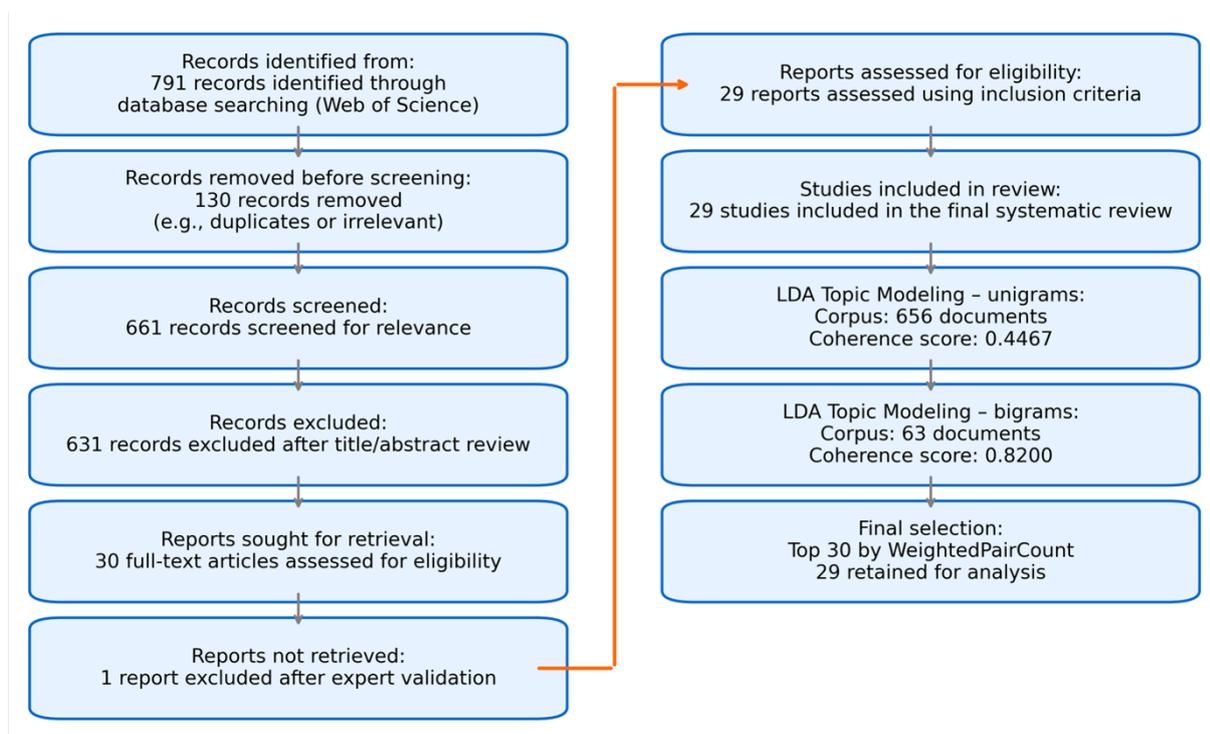


**Figure 1.** PRISMA flow diagram with LDA topic modeling results.

**Table 1.** Terms Reflecting Design and Construction Activities

| Term | Term | Term | Term | Term |
| --- | --- | --- | --- | --- |
| architect | constructing | designer | implemented | pre-design |
| architects | construction | designers | implementing | prototype |
| architectural | constructive | designing | model | prototyped |
| architecture | constructor | designs | modeled | prototypes |
| co-design | create | develop | modeling | prototyping |
| concept | created | developed | modelling | redesign |
| concepts | creating | developer | models | schematic |
| conceptual | creation | developers | plan | schematized |
| conceptualization | creative | developing | planned | scheme |
| conceptualize | creativity | development | planning | schemes |
| construct | design | implement | plans | structural |
| constructed | designed | implementation | post-design | structure |

**Table 2.** Terms Denoting Types of Rooms and Spaces

| Term | Term | Term | Term | Term |
| --- | --- | --- | --- | --- |
| accessibility | chambers | floorplan | roomed | spacing |
| accessible | compartment | floorplans | roomful | spacious |
| adaptive | compartments | function | rooming | spatial |
| aesthetic | configuration | functionality | roomless | spatiality |
| aesthetics | configurations | interior | roomlike | subzone |
| ambience | enclosure | interiority | rooms | unified |
| ambiences | enclosures | interiors | section | unit |
| area | environment | layout | sectioned | unitized |
| areal | environmental | layouts | sectioning | unitizing |
| areas | environmentally | modular | sections | units |
| atria | environments | open-plan | set | usability |
| atrium | facilitate | plan | setting | volume |
| blueprint | facilitated | planning | settings | volumes |
| blueprints | facilitating | plans | space | zone |
| chamber | facilities | preset | spaced | zoned |
| chambered | facility | reset | spaceless | zones |
| chambering | flexible | room | spaces | zoning |

**Table 3.** Terms Used in Non-Relevant Contexts

| Term | Term |
| --- | --- |
| design of experiments | concept car |
| design thinking in marketing | resource extraction |
| resource allocation | architecture of computer systems |
| support vector machine | prototype vaccine |
| data modeling | planning algorithm |

The table 3 contained a list of terms (n = 10) that are formally similar to the keywords in Tables 1 and 2 but were used in non-relevant contexts. It included phrases that formally contain key roots (e.g., design, room, space), but are unrelated to the themes of environmental design or the organization of educational environments. Examples of such expressions include: *design of experiments*, *resource allocation*, *support vector machine*, *concept car*, and others.

The processing of the term tables and the table of 661 documents made it possible to generate new

**Table 4.** Set of Single Words (n = 50)

| Topic | Word | Weight | Topic | Word | Weight | Topic | Word | Weight | Topic | Word | Weight | Topic | Word | Weight |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | development | 0.2708 | 2 | model | 0.3351 | 3 | room | 0.2134 | 4 | inclusive | 0.4492 | 5 | area | 0.155 |
| 1 | including | 0.1083 | 2 | concept | 0.0603 | 3 | environment | 0.1018 | 4 | inclusion | 0.1104 | 5 | plan | 0.09 |
| 1 | function | 0.0737 | 2 | structure | 0.0531 | 3 | space | 0.0941 | 4 | design | 0.0673 | 5 | implementation | 0.076 |
| 1 | setting | 0.0699 | 2 | set | 0.0513 | 3 | unit | 0.0695 | 4 | environment | 0.0578 | 5 | structured | 0.0644 |
| 1 | developing | 0.0637 | 2 | design | 0.0505 | 3 | developed | 0.0536 | 4 | setting | 0.0309 | 5 | development | 0.063 |
| 1 | developed | 0.0393 | 2 | inclusion | 0.0424 | 3 | environmental | 0.0527 | 4 | create | 0.0255 | 5 | included | 0.0607 |
| 1 | design | 0.0385 | 2 | development | 0.0307 | 3 | design | 0.036 | 4 | facility | 0.0168 | 5 | created | 0.0579 |
| 1 | include | 0.038 | 2 | including | 0.0233 | 3 | included | 0.0302 | 4 | designed | 0.0151 | 5 | implementing | 0.033 |
| 1 | creating | 0.0308 | 2 | implementation | 0.0225 | 3 | designed | 0.0267 | 4 | modeling | 0.0147 | 5 | planning | 0.0323 |
| 1 | environment | 0.0286 | 2 | developed | 0.0222 | 3 | setting | 0.0248 | 4 | implementation | 0.0145 | 5 | develop | 0.0313 |

tables indicating the weight of each word:

– Single-word table (n = 50), showing the weight of each word, distributed across Topics 1–5.

– Word pair table (n = 225), indicating the weight of each word pair and their corresponding topics. This table contains word pairs extracted from Table 4. For each pair, the total weight and the assigned topic are provided. Example format:

- development → including → 0.1895538 → 1
- model → concept → 0.1976960725 → 2
- room → environment → 0.157610945 → 3
- inclusive → inclusion → 0.279800545 → 4
- plan → planning → 0.0611436105 → 5

*Topic Modeling*

To analyze publications related to design, inclusivity, and spatial organization, a topic modeling procedure was implemented using the Latent Dirichlet Allocation (LDA) algorithm. The choice of LDA was based on its high efficiency in processing unstructured texts [33] and its applicability in the fields of humanities and pedagogical research [34, 35].

The analysis was conducted in two versions: using single keywords and using pairs of stable word combinations extracted from pre-cleaned texts.

The first dataset included 656 texts and produced a vocabulary of 9,936 unique words. The optimal LDA model generated topics with the following values: coherence score = 0.4467, perplexity = −7.0425, indicating moderate structure and topic diversity.

In the second approach, the analysis was based on keyword pairs weighted according to importance, which allowed the identification of semantically stable connections, such as *development plan*, *function including*, and *resource room*. This corpus consisted of 63 texts and 22 unique term pairs. The five-topic LDA model in this case demonstrated high quality: coherence score = 0.8200, perplexity = −3.3161, indicating well-defined and interpretable topics.

The comparison showed that the use of keyword pairs ensures greater topic clarity and relevance of results.

Based on the calculated WeightedPairCount index, 30 of the most relevant publications were selected. During subsequent expert validation, one of these publications was found to be unrelated to the research topic and was excluded from the final analysis. Thus, the proportion of mistakenly included publications amounted to 3.3%, which falls within the acceptable selection error threshold (up to 5%) recognized as permissible in pedagogical research. This confirms the reliability of the automated document selection method used.

*Justification of the Sample Size (n = 30)*

To justify the sample size in the qualitative thematic analysis, a heuristic $\sqrt{N}$ approach was applied, which is recognized as acceptable in methodological literature. In particular, Lakens notes that heuristic strategies (including $\sqrt{N}$) are a valid way to justify sample size in studies where traditional statistical criteria are not applicable [36]. Moreover, according to a systematic review of studies in medicine and social sciences, a range of 20–30 cases is considered sufficient to achieve thematic saturation – a state in which new data no longer provide substantial new information [37]. Additionally, applied studies also use the heuristic $k \approx \sqrt{n}$ to select a representative subset from large datasets. This is supported in the work of Tarrazo, where the $\sqrt{N}$ rule is used to optimize element selection in portfolio modeling [38]. Therefore, given the total corpus size of 656 documents, the value $\sqrt{656} \approx 25.6$ serves as a justification for selecting 30 publications, which is both methodologically sound and practically manageable for in-depth analysis.

During the topic modeling process using the LDA algorithm, five topics were identified based on the distribution of key terms. However, only four of them were included in the substantive analysis. Following expert interpretation and thematic relevance verification, it was decided not to include the fifth topic in the content analysis. The fifth topic was excluded because most of the publications associated with it addressed administrative, infrastructural, or organizational-management aspects that were only weakly related to the objectives of the present study.

Unlike Topics 1–4, the materials under Topic 5 did not align with the main focus of the systematic review.

The distribution of publications across topics demonstrates the dominance of publications related to pedagogical support, highlighting the significance of this area in inclusive education research (Table 5).

**Table 5.** Distribution of Publications by Identified Topics

| Topic | Number of Publications | % of Sample |
|---|---|---|
| Pedagogical Support | 12 | 41.4% |
| Spatial Environment | 8 | 27.6% |
| Emotional Development | 5 | 17.2% |
| Analytical Tools | 4 | 13.8% |

*Statistical Analysis*

Data processing of the extracted documents was carried out in the PyCharm environment using custom-developed Python scripts with the integration of relevant libraries. The accuracy of the scripts was verified through manual validation of the sample and replication of procedures by two independent members of the research team. The consistency of the results confirms the reproducibility and reliability of the automated operations.

The scripts and processed data can be provided upon request, subject to compliance with academic ethics and licensing restrictions of the original sources.

## Results

To visualize the semantic relationships between terms appearing in the publication corpus, a weighted undirected graph was constructed (Figure 2). The graph nodes represent keywords, while the edges indicate stable word pairings based on the frequency and significance of their co-occurrence in the texts. The edge weight corresponds to the degree of associative relevance of the word pairs and was used to scale the thickness of the lines in the diagram. Color coding was applied to distinguish edges by significance level: red for highly significant connections (above 0.7), blue for moderate significance (0.4 to 0.7), and green for lower significance (below 0.4). The visualization was performed using the *networkx* library, with node positioning determined by the spring layout algorithm. The final graph diagram illustrated the most relevant thematic associations between terms
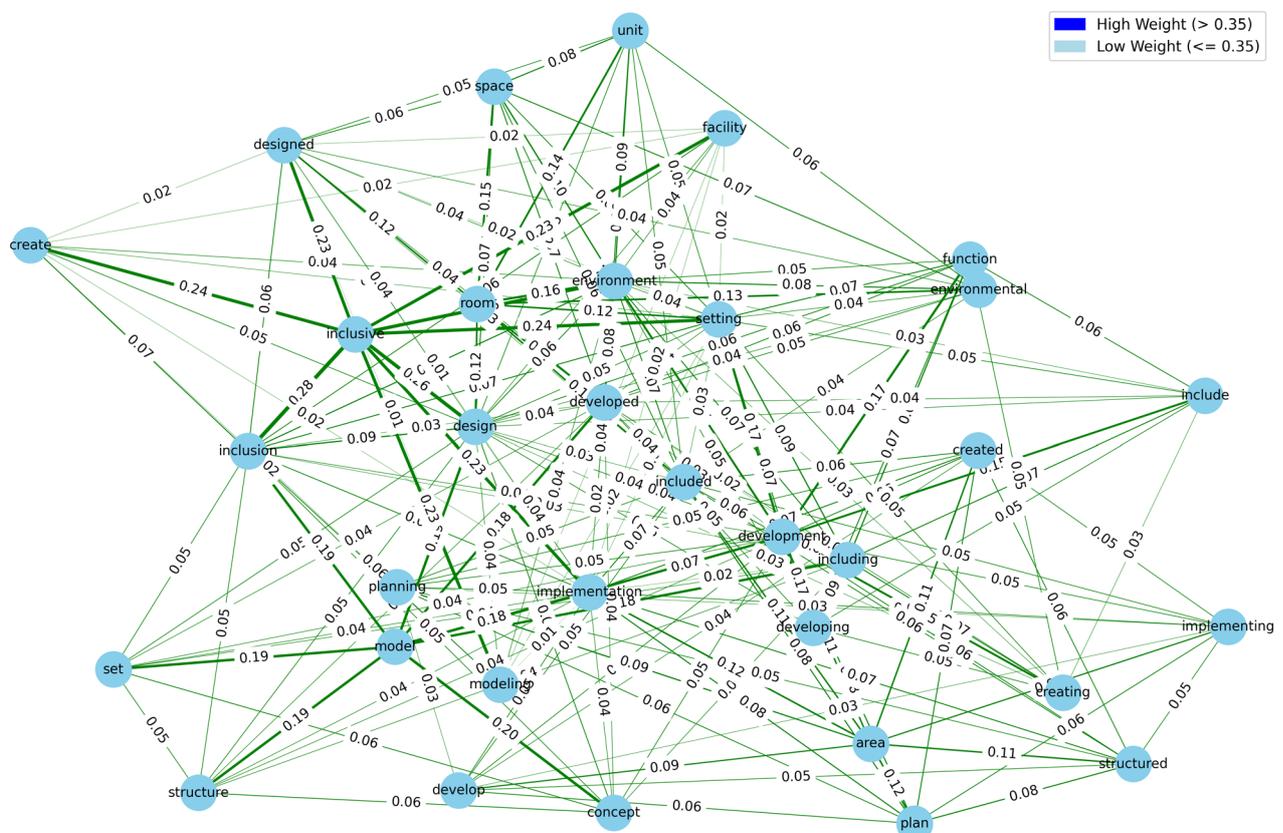


**Figure 2.** Weighted graph of keyword pairs showing semantic relationships between terms used in the analysis of publications on design and educational spaces. Note. A weighted graph is a graph in which each edge is assigned a numerical value reflecting the strength of the connection between two terms.

within the studied subject area.

The graph (Figure 2) reflects thematic clusters, with particularly prominent links related to development and inclusion (e.g., the pairs "development–including" and "inclusive–inclusion"). These clusters form the core of the semantic field, around which other significant concepts are organized. In particular, within the topic of pedagogical modeling, strong associations emerged among the terms "model," "concept," "approach," and "strategy," indicating the frequent use of these terms in the context of educational program development. In the inclusion cluster, stable pairings such as "inclusive–inclusion," "support–needs," and "access–barrier" demonstrate a focus on accessibility and support issues.

As a result of thematic analysis and ranking by weighted keyword pair counts, 29 of the most significant publications were selected (Table 6).

A comparative analysis of publications on Theme 1 reveals a stable thematic core centered on the development of educational strategies aimed at supporting inclusion. Common directions include the creation of inclusive classrooms, integration of digital tools, as well as the implementation of collaborative and differentiated instruction. Systemic barriers frequently identified a lack of pedagogical competencies, limited institutional support, and insufficient integration of the inclusion concept into educational policy. General recommendations encompass the revision of educational programs, support for professional development, strengthening of professional communities, and the use of ICT. Several studies emphasize the importance of contextual factors, such as teacher professional identity and school organizational culture, as conditions for sustainable inclusive transformation.

The general analysis of publications on Theme 2 points to the emergence of an interdisciplinary research field that combines pedagogical, architectural, and technological approaches to designing inclusive educational environments. Key concepts include sensory adaptation, ergonomic design, and flexible space organization. Spatial solutions are considered not only functional but also pedagogically meaningful components that support individualized learning and foster social interaction. Major challenges include the lack of unified inclusive design standards, as well as the need to consider cultural contexts and the diversity of needs. The necessity of cooperation among architects, educators, and sensory integration specialists is substantiated in the development of spaces aligned with the principles of universal design and inclusivity.

The general analysis of publications on Theme 3 shows that emotional well-being and the quality of the social climate are considered key determinants of successful inclusion. The effectiveness of inclusive practice is directly linked to the level of empathy, cultural sensitivity, and interpersonal competence of educators. A positive emotional environment helps reduce anxiety and fosters stable self-esteem in students with special educational needs. Studies emphasize the importance of co-creating inclusive norms, which not only enhances the engagement of all participants but also transforms hidden forms of social hierarchy. The perception of inclusion is noted to vary depending on age, gender, and group cohesion level, highlighting the need to consider socio-psychological factors when designing educational environments.

Additionally, several publications underline that the sustainable development of an emotionally safe environment requires both individual teacher competencies and institutional support. This approach is implemented through psycho-pedagogical support programs, the integration of inclusive culture into the school mission, and the involvement of parents and external experts. Empirical data demonstrate a connection between school climate and the level of social engagement, particularly in adolescent settings. There is also growing interest in tools for assessing emotional inclusion, such as perception of inclusion scales, emotional climate indices, and surveys on perceived fairness and belonging.

Cumulative analysis of publications on Theme 4 demonstrates a shift in research focus from describing inclusive initiatives to systematically evaluating them using both quantitative and qualitative methods. Key trends include the use of international comparative data, structured analytical tools, digital solutions, and reproducible assessment protocols. Institutional flexibility, teacher professional training, and stakeholder engagement in shaping inclusive environments are recognized as priority conditions. The practices described in the literature aim to universalize approaches while maintaining sensitivity to cultural and organizational contexts. Thus, a foundation is being laid for evidence-based pedagogy that combines scalability, adaptability, and empirical verifiability.

Several reviews report the active use of mixed analysis methods (e.g., thematic coding combined with network analysis or factor modeling). This approach enables the identification of hidden patterns in the distribution of inclusive practices. Open international databases (such as OECD TALIS, PISA Inclusive Module) are frequently used, providing additional empirical reliability. It is also noted that a systemic approach to inclusion increasingly relies on evaluating the impact of educational interventions through meta-analyses and randomized studies. There is a growing trend toward developing unified indicators of inclusive education quality, which is important for policy-

**Table 6.** Thematic Distribution of Publications by Areas of Inclusive Education

Theme 1: Inclusive Education and Pedagogical Support

| ID | Research Aim | Target Group | Methodology | Sample Size | Country / Region | Key Findings | Challenges / Barriers | Practical Recommendations | Originality / Value |
|---|---|---|---|---|---|---|---|---|---|
| [9] | To examine the integration of social justice principles into Thailand's teacher education programs and assess the readiness of future educators for inclusive teaching. | Teacher education faculty and student teachers; marginalized groups (ethnic minorities, LGBTQ+). | Qualitative study; thematic analysis of interviews, focus groups, and documents. | 15 faculty members, 25 students | Thailand | There is a gap between policy and practice; low level of practical preparedness for inclusion. | Insufficient support, lack of clear understanding of social justice, weak practical orientation. | Curriculum revision, development of professional training, community engagement projects. | First study of its kind in the Thai context; contributes to inclusive teacher education. |
| [39] | To explore teaching strategies used by teachers in inclusive education in rural primary schools in Indonesia and their perceptions of inclusion. | Primary school teachers (grades 2–6) working with children with special needs. | Qualitative study: classroom observations and short interviews. | 40 teachers from 10 rural schools | Indonesia (rural areas) | Only a few teachers apply effective inclusive strategies such as differentiation and co-teaching. | Low teacher confidence, lack of knowledge, large class sizes. | Need for professional development programs and inclusive teaching competence. | First documentation of real strategies and barriers in rural Indonesian schools; focus on practical teacher preparation. |
| [40] | To study inclusive teaching practices in primary schools in Karnataka (India), focusing on teachers' perspectives and the context of national policy implementation. | Primary school teachers and students, especially children from vulnerable groups, including those with disabilities. | Fieldwork in five schools; analysis of classroom practices and teacher interviews. | 5 schools from different districts | India, Karnataka | The state aims to implement inclusive education based on international frameworks, but there is a lack of localized understanding and practical implementation in schools. | Teachers lack conceptual understanding of inclusion and methodological tools for its implementation. | A coherent national strategy for inclusive education is needed, supported by teacher training and school- and state-level assistance. | Highlights the gap between international rhetoric and local practice; emphasizes the need for a systemic approach to teacher training and support for inclusion in daily teaching. |
| [41] | To examine how self-efficacy predicts teachers' attitudes toward inclusion controlling for gender, school locality, and teaching experience | Government elementary school teachers | Survey of 613 teachers; regression and ANOVA | 613 teachers | India | Found a significant positive correlation between self-efficacy and teachers' attitudes | Self-efficacy had relatively modest predictive power when controlling for demographics | Focus on urban–rural differences and strengthening teachers' confidence in inclusion | Adds evidence from Indian context and examines moderating demographic variables |

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**Table 6.** (Continued)

| ID | Research Aim | Target Group | Methodology | Sample Size | Country / Region | Key Findings | Challenges / Barriers | Practical Recommendations | Originality / Value |
|---|---|---|---|---|---|---|---|---|---|
| [42] | To test the psychometric validity of the Attitudes Towards Inclusion Scale (AIS) and the Intention to Teach in an Inclusive Classroom Scale (ITICS) in the Portuguese context. | Primary and secondary school teachers | Survey; factor analysis; internal consistency and validity analysis; AIS and ITICS scales. | 171 teachers (86% female) | Portugal | The two-factor structure of the AIS (beliefs and feelings) and ITICS (curriculum change and consultation) scales was confirmed; teachers trained in inclusion showed more positive attitudes and intentions. | Lack of inclusion training reduces readiness and positivity among teachers. | Recommend adding new items to the ITICS scale and strengthening teacher training in inclusive education. | Contributes to the adaptation and improvement of psychometric tools for assessing attitudes toward inclusion in Portugal, with relevance for policy and education. |
| [11] | To examine teachers' perceptions of including children with disabilities in preschools and compare them with observed practices. | Educators in inclusive preschools | Mixed methods: questionnaire (closed and open questions) and observation using the Inclusive Classroom Profile (ICP) | 35 educators | Not specified | Educators report high self-efficacy and a positive attitude toward inclusion, but express the need for additional training and support; observation data show that the level of inclusive practices ranges from minimal to good. | Insufficient teacher support and training in inclusive education. | Professional development programs and support are needed to improve the quality of inclusive practices. | The study combines self-assessment and external observation, providing a comprehensive picture of inclusion in preschools. |
| [43] | To justify the importance of the construct "classroom climate" for developing inclusive teaching in mainstream education. | Teachers and researchers | Theoretical literature review | Not specified | International | Classroom climate may act as a mediator between inclusive teaching and learning outcomes; it is linked to achievement, engagement, and well-being, including for students with special educational needs. | Difficulty of implementing inclusive teaching in mainstream classrooms; lack of monitoring and evaluation tools. | Use classroom climate factors and indicators as sensitive and practical tools for assessing and developing inclusive teaching. | Proposes a conceptual model in which classroom climate becomes a key tool for supporting and evaluating inclusive teaching in mainstream education. |
| [44] | To develop and evaluate an ICT tool aimed at preparing teachers for inclusive teaching of children with hearing impairments. | Teachers (12 participants) | User-Centered Design (UCD) methodology, CTT task structure, open development, usability testing using the SUS scale. | 12 teachers | Not specified | The tool received a high usability rating (72.5 points on the SUS scale) and was positively perceived by teachers as a means of improving their preparedness for inclusive education. | Need for specialized training programs for teaching children with disabilities and developmental challenges. | Implementation of ICT tools and training teachers in their use in inclusive classrooms. | The use of open-source and user-centered design allowed the creation of an effective and accessible tool for teacher preparation. |

**Table 6.** (Continued)

| ID | Research Aim | Target Group | Methodology | Sample Size | Country / Region | Key Findings | Challenges / Barriers | Practical Recommendations | Originality / Value |
|---|---|---|---|---|---|---|---|---|---|
| [45] | To study the challenges, conditions, and strategies for implementing inclusive education in Ukraine. | 304 educational professionals | Legal analysis of international and national regulations; survey of Inclusive Resource Center staff. | 304 respondents | Ukraine | Ukraine has the prerequisites for developing inclusive education: legal, financial, organizational, staffing, and sanitary conditions have been established. Key directions for implementing inclusion across all education levels have been identified. | Informational, mental, institutional, and physical barriers to inclusion development. | Improve regulatory frameworks, develop multidisciplinary approaches, eliminate systemic barriers. | A comprehensive legal and sociological analysis of inclusive education in the Ukrainian context; emphasis on the strategic level. |
| [46] | To determine teachers' attitudes toward teaching students with mild learning disabilities (MLDs) in inclusive classrooms. | Primary school teachers in private inclusive and non-inclusive schools in Karachi. | Quantitative method, stratified sampling, structural modeling using Smart PLS 3.0. | 230 teachers | Pakistan | Positive teacher attitudes toward students with MLD predict readiness for inclusive practice; however, a weak linear relationship was found between attitude and practical inclusion. Improving teachers' self-efficacy can significantly enhance their readiness through adequate resources and support. | Insufficient teacher training for working with children with MLD; weak link between beliefs and actions. | Increase teacher self-efficacy, provide targeted resources, train for work with MLD, offer school-level policy recommendations. | A comprehensive analysis of factors affecting the inclusion of students with mild learning disabilities, emphasizing the role of teacher self-efficacy in inclusive practices. |
| [47] | To examine how sustainable professional teacher communities promote the implementation of inclusive practices through teacher transformation. | Teachers participating in 10 professional communities. | Qualitative research; observation of teacher professional communities operating throughout the academic year. | 156 educators | Not specified | Four stages of teacher transformation were identified: initial resistance to inclusion, realization of pedagogical misconceptions, development of nonjudgmental professional dialogue, and the formation of stable inclusive practices. Communities provide both emotional support and systematic development of professional competencies, fostering lasting changes in the educational environment. | Initial resistance to inclusion; pedagogical misconceptions. | Build sustainable professional communities as platforms for reflection, experience-sharing, and gradual acceptance of inclusion through collaborative learning. | A description of a sustainable model of professional development as a basis for systemic change in schools and the formation of inclusive educational practices. |

**Table 6.** (Continued)

Theme 2: Spatial Organization of Inclusive Environments and Interior Design

| ID | Research Aim | Target Group | Methodology | Sample Size | Country / Region | Key Findings | Challenges / Barriers | Practical Recommendations | Originality / Value |
|---|---|---|---|---|---|---|---|---|---|
| 48 | To identify and describe the benefits of inclusive classrooms for child development and socialization. | Children with special educational needs, parents, and teachers. | Analysis of academic publications on inclusive education; survey of teachers and parents of students in inclusive classrooms. | Not specified | Not specified | Inclusive education promotes development and successful socialization of children with special needs; it requires a suitable educational environment. | Need for new educational models; difficulties integrating into society. | Create inclusive environments, engage parents and teachers, consider children's individual needs. | Emphasizes the role of inclusive education in integrating children with disabilities into society. |
| 16 | To identify preferred relaxation methods among autistic adults and define the requirements for effective sensory rooms. | Adults with autism. | Online survey (AQ-50 + questionnaire with open/closed questions); qualitative content analysis. | N=150 (part 1), N=96 (part 2), N=13 (part 3) | English-speaking countries | Autistic adults use diverse sensory and behavioral relaxation strategies. Visual, auditory, and somatosensory modalities are key. Preferences vary, underscoring the need for personalization. | Limited availability of sensory rooms; low personalization; risk of misunderstanding needs. | Individualized design: adjustable lighting, sound, noise isolation, spaciousness. | Highlights the need for personalized sensory spaces. Offers a toolkit and design principles based on empirical data. First systematic classification of sensory relaxation categories in autistic adults. |
| 15 | To study the importance of inclusive school environment design for students with special educational needs. | Primary school children with disabilities. | Theoretical analysis of inclusive design and learning environment principles. | Not available | Not specified | Inclusive classrooms must consider the unique needs of all learners. Physical space (furniture, lighting, ventilation, colors, therapeutic elements) plays a vital role in supporting sensory, language, and emotional development in children with disabilities. | Lack of a universal design approach; difficulty adapting for sensory and cognitive differences. | Support for varied learning formats (pair, group, independent), use of sensory elements, adapted interiors. | Emphasizes physical space as a key factor in inclusive learning. Proposes a practical approach to designing environments tailored to multisensory perception and the needs of young learners with disabilities. |

**Table 6.** (Continued)

| ID | Research Aim | Target Group | Methodology | Sample Size | Country / Region | Key Findings | Challenges / Barriers | Practical Recommendations | Originality / Value |
|---|---|---|---|---|---|---|---|---|---|
| 49 | To present a clinical case of a child with autism and psychotic symptoms and search for effective therapy. | One child | Detailed case study: diagnosis, behavioral intervention, pharmacological treatment, educational program. | 1 | Not specified | A 5-year-old boy with ASD developed egodystonic hallucinations, speech regression, and reduced social interaction. ABA, medications, steroids, and immunotherapy were largely ineffective. A multidisciplinary center provided broad support including music, physical, and occupational therapy. | Challenges in differential diagnosis of psychosis in autistic children; limited treatment efficacy; behavioral and sensory difficulties. | Individualized approach: combining ABA, therapies, parental support, and multidisciplinary assessment; focus on safety, sensory regulation, and extended diagnostics. | Describes a rare combination of autism and early psychotic symptoms; emphasizes the need for comprehensive multidisciplinary support and family-centered intervention. Details on medical evaluation, therapies, and educational strategies are included. |
| 50 | To identify teaching practices that promote inclusive learning environments in higher education. | 29 health and social service students | Appreciative Inquiry (AI), focused on identifying effective teaching practices. | 29 | Not specified | Identified 26 inclusive teaching practices and 5 resulting student outcomes. Based on Donabedian's model: structure (course/class setup), process (teacher-student interaction), and outcome (integration of both). | Alienation of BIPOC students; lower graduation rates compared to white students. | Implementation of recommended inclusive practices based on Donabedian's model to enhance student engagement and sense of belonging. | Provides an empirically validated set of inclusive teaching practices organized by structure/process/outcome model, enabling application across disciplines to support diverse student populations. |
| 51 | To develop a learning environment model using MOOCs to improve students' self-regulation. | 3 experts in design/technology, 80 high school students | Design research: theoretical analysis, surveys, pilot experiment. | 3 experts, 80 students (Khon Kaen Province) | Thailand | A 7-component learning environment model was developed: problem-based learning, resource room, self-regulation room, cognitive tools, collaboration, scaffolding, coaching. | Not explicitly stated; implies challenges in effective MOOC design and evaluation. | Implementation of the 7-component model to support autonomous learning and self-regulation skills. | Presents an integrated MOOC-based model for enhancing self-regulation, grounded in theory and empirically tested with high school students in Thailand. |

**Table 6.** (Continued)

| ID | Research Aim | Target Group | Methodology | Sample Size | Country / Region | Key Findings | Challenges / Barriers | Practical Recommendations | Originality / Value |
|---|---|---|---|---|---|---|---|---|---|
| 8 | To compare the effects of a VR sensory room and a physical sensory room on well-being and physiological indicators in psychiatric inpatients | Inpatients with bipolar disorder | Quasi-randomized study using self-assessment scales (VAS, MADRS-S, Beck Anxiety Scale, CGI); pre/post comparison | 60 participants (40 – VR, 20 – physical room) | Sweden | Both VR and physical sensory rooms improve well-being and reduce physiological arousal. No statistically significant difference between the two. VR can serve as an alternative when a physical room is unavailable. | Limited sample power, potential inter-departmental condition differences | Use VR sensory rooms as an alternative in resource-limited settings; consider individual responses to sensory stimuli | First study to show comparable effectiveness of VR and physical sensory rooms in psychiatric settings; highlights potential of digital solutions in healthcare |
| 17 | To present the EDU-AI machine learning model for automatic classroom layout generation at early design stages | Classroom layouts | Two-stage ML model (GAN + Pix2Pix); trained on standard projects from Turkish Ministry of Education; validated on external plans; SSIM used for evaluation | Sample size not explicitly stated; standard and synthetic data used | Turkey | The model can generate classroom layouts with satisfactory accuracy even with limited data. Applicable at the early design stage and adaptable to various typologies. | Limited training dataset; need for adaptation to different countries and school types | Use EDU-AI during early design stages; retrain model for local conditions | First study proposing an ML tool (GAN + Pix2Pix) for zoning and furnishing classroom layouts; high applicability in educational architecture |
| 21 | To study the impact of emotionally inclusive classroom climate on adolescent well-being and identify key teacher competencies | Adolescents in secondary school | Systematic literature review in ERIC and WoS databases using PRISMA protocol; JBI Critical Appraisal Tools | 32 studies (2016–2020) | Not specified | A positive association was found between emotionally inclusive classroom climate and adolescents' emotional well-being. Teachers play a critical role, and their training in emotional, interpersonal, and intercultural skills is essential. | Lack of adolescent-focused studies compared to primary education | Enhance teacher training in emotional and intercultural competencies; foster inclusive classroom climate | Provides a systematic overview of the importance of emotional climate in secondary education; highlights the undervalued role of teachers in adolescent support |

Theme 3: Emotional and Social Development of Children in Inclusive Education

**Table 6.** (Continued)

| ID | Research Aim | Target Group | Methodology | Sample Size | Country / Region | Key Findings | Challenges / Barriers | Practical Recommendations | Originality / Value |
|---|---|---|---|---|---|---|---|---|---|
| 22 | To describe a pilot virtual co-design session for jointly developing inclusive classroom norms | Engineering faculty and students | Virtual co-design session: teachers and students first discussed in separate groups, then together. Included surveys, idea artifacts, final norms, and observer reflections | Number not specified (noted as two stages: 20 and 40 min) | Not clearly stated | Sessions enabled the identification of exclusionary practices and proposals for inclusive norms. Revealed both explicit and implicit power dynamics between and within groups. | Power imbalances among participants; limited co-design experience | Structure co-design sessions with attention to power dynamics; ensure safe space for equal contribution | Valuable contribution to inclusive educational practices in engineering, emphasizing social interaction and power dynamics |
| 52 | To validate the PIQ (Perception of Inclusion Questionnaire) scale with a Swedish sample of students with and without SEN | 5th and 8th grade students in inclusive schools | Used PIQ to measure emotional/social inclusion and academic self-concept | Exact number not provided | Sweden | Students with special educational needs (SEN) had lower emotional inclusion and academic self-concept. 8th-grade girls reported lower academic self-concept than younger girls and boys. However, girls with SEN had higher self-concept than boys with SEN. | Gender, age, and SEN status complicate result interpretation | Consider gender and age when assessing perceptions of inclusion and academic self-concept; adapt support strategies accordingly | Confirms PIQ applicability in Sweden; identifies previously unreported gender differences in this age group |
| 53 | To assess the impact of classroom inclusive norms on children's expectations and reasoning about including peers with learning difficulties | 3rd–6th grade students (M = 10.2 years) | Multilevel analysis of children's responses to scenarios involving inclusion of peers with learning difficulties | 1019 students | Switzerland | Children expected less inclusion from friends and fictional characters than from themselves. Inclusive norms positively influenced both personal and peer-expected behaviors. Stronger perception of norms reduced concerns about group success. | Individual differences in perceiving inclusive norms may hinder inclusion | Psychologists should strengthen students' perception of inclusive norms and consider individual differences | The study includes multiple perspectives (self, friends, and third-person characters), demonstrating the role of subjective norm perception in inclusion attitudes |

Theme 4: Analytical Tools and Systematic Reviews of Inclusive Practices

**Table 6.** (Continued)

| ID | Research Aim | Target Group | Methodology | Sample Size | Country / Region | Key Findings | Challenges / Barriers | Practical Recommendations | Originality / Value |
|---|---|---|---|---|---|---|---|---|---|
| 26 | To conduct a systematic review of best inclusive teaching practices across countries | Not applicable (literature review) | Systematic literature review | Not specified | International | Five key categories identified: use of ICT, individualized learning, classroom management methods, collaboration, and curriculum adaptation | Implementing inclusion in diverse educational contexts is complex | Use technology, adapt curricula, individualize instruction, and apply flexible classroom management strategies | A comprehensive and structured global review of inclusive teaching practices, with clearly identified categories of effective approaches |
| 28 | To describe the development of an inclusive physical education teaching model for children with special educational needs | Children with special educational needs | Qualitative research, participatory action approach | Not specified | Colombia | The process included four stages: diagnosis, model design, implementation of teaching units, and evaluation. Emphasized the importance of shifting from integration to full inclusion. | Need for systemic change and active involvement of all participants | Use participatory approach; develop adapted programs involving both teachers and students | Practical case of inclusive PE teaching model creation in a specific school using a participatory methodology |
| 27 | To explore barriers to implementing inclusive education in Kazakhstan and other countries | System level | Comparative analysis of legislation and research | Not specified | Kazakhstan and others | A general commitment to inclusion was noted, yet subjective barriers persist globally: negative attitudes, lack of training and experience. Only a few countries have moved from policy to real practice. | Insufficient teacher training, subjective attitudes toward inclusion, lack of practical experience | Early and specialized teacher education in inclusive practices, including internships in relevant classrooms | Justifies the need for both mental and professional preparation of teachers as a key condition for effective inclusion implementation |
| 29 | To examine SOAR factors (Strengths, Opportunities, Aspirations, Results) promoting inclusive education | Teachers and administration of an inclusive school in Karachi | Qualitative study (semi-structured interviews, case study) | 16 participants | Pakistan | The inclusive school demonstrates successful practices through emphasis on social connection, integration of daily activities in learning, and focus on the strengths of students with SEN. Teachers are motivated by the school's inclusive vision and adjust teaching methods accordingly. | Doubts among teachers and administrators about broad inclusion in mainstream schools | Create a supportive environment, foster social relationships, use real-life activities in teaching | A case of successful inclusive schooling in a developing country; uses the SOAR framework to analyze inclusive practices and teacher motivation |

**Table 6.** (Continued)

| ID | Research Aim | Target Group | Methodology | Sample Size | Country / Region | Key Findings | Challenges / Barriers | Practical Recommendations | Originality / Value |
|---|---|---|---|---|---|---|---|---|---|
| 10 | To identify and characterize inclusive teaching practices and classroom climate from students' perspectives | Undergraduate college students | Qualitative research (analysis of students' open-ended responses) | 365 students | USA (public and private institutions) | Students emphasized the importance of a respectful, open, and welcoming atmosphere. Inclusive teaching positively affects all students, particularly those with disabilities and from ethnic minorities. Specific behaviors of teachers and peers that facilitate or hinder inclusion were identified. | Variations in perceptions of inclusion; inconsistent inclusive behavior by faculty and students | Develop skills in respectful communication, active listening, and support for diversity in the classroom | Elevates student voices as a data source; covers a range of university types; offers practical guidance for faculty on fostering an inclusive environment |
| 30 | To assess the implementation of a Pandemic Action Plan with a focus on telemedicine technologies | Medical institutions (hospitals) | Multi-phase project (3 stages), interviews with heads of 8 hospitals, structured expert group discussion | 8 institutions | USA | Tools and strategies from the developed Action Plan helped overcome critical challenges during the COVID-19 pandemic. Implementation was most effective in organizations that had already integrated telemedicine into daily operations. Adoption of new technologies during a crisis proved difficult. Ongoing preparedness enhances healthcare resilience in emergencies. | Lack of preparedness for telemedicine use; challenges in urgent adoption of tools | Integrate telemedicine solutions and emergency response plans into daily institutional operations before crises occur | Empirical evaluation of a pandemic response plan; involvement of leading healthcare experts; interviews with 8 institutions that applied the plan |

making at both the school and educational governance levels.

## Discussion

The aim of this study was to analyze the directions and features of scientific publications related to inclusive education, with a focus on spatial environment design, pedagogical support, socio-emotional development, and systematic evaluation of practices. The results revealed a consistent trend toward expanding the scope of inclusion, incorporating interdisciplinary approaches, and strengthening the empirical grounding of conclusions.

The findings align with existing systematic and thematic reviews that emphasize the value of topic modeling algorithms for analyzing large text corpora in the humanities and education. For example, Jacobi et al. [34] demonstrated that the LDA method reliably identifies latent thematic structures and enables quantitative interpretation of content patterns in texts. Albalawi et al. [35] confirmed the applicability of LDA to the analysis of short texts such as abstracts and metadata of academic publications, which is particularly relevant for the present study. Unlike reviews focused mainly on theoretical models, this study is based on an empirical corpus of publications. It demonstrates how semantic links between terms reflect dominant research directions in the field of inclusion and educational environment design.

Moreover, the results obtained are consistent with the findings of the reviews by Mitchell [23] and Sharma et al. [24], which confirm the necessity of a systematic approach to inclusive education. However, unlike these works, the present study emphasizes the visualization of semantic connections between key concepts of inclusion. In the review by Black-Hawkins [25], the focus is placed on institutional indicators of inclusivity. Our approach is based on pairwise semantic analysis, which enables the identification of latent thematic interconnections.

*Theme 1: Inclusive Education and Pedagogical Support*

The topic of inclusive education remains one of the key priorities in contemporary educational science, especially in the context of shifting from the formal declaration of inclusion to its meaningful implementation in educational practice. Analysis of recent studies shows that successful inclusion is impossible without rethinking pedagogical strategies, transforming organizational culture, and developing the professional identity of educators [9, 11, 47].

Other studies emphasize the importance of differentiated and collaborative teaching, the use of ICT, and the creation of an inclusive classroom climate as key components of inclusive pedagogy [39, 43, 44]. At the same time, persistent barriers have been identified, including insufficient training of specialists, a low level of institutional support, pedagogical misconceptions, and a superficial understanding of the concept of inclusion itself [9, 11, 40].

Considerable attention is given to the transformation of teachers' professional thinking and the development of sustainable professional communities that facilitate experience sharing and the collective search for inclusive solutions [47]. Some studies demonstrate that a positive attitude toward inclusion is linked to self-efficacy and job satisfaction [41, 42, 46]. An important contribution to the field is the consideration of cultural and organizational context, which broadens the understanding of inclusion and enhances the applicability of research across different countries and educational systems [40, 43, 45].

Overall, the reviewed studies confirm that inclusion requires not only a regulatory framework but also a profound transformation of pedagogical practice. This aligns with the findings of the European Agency for Special Needs and Inclusive Education, which stresses the need to shift from a "services" model to a "participation" model in education, where the teacher plays a central role [11].

Comparison with other sources shows that in countries with a higher level of teacher training and a well-developed supportive educational environment, the level of acceptance and effectiveness of inclusion is significantly higher. For instance, as demonstrated in [39], the use of digital tools and co-teaching has a positive impact on the engagement of all students. In contrast, studies from countries with fragmented teacher training (e.g., [40]) reveal limited implementation, even when political support is present.

Interpretation of the data suggests that pedagogical support should be viewed as a systemic phenomenon. It must include not only training in inclusive teaching methods but also the development of an attitude of acceptance toward diversity. The latter requires a stable institutional culture. In this context, teachers' self-efficacy and professional well-being serve as mediators between educational policy and the quality of inclusive practice [41, 42].

Thus, despite the significant accumulation of data, there is still a lack of studies that consider the interaction of systemic factors, including institutional mechanisms, cultural context, and the resilience of professional communities. This highlights the need for future multifactorial research aimed at integrating pedagogical support into the broader context of educational reform.

*Theme 2: Spatial Organization of Inclusive*

*Environments and Interior Design*

The spatial organization of inclusive environments is emerging as a crucial direction in both research and design practice, as architectural and digital solutions have a direct impact on the quality of inclusive education. Studies on sensory adaptation of spaces highlight the importance of environmental factors for the emotional and cognitive comfort of learners. For example, the study by Jawad [15] thoroughly examines lighting, ventilation, and color design parameters that support sensory balance in children with disabilities. Similarly, the study by Mccabe et al. [16] emphasizes a personalized approach to designing sensory spaces for adults with autism spectrum disorders.

The development of digital solutions opens new horizons for shaping inclusive environments. According to the findings of Ilioudi et al. [8], virtual sensory rooms prove to be an effective alternative to physical spaces, especially in situations with limited access. A promising direction is the application of artificial intelligence [17], which enables the automatic generation of inclusive classroom layouts during the design phase, thereby simplifying the implementation of universal design principles.

However, the implementation of such solutions is accompanied by several challenges. Multiple publications [48, 49] emphasize the lack of universal standards as well as the insufficient consideration of cultural differences and individual needs in architectural designs. This underscores the need for an interdisciplinary approach involving collaboration among architects, educators, and sensory integration specialists.

The interpretation of the presented data suggests that the spatial environment should not be viewed merely as a physical shell but as an active participant in the educational process. In this context, space can either enhance or restrict inclusive opportunities. Research confirms that well-designed learning environments help reduce anxiety, improve attention, and foster positive interactions among learners, including those with disabilities [8, 15].

Comparative analysis with other studies shows that the most successful projects are implemented through close cooperation between architects and educators. This approach is supported by the findings of Mccabe et al. [16], who emphasize the need to develop universal educational spaces based on principles of multi-level sensory stimulation. Moreover, the results demonstrate that even minor architectural modifications, such as the introduction of "quiet zones" or tactile navigation, can significantly improve the accessibility of the educational environment.

Although architectural adaptation is recognized as an essential component of an inclusive setting, the pedagogical motivation behind spatial decisions requires further clarification. Specifically, the flexible organization of learning space creates conditions for differentiated instruction by supporting group work, pair activities, and individualized learning paces. As a result, spatial parameters function not just as environmental conditions but as an active tool for implementing inclusive pedagogical strategies.

The implications of these studies highlight the need to implement inclusive design standards as mandatory components of architectural evaluations for educational institutions. There is also a clear demand for the development of prototypes and pilot solutions that can be replicated. This approach is particularly relevant for regions with limited budgets or complex infrastructure. The use of digital technologies, including virtual and augmented reality, can serve as a valuable resource for modeling inclusive environments during the early design phase.

As a result, space in an inclusive school is no longer a neutral backdrop but becomes a tool for pedagogical and social interaction. However, the widespread adoption of such solutions requires systemic support, interdisciplinary collaboration, and consideration of cultural and behavioral diversity, which opens up a broad field for future research.

*Theme 3: Emotional and Social Development of Students in Inclusive Education*

Emotional and social development of students in inclusive educational settings is becoming the focus of an increasing number of empirical and theoretical studies. A close relationship has been confirmed between classroom climate and adolescents' emotional well-being. A systematic review by Iglesias-Diaz et al. [21] emphasizes the importance of preparing teachers to work within emotionally diverse and intercultural environments. The influence of inclusive norms on students' attitudes toward peers with special educational needs (SEN) was analyzed in the study by Barth and Gruetter [53]. The authors found that a positive perception of norms fosters greater willingness to cooperate and reduces concerns about the group's academic performance.

Gender and age differences in perceptions of inclusion were explored in the study by DeVries et al. [52], which identified variations in academic self-esteem between boys and girls, as well as between students with and without SEN. This highlights the need for individualized psychological and pedagogical support. At the same time, the study by Mejia et al. [22] demonstrates the potential of co-design as a tool for shaping inclusive norms. Collaborative efforts between students and educators help reveal underlying power dynamics and foster norms that ensure more equitable

interactions within the learning group.

The interpretation of the findings confirms that students' socio-emotional well-being in inclusive settings depends not only on being educated together but also on the quality of interpersonal interactions developed within the classroom. It is important to note that the emotional comfort of students with SEN is closely linked to their peers' attitudes and teachers' behavioral dispositions [21].

Comparison with other studies shows that a positive classroom climate, participation in joint projects, and inclusive communication ethics significantly increase students' empathy and reduce anxiety levels [53]. The gender differences revealed in self-esteem and perception of inclusiveness further emphasize the need for flexible forms of psychological support and interdisciplinary guidance, especially during adolescence [52].

These findings imply the necessity of targeted teacher training for managing emotional dynamics in inclusive classrooms. In this context, co-design can serve not only as a tool for spatial adaptation but also as a means of building shared values [22]. Such recommendations help make pedagogical practice more deliberate and resilient to conflict.

In summary, the topic of emotional and social development becomes central in the discussion of inclusive education quality. This area requires a comprehensive approach that integrates pedagogical, psychological, and cultural dimensions.

*Theme 4: Analytical Tools and Systematic Reviews of Inclusive Practices*

An analysis of the publications revealed a growing interest among researchers in developing a comprehensive understanding and evaluation of the effectiveness of inclusive education. Most studies are based on systemic approaches and international data, which allows researchers to identify both universal and context-specific features of inclusion implementation [26, 27]. Considerable attention is given to practical experiences, ranging from the development of teaching models involving children with special educational needs (SEN) to the adaptation of existing strategies that take into account cultural and organizational conditions [28, 29].

Professional development of teachers, the creation of a respectful and open atmosphere in educational settings, and the inclusion of student perspectives are seen as key conditions for establishing effective inclusive practices [10]. Furthermore, the studies emphasize the importance of the readiness of educational and social institutions to apply inclusive technologies not only under normal circumstances but also in crisis situations [30].

A unifying element across the reviewed research is the focus on evidence-based and reproducible approaches to evaluating inclusion, as well as a commitment to translating educational policy into practical action.

The findings of the analysis on assessment tools and systematic reviews of inclusive practice indicate a growing trend toward a structured and international approach to inclusion research. Studies confirm that systemic analytics not only enable the identification of inclusion levels across different countries and institutions but also help to establish strategic benchmarks for educational policy [26, 27]. The interpretation suggests that the demand for systemic models arises from the need to consider a wide range of factors, from interpersonal interaction at the micro level to education policy at the macro level. At the same time, several publications emphasize that universal frameworks must be adapted to specific cultural and organizational contexts [28, 29].

Comparison with other approaches highlights the importance of involving students in assessment processes. This approach not only enhances the relevance of the results but also strengthens the agency of educational stakeholders. Moreover, the use of digital and telecommunication tools broadens the concept of inclusion as a flexible and adaptive system [30].

The implications point to the need for further integration of research findings into practice. Without effective mechanisms for translating research results into educational and administrative action, the principles of inclusion risk remaining merely declarative.

*Geographical Diversification of the Analyzed Sources*

In addition to the thematic analysis, an important outcome of the review was the identification of the geographical representation of the publications, which broadens the interpretation of inclusion-related themes by incorporating regional contexts. A key aspect of interpreting the identified thematic directions is the geographical coverage of the analyzed literature, which expands the framework of inclusive education analysis by accounting for intercultural and institutional diversity.

European experience is widely represented through studies from the United Kingdom (Florian & Beaton [3]; Imrie [12]), Austria (Schwab [18]), Netherlands (De Boer et al. [20]), Portugal (Laranjeira et al. [42]), and Greece (Ioannidi & Malafantis [1]). These publications focus on systemic pedagogical support, the role of teachers, and the development of emotional climate in educational settings.

Canada and Australia also play a significant role: Loreman [6] advances the concept of inclusive pedagogy, while Byers & Imms [14] and Lawrie et al. [4] emphasize the importance of physical space and architectural flexibility in implementing inclusive

strategies.

*Countries with Transitional and Emerging Educational Systems*

Publications from India (Ramchand [40]; Sharma et al. [24]), South Africa (Walton & Rusznyak [7]), Thailand (Nopas [9]), Indonesia (Kurniawati [39]), Kazakhstan (Maulsharif et al. [27]), Pakistan (Kamran et al. [29]), Ukraine (Udych et al. [45]), and Colombia (Cruz et al. [28]) represent countries with transitional and emerging educational systems. These studies highlight challenges related to resource limitations, insufficient teacher training, and sociocultural barriers to inclusion.

International and multinational reviews, such as those by Mitchell [23] and country-level syntheses (Lawrie et al. [4]), provide a broader analytical framework, enabling comparison of national strategies and identification of global patterns.

Thus, the geographical diversification of sources confirms both the universality of certain inclusion-related themes and the need to adapt inclusive approaches to specific national contexts. This foundation supports future comparative research and facilitates transnational exchange of effective educational practices.

*Relevance of Identified Themes to Physical Education Practice*

Although most of the analyzed publications focus on cognitive, social, and spatial inclusion, several solutions and methodological approaches are directly relevant to the field of physical education and sports pedagogy. For example, the study by Cruz et al. [28] proposed an inclusive physical education plan for younger students that emphasizes the importance of adaptive motor activities and flexible teaching. Kamran et al. [29] analyzed inclusive practices in a Pakistani school using the SOAR method and demonstrated that physical activity and its pedagogical organization play a key role in fostering a positive inclusive learning experience.

Moreover, many strategies discussed in other thematic sections, such as spatial transformation, sensory regulation, tutor support, and variability in instructional formats, are applicable in physical education contexts. In such settings, inclusion requires coordinated consideration of motor, social, and emotional components. Therefore, the findings and conceptual conclusions have strong potential for application in inclusive physical and sports education practice, particularly in the design of learning environments, organization of group activities, and provision of pedagogical support.

*Summary of Findings Across Thematic Areas*

While themes such as inclusive pedagogy, spatial design of learning environments, and social support have already attracted scholarly attention, the novelty of this study lies in its interdisciplinary integration of these aspects through semantic modeling. The thematic structuring of the literature corpus enabled the identification of hidden interconnections among architectural, pedagogical, and institutional components of inclusion, which have not been systematically addressed in previous reviews.

The identified thematic clusters not only confirm stable directions in inclusive practice but also help to establish practical guidelines for different target groups of professionals:
• For educators, key priorities include fostering an emotionally safe environment, applying differentiated approaches and digital tools, and participating in the formation of inclusive norms.
• For architects and designers, priorities involve applying universal design principles, ensuring sensory adaptability, organizing classrooms with flexibility, and accounting for cultural differences.
• For administrators, important tasks include institutionalizing inclusive support, integrating relevant competencies into professional standards, and ensuring interdisciplinary collaboration.

Therefore, the findings have clear practical applicability in both educational and architectural design contexts.

Furthermore it should be emphasized that systematic reviews and assessment tools are not only a reflection of the current state of inclusion but also serve as instruments for its sustainable development. This approach fosters evidence-based decision-making, enhances the accountability of educational institutions, and strengthens the connection between policy and practice. Their use makes it possible to identify weak points in the implementation of inclusive strategies and to suggest specific directions for improving educational approaches. Through systematic analysis, it becomes feasible to monitor change dynamics, assess program effectiveness, and build representative databases essential for comparative international studies. These tools also promote more active involvement of all stakeholders in the development and implementation of inclusive solutions. All of this highlights the need for continuous methodological updates and the advancement of multidisciplinary approaches in inclusion assessment.

The findings are not only of analytical value but also offer practical guidance for the advancement of pedagogical theory and educational policy. In particular, the thematic core related to architectural adaptation, emotional climate, and pedagogical support underscores the need to integrate institutional and spatial mechanisms in the design of teacher training programs. This confirms that inclusion cannot be treated solely as a pedagogical issue but requires alignment among educational policy, environmental design, and teacher preparation.

Therefore, the results of this review can serve

as a foundation for recommendations to reform pedagogical standards, in which an interdisciplinary model of teacher training for inclusive classrooms should be embedded.

*Limitations of the Study*

The conducted study has several limitations that should be considered when interpreting the findings. First, the analysis included only publications in English, which may have led to the exclusion of important studies published in other languages. This is especially relevant for research from countries with developing inclusive education systems. Second, the timeframe was limited to a five-year period. While this made it possible to reflect current trends, it excluded earlier foundational studies that contributed to the development of inclusion theory. Additionally, the data source was limited to the Web of Science database, which narrows the overall coverage. It is likely that a number of relevant studies are indexed in other academic databases and registries.

One of the methodological limitations of this review is the use of LDA modeling, in which the initial iteration resulted in a topic coherence score of less than 0.5. Although further calibration of the model, including adjustments to the number of topics and improvements to dictionary filtering, enhanced the interpretability of the topics, the initially low coherence score may indicate partial thematic overlap or insufficient topic separation [33, 34, 35]. Such parameters are typical for texts in the humanities, which often contain high thematic interconnection and complex terminology. Nevertheless, the interpretation results were manually verified and aligned with the context of inclusive education, which improved their substantive validity.

Additional methodological limitations include the dependency on the quality of source metadata in the Web of Science database, the possibility of semantic distortions during automated text processing, and the restricted scope of English-language publications. Despite the high coherence of the topic models, their interpretation requires consideration of cultural and contextual differences.

A separate limitation is the focus on school education. The analysis did not include publications related to inclusion in the field of adult education. This leaves out important aspects of lifelong learning and social adaptation. In addition, some architectural and design solutions aimed at creating a comfortable and supportive learning environment in institutions with unique cultural and regional characteristics were not considered. These limitations indicate directions for future, broader research.

## Conclusions

The present study made it possible to systematize the key directions of scholarly reflection in the field of inclusive education based on thematic modeling of publications.

Theme 1. Inclusive education and pedagogical support. The importance of creating an emotionally supportive environment, developing teachers' professional competencies, and using digital tools in inclusive settings was confirmed.

Theme 2. Spatial organization of the inclusive environment. Spatial solutions play an active role in supporting inclusive scenarios. The need for flexible, multisensory, and personalized architecture of educational spaces was highlighted.

Theme 3. Emotional and social development. The role of a positive social climate, emotional engagement, and student participation in shaping inclusive norms was emphasized as factors of sustainable integration.

Theme 4. Systematic assessment and analytical tools. An increase in the use of digital and evidence-based methods aimed at standardizing and ensuring the reproducibility of inclusive practice evaluation was noted.

The systematic review identified areas where further research can contribute to a deeper understanding and practical implementation of inclusive education. This includes the evaluation of the effectiveness of applied strategies, adaptation of solutions to diverse contexts, and the development of new tools for monitoring and supporting inclusive practices.

## Conflict of Interest

One of the authors (Wladyslaw Jagiello) serves as the Deputy Editor and publisher of this journal. Another author (Tetiana Yermakova) is a member of the editorial board. To ensure objectivity in the review process, the manuscript was assessed by an independent editorial board member and reviewed by external reviewers who have no association with the authors. The Deputy Editor and the editorial board member did not participate in the peer review or editorial decision-making regarding this manuscript. The other co-authors (Iryna Bondarenko, Vladyslav Kutateladze) declare no conflict of interest related to this publication.

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# Effects of technical drill and plyometric training on shot accuracy in tennis athletes aged 16–19 with different agility levels

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## Abstract

| | |
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| *Background and Study Aim* | Accuracy in tennis represents an important element of technical performance, contributing to successful shot execution during match play. Agility, as one of the physical components, can influence an athlete's ability to reach optimal positions and maintain control during strokes, which may affect shot accuracy. Although various training methods are used to target agility and accuracy, their relative effectiveness continues to attract practical interest. This study aimed to analyze and empirically examine the effect of technical drill and plyometric training on accuracy, considering the agility levels of tennis athletes. |
| *Material and Methods* | This experimental study employed a 2 × 2 factorial design, involving an experimental group (EG) and a control group (CG). The sample consisted of 24 athletes, allocated through ordinal pairing using the A-B-B-A method based on initial agility test results. The groups were categorized as A1B1 (EG-High Agility), A1B2 (EG-Low Agility), A2B1 (CG-High Agility), and A2B2 (CG-Low Agility). The intervention consisted of technical drill and plyometric training (EG) and routine training (CG). It was implemented over six weeks, with three sessions per week. Training dosage for the technical drill was 3–5 sets, 8–12 repetitions, with 60–120 seconds of recovery at 60–85% intensity. For plyometric training, the dosage was 3–5 sets, 10–20 repetitions, with 60–180 seconds of recovery at 85–95% intensity. Data were collected using the Illinois Agility Test and the Groundstroke Accuracy Test. |
| *Results* | Two-way ANOVA results showed a significant effect of the experimental program on accuracy (F = 33.608, $p < 0.001$), with a high coefficient of determination ($R^2 = 0.834$, or 83.4%). Tukey's HSD post hoc test revealed that A1B1 outperformed A2B1 and A2B2 ($p < 0.001$). A1B2 also performed significantly better than A2B1 and A2B2 ($p < 0.001$). The findings demonstrate that a six-week program combining technical drills and plyometric training significantly and effectively improved shot accuracy in tennis athletes aged 16–19. |
| *Conclusions* | The training model examined in this study reflects a structured integration of technical and physical components in tennis practice. Its application may inform program development aimed at supporting targeted performance characteristics in adolescent athletes. Such integration also aligns with pedagogical principles of holistic athlete development, where motor learning is enhanced through purposeful coordination of physical and technical stimuli in training contexts. |
| **Keywords**: | tennis performance, technical drills, plyometric training, agility, shot accuracy |

## Introduction

Tennis performance at the competitive youth level involves the integration of technical precision and physical responsiveness under conditions of speed and pressure. Shot accuracy is one of several factors that may influence point outcomes, match control, and tactical decision-making. This ability is shaped not only by stroke technique but also by the athlete's capacity to reach optimal positions, adjust movement patterns in real time, and execute controlled strokes, which are capacities associated with agility as a contributing physical attribute.

In this context, shot accuracy in tennis can be understood as a performance element grounded in the principles of motor learning and precise movement control [1]. During a fast and dynamic tennis match, the ability to place the ball in difficult-to-reach areas or to execute a decisive serve contributes to point outcomes and game flow [2]. Accuracy not only supports the implementation of pre-planned strategies but also challenges the opponent's positioning, creating opportunities and influencing the tempo of play. As a result, structured training that emphasizes consistent repetition is commonly used to develop the motor patterns required for accurate execution [3].

Several factors influence accuracy, including muscle strength, hand-eye coordination, mental concentration, and fundamental stroke techniques [4]. However, among these factors, agility plays an

important role in the context of motor control and quick decision-making. This is particularly relevant for tennis players aged 16–19 years, who are in a stage of advanced physical and technical development [5]. Optimal agility allows athletes to reach an effective position before striking. This enables them to apply proper techniques and generate accurate shots [6, 7]. Conversely, insufficient agility causes delays in reaching the ball. It leads to off-balance strokes and ultimately results in inaccurate or erroneous shots [8]. Therefore, agility development is important to support accuracy, especially during this phase when the integration of physical and technical elements shapes performance.

Various training models have been developed and implemented in sports training programs to enhance both agility and accuracy. Common agility drills include ladder drills, cone drills, shuttle runs, and rapid change-of-direction exercises [9, 10, 11]. These are all designed to improve reaction speed and movement coordination. Meanwhile, accuracy can be improved through target practice, basket drills, and systematic repetition of basic shooting techniques. These methods focus on building muscle memory and forward pass control [12, 13, 14].

However, previous studies and systematic reviews on the effects of plyometric training in tennis athletes, such as those conducted by Deng et al., reported positive effects on agility and explosive power. At the same time, they found no definitive evidence that plyometric training alone can improve accuracy [15]. This indicates a gap in understanding the most effective training combinations. Therefore, further exploration of the effectiveness of combining technical and plyometric training is needed, particularly in programs aimed at improving agility and accuracy in tennis athletes aged 16 to 19. In addition, studies that examine whether baseline agility levels influence the training outcomes remain relatively scarce in the current research literature.

When combined, technical drills and plyometric training have potential for enhancing both agility and accuracy. Technical drills emphasize repetitive practice of tennis-specific movements, such as forehand, backhand, serve, and volley. These drills are aimed at internalizing efficient movement patterns and minimizing errors through repetition and refinement [3]. Through consistent repetition and corrective feedback, athletes can refine stroke biomechanics, which directly contributes to accuracy improvement.

In contrast, plyometric training involves explosive movements such as jumping and bounding. This type of training enhances muscular power, speed, and overall explosiveness [15]. These improvements lead to better on-court agility and allow athletes to reach the ball more quickly. As a result, they can strike with greater power and control, which may indirectly improve accuracy [16]. The structured combination of these two types of training is expected to support accuracy development by addressing both physical capacity and technical execution.

Analysis of research findings has shown that combined physical and technical training methods may lead to improvements in both agility and shot accuracy in adolescent tennis athletes. Researchers emphasize that the interaction between explosive strength and motor coordination plays an important role in optimizing performance outcomes. Authors also point out that athlete-specific factors, such as baseline agility, may influence how training adaptations occur. Nevertheless, certain unresolved aspects still limit the development of clearly defined and widely applicable training strategies. This gap continues to hinder the formulation of structured programs that effectively integrate technical and physical components for targeted accuracy improvement.

To address this gap, the present study focuses on the relationship between combined technical and physical training and shot accuracy in adolescent tennis players, taking into account individual differences in agility. Particular attention is given to the context of regional Indonesian athletes, where training environments and physiological characteristics may differ from those in other populations. This focus is intended to support a better understanding of how combined technical and plyometric training may influence shot accuracy in youth tennis players, depending on their baseline agility characteristics.

## Materials and Methods

### Participants

The study population included all tennis athletes in Tasikmalaya City, Indonesia. Sampling was purposive, with the following inclusion criteria:
- active athletes,
- regional championship winners,
- aged 16–19 years,
- free from injury,
- not engaged in competition-specific training.

Based on these criteria, 24 athletes were recruited.

The characteristics of male athletes (mean ± SD) were as follows:
- Age: 17.7 ± 0.9 years (range 16.3–19.0)
- Height: 167.9 ± 1.5 cm (range 165.3–170.3)
- Weight: 59.1 ± 1.5 kg (range 57.1–61.7)

The characteristics of female athletes were:
- Age: 17.6 ± 0.6 years (range 16.7–18.9)
- Height: 166.0 ± 1.0 cm (range 164.2–167.6)
- Weight: 51.9 ± 1.1 kg (range 50.1–53.7)

Following ordinal pairing, the experimental group (EG) consisted of 12 athletes (six male, six female), and the control group (CG) also consisted of 12 athletes (six male, six female).

*Ethical Considerations*

Ethical approval was obtained (Permit No. 05/UN58.10/PT/2024), and all procedures complied with ethical standards to protect participants' rights and welfare. Since the participants were underage athletes (aged 16 to 19), informed consent was obtained from each athlete's parent or legal guardian. In addition, verbal assent was provided by the athletes themselves after a clear explanation of the study's purpose, procedures, risks, and potential benefits. Participation was voluntary, and athletes had the right to withdraw from the study at any time without consequences. The study was conducted at the Siliwangi University tennis courts in Tasikmalaya, Indonesia. This location was selected for its accessibility and suitability for close monitoring, which helped ensure adherence to the protocol and maintain internal validity.

*Research Design*

This study employed an experimental design using a 2 × 2 factorial model, involving two groups: an experimental group (EG) and a control group (CG). Both groups completed pretest and posttest measurements.

The EG received a combined intervention consisting of technical drills and plyometric training. In contrast, the CG received no specific training intervention but instead participated in routine tennis training. This included unstructured fundamental technique practice, free game play, and general warm-up and cool-down activities. The CG served as a comparison group to assess the effects of the intervention applied to the EG.

To ensure group equivalence, participants were assigned using ordinal pairing with the A-B-B-A method. This process resulted in four subgroups:
• A1B1 (EG – high agility),
• A1B2 (EG – low agility),
• A2B1 (CG – high agility),
• A2B2 (CG – low agility).

Athletes were first ranked by their pretest agility scores, separated by gender, from highest to lowest. This pairing method minimized group allocation bias and ensured balanced distribution across conditions. As a result, observed posttest differences could be more confidently attributed to the intervention.

*Intervention Programs and Instruments*

The main intervention program, consisting of technical drill and plyometric training for the experimental group (EG), was adapted from previous research. Modifications were made to training load and track distance to match the characteristics and performance levels of athletes aged 16 to 19, as well as to reflect available facilities. The intervention lasted for 6 weeks and included 18 sessions, with three sessions per week. Training was conducted on Mondays, Wednesdays, and Fridays from 4:00

PM to 6:00 PM. The control group (CG) followed a regular training routine without exposure to the intervention. However, it matched the EG in training time, general activity format, and training location.

To ensure safety and minimize the risk of injury, especially given the high intensity of plyometric training, the EG participants completed an adaptation phase before starting the intervention. This phase consisted of two weeks (six sessions) of core training, aimed at preparing the neuromuscular system and reducing injury risk [17, 18]. The training load included three sets of 8–12 repetitions, with 60–120 seconds of recovery.

Upon entering the main training program, each experimental group (EG) session, which combined technical and plyometric components, followed this structure: warm-up, technical exercise, plyometric exercise, cool down, and evaluation. This sequence was selected to optimize training effectiveness. Technical drills, which require concentration and precision, were performed first to avoid interference from neuromuscular fatigue. Plyometric exercises, which demand maximum explosive power, were conducted afterward. All training sessions were supervised by one head coach and two assistant coaches. All were qualified in tennis coaching and in strength and conditioning. Their role was to ensure standardized instruction and to closely monitor movement accuracy and training dosage.

The technical drill program included seven exercise models [19]:
• Forehand Turn Core
• Forehand Turn Cone Back Cone
• Forehand Forward Direction
• Forehand Hurdle Jump
• Forehand Sideways
• Forehand Turn Cone Center Service to Baseline
• Forehand One Way Service Center to Baseline.

These drills have previously been shown to improve forehand and backhand performance in amateur tennis players aged 15 to 19 years [3]. The training dosage was 3 to 5 sets of 8 to 12 repetitions, with 60 to 120 seconds of recovery between sets, performed at 60 to 85 percent intensity.

The plyometric training program was structured progressively as follows:
• Week 1: Squat jumps, reverse lunge knee ups, burpees
• Week 2: Clapping push ups, box jumps, stairway hops, tuck jumps
• Week 3: Lateral bounds, squat thrusters, plyometric lateral lunges, reverse lunges with knee up
• Week 4: Box drill, frog squat jumps, long jumps, burpees with tuck jumps
• Week 5: Lateral triple jumps, alternating lunge jumps, judo rolls with jumps, kneeling jump squats
• Week 6: Single leg deadlifts into jumps, pistol squats, horizontal jumps to tuck jumps, snowboard hops, skater hops

The plyometric load was 3 to 5 sets of 10 to 20

repetitions, with 60 to 180 seconds of recovery, performed at 85 to 95 percent intensity [5, 20]. This progression was designed to gradually increase the volume and complexity of explosive movements, targeting the power and agility demands of tennis.

Agility was measured using the Illinois Agility Test, which has a reported reliability coefficient greater than 0.83 for tennis athletes [21, 22]. Accuracy was assessed using the Groundstroke Accuracy Test [23, 24, 25]. The test setup included a target grid made of contrasting colored tape, carpet, or mat. The grid was divided into three zones. Additional equipment included a ball feeder (ball machine), scoring sheets, and optionally a camera to validate shot placement. Scoring criteria were as follows:

- Bullseye (a two-by-two meter box near the baseline corner or cross court) = 3 points
- Medium zone (three by three meter area) = 2 points
- Outside the target but within the court = 1 point

During the test, athletes performed ten forehand and ten backhand strokes. Each shot was executed after one bounce. Serving and volleying were not included.

*Statistical Analysis*

Data were analyzed using two way ANOVA. Since the analysis revealed a significant interaction effect, further comparisons were conducted using the Tukey HSD (Honestly Significant Difference) test. Tukey's HSD was selected because it strictly controls the family wise error rate and reduces the risk of Type I error in multiple comparisons. This post hoc test is particularly appropriate when the assumptions of normality and homogeneity of variances are met. All statistical analyses were performed using SPSS version 27 [26].

## Results

The initial phase of the analysis involved descriptive statistics to provide an overview of the pretest and posttest scores for both accuracy and agility across all subgroups (A1B1, A1B2, A2B1, and A2B2). To determine whether the data met the assumptions for parametric analysis, normality was assessed using the Shapiro–Wilk test. The descriptive values and normality test results for each group are presented in Table 1.

As shown in Table 1, all Shapiro–Wilk test results yielded p-values greater than 0.05, indicating that the data for all groups were normally distributed. These findings confirm that the assumptions required for parametric analysis were met, justifying the use of two way ANOVA and Tukey HSD post hoc testing in subsequent analyses. Based on the mean values reported in Table 1, accuracy improved by 9 points in A1B1, 8 points in A1B2, 2 points in A2B1, and 1 point in A2B2. Similarly, agility improved by 2.05 seconds in A1B1, 2.00 seconds in A1B2, 0.59 seconds in A2B1, and 0.70 seconds in A2B2. These

**Table 1.** Pretest and posttest descriptive statistics and Shapiro–Wilk normality test results for accuracy and agility

| Group | Tests | Descriptive Statistics | | | | Shapiro–Wilk | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | | Min | Max | Mean | SD | Statistic | df | Sig. |
| A1B1 | Pretest Accuracy | 18 | 22 | 19.17 | 1.60 | 0.809 | 6 | 0.070 |
| | Posttest Accuracy | 27 | 30 | 28.00 | 1.27 | 0.831 | 6 | 0.110 |
| A1B2 | Pretest Accuracy | 18 | 22 | 20.17 | 1.47 | 0.958 | 6 | 0.804 |
| | Posttest Accuracy | 27 | 29 | 28.00 | 0.89 | 0.853 | 6 | 0.167 |
| A2B1 | Pretest Accuracy | 19 | 22 | 20.50 | 1.38 | 0.861 | 6 | 0.191 |
| | Posttest Accuracy | 20 | 25 | 22.50 | 1.87 | 0.982 | 6 | 0.961 |
| A2B2 | Pretest Accuracy | 20 | 22 | 21.00 | 0.89 | 0.853 | 6 | 0.167 |
| | Posttest Accuracy | 20 | 24 | 22.00 | 1.41 | 0.982 | 6 | 0.960 |
| A1B1 | Pretest Agility | 16.9 | 20.5 | 18.58 | 1.51 | 0.895 | 6 | 0.343 |
| | Posttest Agility | 14.9 | 18.2 | 16.53 | 1.20 | 0.988 | 6 | 0.984 |
| A1B2 | Pretest Agility | 16.5 | 20.2 | 18.42 | 1.38 | 0.968 | 6 | 0.878 |
| | Posttest Agility | 15.1 | 17.9 | 16.42 | 1.19 | 0.886 | 6 | 0.299 |
| A2B1 | Pretest Agility | 16.6 | 20.5 | 18.35 | 1.50 | 0.952 | 6 | 0.758 |
| | Posttest Agility | 16.1 | 19.4 | 17.77 | 1.30 | 0.952 | 6 | 0.754 |
| A2B2 | Pretest Agility | 16.9 | 19.9 | 18.37 | 1.11 | 0.977 | 6 | 0.935 |
| | Posttest Agility | 16.1 | 18.6 | 17.67 | 1.12 | 0.853 | 6 | 0.166 |

Note. A1B1 = Experimental Group with High Agility; A1B2 = Experimental Group with Low Agility; A2B1 = Control Group with High Agility; A2B2 = Control Group with Low Agility. SD = Standard Deviation. All p-values > 0.05, indicating normal distribution in all groups.

descriptive changes support the overall trend observed in the experimental group compared to the control group [27].

Following the normality test, a homogeneity of variances test was conducted using Levene's method to ensure that the data met the assumptions for ANOVA. The results are presented in Table 2.

As shown in Table 2, the homogeneity test based on the mean value yielded a significance level of 0.493 for accuracy and 0.800 for agility. Both values exceed the 0.05 threshold, indicating that the variances were homogeneous across groups. Thus, the data meet the assumption of homogeneity required for parametric testing.

After confirming that the assumptions of normality and homogeneity were met, a two way ANOVA was conducted to evaluate the effects of the intervention and the athletes' initial agility levels on shot accuracy. The results of this analysis are presented in Table 3.

As shown in Table 3, the two way ANOVA revealed a statistically significant model (F = 33.608, p < 0.001), indicating that the combination of training type and agility level significantly influenced shot accuracy. The model explained 83.4% of the variance in accuracy scores ($R^2$ = 0.834; Adjusted $R^2$ = 0.810). The effect size, estimated using partial eta squared ($\eta^2$ = 0.834), indicated a large effect according to standard benchmarks ($\eta^2 > 0.14$). This suggests that the interaction between the type of training intervention and the athletes' baseline agility levels accounted for a substantial proportion of the observed variance in shot accuracy.

A significant interaction effect was observed in the two way ANOVA, indicating that the training program's effect on shot accuracy varied depending on the athlete's initial agility level. To further explore the nature of these differences between specific groups, a post hoc analysis using Tukey's HSD test was conducted. The results are presented in Table 4.

As shown in Table 4, the post hoc Tukey HSD analysis yielded the following results:

- Training effect: Both experimental subgroups (A1B1 and A1B2) performed significantly better than both control subgroups. Specifically, A1B1 outperformed A2B1 (Mean Difference = 5.50, p < 0.001) and A2B2 (Mean Difference = 6.00, p < 0.001). Similarly, A1B2 showed significantly higher shot accuracy than A2B1 and A2B2 (both p < 0.001). These results confirm the effectiveness of the combined technical drill and plyometric training program in improving shot accuracy.
- Influence of agility within the experimental group: There was no significant difference in accuracy between A1B1 (high agility) and A1B2 (low agility) (Mean Difference = 0.00, p = 1.000), suggesting that the training program was equally effective regardless of initial agility level.
- Influence of agility within the control group: No significant difference was observed between A2B1 and A2B2 (Mean Difference = 0.50, p = 0.926), indicating that in the absence of targeted intervention, initial agility had no meaningful effect on shot accuracy.

## Discussion

This study aimed to evaluate the effects of a combined technical drill and plyometric training program on shot accuracy among tennis athletes aged 16 to 19 years, with particular attention to how baseline agility levels might influence training outcomes. The results showed that athletes who

**Table 2.** Levene's test results for homogeneity of variance in accuracy and agility among tennis athletes aged 16 to 19 years

| Variable | | Levene Statistic | df1 | df2 | Sig. |
|---|---|---|---|---|---|
| Accuracy | Based on Mean | 0.932 | 7 | 40 | 0.493 |
| | Based on Median | 0.710 | 7 | 40 | 0.664 |
| Agility | Based on Mean | 0.539 | 7 | 40 | 0.800 |
| | Based on Median | 0.530 | 7 | 40 | 0.807 |

**Table 3.** Results of the two way ANOVA for shot accuracy by training type and agility level

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 199.125 | 3 | 66.375 | 33.608 | 0.000 |
| Intercept | 15150.375 | 1 | 15150.375 | 7671.076 | 0.000 |
| Interaction | 199.125 | 3 | 66.375 | 33.608 | 0.000 |
| Error | 39.500 | 20 | 1.975 | | |
| Total | 15389.000 | 24 | | | |
| Corrected Total | 238.625 | 23 | | | |

Note. $R^2$ = 0.834; Adjusted $R^2$ = 0.810

**Table 4.** Tukey HSD post hoc comparisons of shot accuracy across experimental and control subgroups

| (I) Interaction | | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| A1B1 | A1B2 | 0.00 | 0.811 | 1.000 | -2.27 | 2.27 |
| | A2B1 | 5.50* | 0.811 | 0.000 | 3.23 | 7.77 |
| | A2B2 | 6.00* | 0.811 | 0.000 | 3.73 | 8.27 |
| A1B2 | A1B1 | 0.00 | 0.811 | 1.000 | -2.27 | 2.27 |
| | A2B1 | 5.50* | 0.811 | 0.000 | 3.23 | 7.77 |
| | A2B2 | 6.00* | 0.811 | 0.000 | 3.73 | 8.27 |
| A2B1 | A1B1 | -5.50* | 0.811 | 0.000 | -7.77 | -3.23 |
| | A1B2 | -5.50* | 0.811 | 0.000 | -7.77 | -3.23 |
| | A2B2 | 0.50 | 0.811 | 0.926 | -1.77 | 2.77 |
| A2B2 | A1B1 | -6.00* | 0.811 | 0.000 | -8.27 | -3.73 |
| | A1B2 | -6.00* | 0.811 | 0.000 | -8.27 | -3.73 |
| | A2B1 | -0.50 | 0.811 | 0.926 | -2.77 | 1.77 |

Note. A1B1 = Experimental Group with High Agility; A1B2 = Experimental Group with Low Agility; A2B1 = Control Group with High Agility; A2B2 = Control Group with Low Agility. *$p < 0.05$

received the combined training intervention achieved significantly greater improvements in shot accuracy compared to those who participated in routine training. This positive effect was observed regardless of whether the athletes initially demonstrated high or low agility. No significant performance differences were found within the control group, indicating that the observed improvements were attributable to the specific features of the intervention. These findings support the assumption that integrating technical and plyometric components in training may enhance stroke precision in adolescent tennis players. The following discussion situates these results within the broader context of previous research and considers their practical implications.

The results revealed a significant interaction between training type (experimental vs. control) and baseline agility level (high vs. low) in relation to shot accuracy. Athletes in the experimental groups achieved significantly greater improvements compared to those in the control groups, regardless of initial agility. No significant differences were found between the two experimental subgroups or between the two control subgroups. This indicates that the combined technical drill and plyometric training program was effective in enhancing shot accuracy across different agility levels.

These findings align with prior research demonstrating the benefits of targeted training interventions in tennis. Rahim et al. showed that an 8-week "Easy Five" program improved both accuracy and agility in young players [28]. Similarly, Deng et al., in a meta-analysis, confirmed that physical training can significantly enhance muscle strength, explosive power, agility, speed, and stroke precision in female tennis athletes [29]. Other studies have found that agility- and coordination-focused warm-up routines can improve forehand accuracy in children [6].

What distinguishes the present study is its factorial design, which assessed not only the effects of combined technical and plyometric training, but also how these effects varied by athletes' initial agility levels. Previous reviews typically examined interventions in isolation and did not account for individual differences in physical characteristics, particularly during adolescence. By addressing this methodological gap, the current study provides a more nuanced understanding of how training programs may be adapted for athletes with differing baseline attributes.

Overall, the results reinforce the idea that technical and plyometric components interact synergistically to enhance stroke accuracy. Technical drills contribute to motor pattern refinement and stroke biomechanics, while plyometric exercises increase neuromuscular responsiveness. Prior studies have shown that drill-based training, especially when integrated with agility tasks, has a measurable impact on forehand and backhand execution among amateur tennis players [3, 30], with drill-based methods showing particularly strong effects.

The observed improvement in shot accuracy can be attributed to the combined effect of plyometric

exercises, which develop agility and explosive strength, and technical drills, which improve coordination and stroke mechanics. These effects can be explained by motor learning theory, which emphasizes the importance of training specificity and the principle of transfer of learning [31]. Plyometric exercises improve neuromuscular function and muscular power, which supports faster directional changes and acceleration. These are fundamental components of agility. Previous studies have confirmed the effectiveness of plyometric training for improving these aspects [31, 32].

In tennis-specific research, Deng and colleagues reported in a meta-analysis that plyometric training has a moderate positive effect on sprint performance, lower-body power, and agility in tennis athletes [15]. However, the analysis did not show conclusive evidence that plyometric training alone improves serve or stroke accuracy.

Although this study did not separate the effects of technical drills and plyometric exercises, it is reasonable to assume that each training component contributed through distinct pathways. Technical drills most likely had a direct effect on stroke execution and coordination due to the repetitive and task-specific nature of the exercises. Plyometric training, in contrast, may have produced indirect benefits by increasing explosive power and reactive movement, which allowed players to reach better positions for accurate strokes. Future studies should examine the effects of each component independently to better understand their individual contributions.

The main distinction of the current study compared to previous research is the integration of technical drills into the training program. This integration aimed to directly improve coordination and stroke precision, which are closely linked to shot accuracy. Findings from Novak and Sinkovic support this model. They reported that six weeks of plyometric training improved neuromuscular characteristics, speed during direction changes, and reactive agility in junior tennis players [5, 16]. Plyometric exercises are also closely related to high-intensity interval training. For example, Choudhary and colleagues demonstrated that an eight-week high-intensity program significantly improved explosive strength, sprinting ability, and agility in adolescent tennis players aged 15 to 19 years [4].

Improved agility, as shown by Hernández-Davo et al., who reported significant correlations between the hexagon agility test and sprinting, change of direction performance, and jumping ability, enables athletes to reach optimal positions more quickly and to execute strokes with greater biomechanical precision. This directly contributes to higher shot accuracy [33]. Clear associations between groundstroke outcomes (both speed and accuracy) and physical attributes such as lower-

and upper-body power, tennis-specific agility, and linear speed further emphasize the importance of physical conditioning for stroke accuracy [34]. From a motor control perspective, enhanced agility allows players to adjust their movement patterns more effectively in response to dynamic match situations, such as ball trajectory and opponent behavior. This responsiveness increases the likelihood of executing technically accurate strokes.

The significant interaction found in this study, combined with the absence of accuracy differences between high- and low-agility subgroups within the experimental group, indicates that the intervention was effective across a range of initial agility levels. The results suggest that both agility subgroups experienced sufficient training adaptations to achieve comparable post-intervention accuracy. Although previous research has indicated that older biological age is generally associated with superior speed, agility, and power in youth athletes [35], the present study focused on individuals aged 16 to 19 years. This age range is typically beyond the peak height velocity phase, which means that structured training programs can produce optimal gains in both physical and technical performance capacities [36].

Taken together, the findings highlight the potential of integrated training programs that combine technical and physical components to improve tennis performance in adolescent athletes. By simultaneously targeting movement control and shot accuracy, such programs address key demands of match play in a dynamic sport environment. The improvements observed in this study reflect the advantages of training models that are aligned with the developmental needs of youth athletes, particularly during phases of enhanced physical adaptability. This type of structured approach may offer a practical foundation for performance enhancement in competitive tennis training contexts.

These findings can be interpreted through the lens of motor learning theory, particularly Schmidt's Schema Theory, which posits that repeated practice of context-relevant motor tasks under varied conditions facilitates the development of generalized motor programs. By incorporating both technical drills that simulate sport-specific strokes and plyometric exercises that enhance neuromuscular responsiveness, the intervention appears to engage both parameter selection and schema generalization processes. This dual pathway may explain why improvements in shot accuracy were observed regardless of initial agility levels. Moreover, the study design acknowledges individual physical variability, emphasizing the relevance of baseline motor capacities in shaping training adaptations.

From a practical standpoint, the intervention model applied in this study offers a feasible and adaptable training structure for adolescent tennis athletes, particularly within resource-limited

or regional settings. The program's reliance on basic equipment and structured implementation makes it suitable for integration into existing training regimens. The findings suggest that such combined training may benefit athletes across a range of agility levels, reinforcing the importance of inclusive approaches that accommodate inter-individual differences during critical periods of athletic development.

*Limitations*

This study has several limitations. The relatively small sample size and the inclusion of only regional-level athletes aged 16 to 19 years may restrict the generalizability of the findings to other age groups or performance levels. The six-week intervention period may not have been long enough to capture long-term adaptations, maintenance effects, or delayed performance responses. Furthermore, the study design did not isolate the independent effects of technical drills and plyometric training, which limits the ability to determine the specific contribution of each component. Future research should employ larger and more diverse samples, extend the intervention duration, and use designs that can separately assess the effects of different training components. Additional studies are also recommended to investigate whether similar outcomes occur in athletes from other developmental stages or higher competition levels.

The findings of this study reinforce the conceptual understanding that structured integration of technical and physical training elements can support the development of performance accuracy in adolescent tennis athletes. The coordinated application of movement-specific drills and explosive conditioning appears to address both the motor control demands and physical responsiveness required in tennis. From a theoretical perspective, the study aligns with established principles of motor learning, suggesting that targeted, context-specific training contributes to more efficient skill acquisition and execution. These insights can inform the design of training models aimed at optimizing performance during critical developmental stages.

## Conclusions

The findings of this study reinforce the conceptual understanding that structured integration of technical and physical training elements can support the development of performance accuracy in adolescent tennis athletes. The coordinated application of movement-specific drills and explosive conditioning appears to address both the motor control demands and physical responsiveness required in tennis. From a theoretical perspective, the study aligns with established principles of motor learning, suggesting that targeted, context-specific training contributes to more efficient skill acquisition and execution. These insights can inform the design of training models aimed at optimizing performance during critical developmental stages.

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## Conflict of Interest

The authors declare no conflict of interest.

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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, α = 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

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 | |
| | 4. BOSU V-sit toe touches | 10 reps | Strength–Dynamic Stabilization |
| | 5. BOSU superman | 20 reps | |
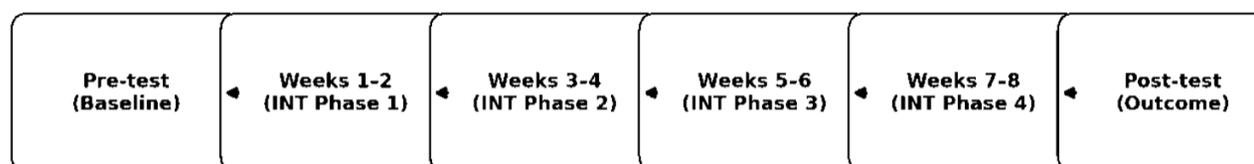


**Figure 1.** Timeline of the Study Design

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.

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-2 scores. At baseline, no significant differences were observed between the groups across the

**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

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 of the present study. Similarly, Özsaydi et al. [30] identified significant differences in speed–agility

**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 |

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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# Adaptive pacing and fatigue management in Thai premier league soccer: a GPS-based analysis of match demands

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

## Abstract

| | |
|---|---|
| *Background and Study Aim* | Soccer is characterized by continuous alternation between high-intensity efforts and recovery phases, requiring players to sustain repeated sprints, accelerations, and directional changes. Managing fatigue effectively during these demanding actions helps maintain performance throughout a match. Although Global Positioning System (GPS) technology is widely applied to quantify external workload in elite sports, its relative effectiveness in assessing pacing and match intensity under tropical conditions remains a subject of practical interest. The aim of this study was to examine half-time differences, analyze intensity-zone distribution, and test the adaptive pacing hypothesis in professional soccer players. |
| *Material and Methods* | Sixteen male players from Rajpracha Football Club (N = 16; mean age = 27.7 ± 1.34 years; BMI = 21.1 ± 1.75 kg/m²) were monitored across 22 official matches. Variables included total distance covered (TDC), distances across five intensity zones (Zones 1–5), and sprint-related metrics. Paired t-tests and one-way ANOVA with Tukey's post hoc comparisons ($p < 0.05$) were applied. Effect sizes (Cohen's d) were calculated to assess practical significance. |
| *Results* | The findings confirmed the adaptive pacing hypothesis. A large and significant reduction was observed in TDC and submaximal running (Zones 1–3) during the second half (Cohen's d ≈ 0.96), while high-speed running (Zones 4–5) and sprint metrics remained stable. Positional heat maps revealed distinct workload profiles corresponding to the tactical roles of defenders, midfielders, and forwards. |
| *Conclusions* | Thai professional players demonstrated advanced behavioral and physiological adaptation by regulating effort to preserve decisive high-intensity performance under tropical fatigue conditions. These results provide baseline evidence for the Thai Premier League and highlight a pedagogical need for situational pacing instruction and position-specific conditioning programs. Such programs should emphasize the quality of high-intensity effort rather than total volume. Future studies should integrate internal physiological indicators and predictive analytics to optimize workload management in professional soccer. |
| **Keywords**: | adaptive pacing, GPS-based workload, Thai Premier League, high-speed running, pedagogical application |

## Introduction

The modern game of soccer has evolved into a global cultural and athletic phenomenon that demands not only technical and tactical excellence but also well-developed physiological adaptability. Over the past two decades, the sport has shifted toward faster transitions, a higher tempo, and more dynamic phases of play. Players are required to repeatedly perform accelerations, sprints, and directional changes within limited recovery intervals. This intermittent physiological structure challenges both aerobic and anaerobic systems, where efficient energy turnover and fatigue resistance are essential for sustaining performance [1, 2]. Continuous alternation between high- and low-intensity activities requires advanced neuromuscular coordination, metabolic flexibility, and cognitive anticipation, which together contribute to maintaining performance stability under competitive stress. Recent evidence also shows that seasonal variations in match intensity are closely linked to GPS-derived workload data, reflecting the evolving physiological demands of the modern game [3]. Therefore, the ability to monitor and manage these demands has become a central component of applied sports science, combining physical, psychological, and tactical data to optimize player development and match readiness.

In this context, Global Positioning System (GPS) technology has transformed performance analysis by providing a precise and objective method for quantifying physical workload in competitive soccer. Through continuous high-frequency data capture, GPS devices measure total distance covered, sprint frequency, and movement intensity across predefined velocity zones [4]. Recent advances in wearable sensor design and integration with video-tracking systems have improved the accuracy of movement detection and contextual interpretation [5, 6]. These external load parameters act as key indicators of physiological stress during match play, allowing practitioners to identify pacing strategies, fatigue accumulation, and movement efficiency. GPS data also serve as a pedagogical tool that supports evidence-based coaching. When interpreted appropriately, GPS-derived metrics help in individualized load planning, recovery optimization, and the development of tactical awareness through reflective feedback [7]. The integration of such data-driven approaches enhances athletes' ability to self-regulate effort and maintain performance quality in competitive settings.

Analysis of research findings has shown that physical workload monitoring through GPS technology provides valuable insights into the physiological and tactical dimensions of modern soccer. Researchers emphasize that understanding pacing behavior, fatigue regulation, and performance maintenance under varying environmental and competitive conditions remains essential for optimizing training processes. Despite growing attention to workload quantification, there is still a need to refine approaches that integrate external load metrics with behavioral and contextual factors influencing player performance. At the same time, despite substantial growth in GPS-based research, most evidence remains concentrated in European leagues, where environmental and tactical conditions differ markedly from those of tropical regions. This geographic imbalance limits the generalizability of findings and overlooks the unique physiological and cultural challenges inherent to Asian competitions. Professional soccer in Southeast Asia, particularly the Thai Premier League, is played under conditions of high temperature and humidity that intensify fatigue and influence pacing behavior [8]. Concurrently, the Thai league has undergone significant professionalization and commercial development in recent years [9], yet scientific analyses addressing its specific match demands remain scarce. Furthermore, methodological issues such as position-specific reference values and individualized load benchmarking, which are increasingly emphasized in elite contexts [10], have received little attention in Thai soccer research.

Given the specific climatic and tactical context of Thai professional soccer, a detailed assessment of physical workload patterns can provide valuable insight into how players regulate intensity throughout a match. Building upon this perspective, the aim of this study was to examine half-time differences, analyze intensity-zone distribution, and test the adaptive pacing hypothesis in professional soccer players.

## Materials and Methods

### Participants

Sixteen professional male soccer players from Rajpracha Football Club were included in the study (mean age = 27.7 ± 1.34 years; BMI = 21.1 ± 1.75 kg/m²). The sample size (n = 16) and the number of monitored matches (N = 22) were consistent with methodological standards reported in previous elite-level team sport analyses [11]. The inclusion of a single club was justified as a robust case study because of the team's consistent tactical framework, competitive stability, and uniform data collection procedures. All players participated in the Thai national soccer league during the 2022 season. Each athlete provided written informed consent before participation. The study protocol was reviewed and approved by the Human Research Ethics Committee of Walailak University (WUEC-22-286-01), ensuring compliance with the Declaration of Helsinki and the ethical standards of human research integrity.

### Study Design

### Data Collection Procedure

This investigation used an observational and quantitative repeated-measures design to examine the physical demands of professional soccer under real competitive conditions. Match activity data were collected across twenty-two official fixtures of the Thai national soccer league during the 2022 season. This study involved a secondary analysis of a dataset previously collected for baseline positional profiling [12]. The primary aim was to analyze physical demands using Global Positioning System (GPS) technology and to compare performance variables between the first and second halves of matches, focusing on adaptive pacing strategies. The average environmental conditions across the twenty-two match days were recorded using official meteorological data. The mean ambient temperature was 30.2 ± 2.1°C, and the relative humidity was 74 ± 6%. These data confirmed that all matches were played in tropical, hot, and humid environments, consistent with evidence that heat stress can accelerate fatigue accumulation during soccer play [8].

Player movements were recorded using portable GPS devices (SPI HPU, GPSports Systems, Catapult Sports, Australia) operating at 5 Hz, with interpolation to 15 Hz via the manufacturer's cubic spline algorithm to improve the precision of

instantaneous velocity estimation [13]. Each GPS unit was placed in a specialized elastic vest (K-Shirt) to ensure stability during rapid movements. To maintain intra-individual reliability, each player used the same GPS unit throughout all monitored matches. The GPS system recorded total distance covered (TDC), total sprint distance (TSD), number of sprints (ToS), maximum speed (TMS), and distance covered across five predefined intensity zones: Zone 1 (1.0–5.99 km/h), Zone 2 (6.0–10.99 km/h), Zone 3 (11.0–15.49 km/h), Zone 4 (15.5–19.9 km/h), and Zone 5 (>20 km/h), following professional match analysis conventions (Bradley et al., 2009). A sprint was defined as any running action exceeding 20 km/h for at least one second with acceleration greater than 2 m/s² [14].

After each match, raw GPS data were downloaded and processed using Team AMS software (Catapult Sports, Australia). Data were excluded if the Horizontal Dilution of Precision (HDOP) exceeded 1.5 or if signal loss occurred. Valid datasets were retained for analysis, and positional spatial distributions were generated using the Field Viewer module (Catapult Sports, Australia) with a grid resolution of 5 m × 5 m to ensure consistent visualization quality across all matches.

*Statistical Analysis*

All statistical analyses were conducted using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were expressed as mean ± SD. Data normality was assessed using the Shapiro–Wilk test, and extreme values were managed by the winsorization method (±3 SD). Paired t-tests were used to compare first- and second-half performance variables, including total distance, sprint distance, sprint frequency, and maximum speed. One-way analysis of variance (ANOVA) with Tukey's post hoc test was applied to examine differences across intensity zones (Zones 1–5). Statistical significance was set at $p < 0.05$ with 95% confidence intervals. Effect sizes (Cohen's d) were calculated to determine the magnitude of meaningful differences and to support the interpretation of practical significance. The anonymized raw and processed GPS dataset supporting this study's findings is available upon reasonable request from the corresponding author in .csv format for verification and replication.

## Results

The analysis revealed consistent physiological and workload patterns across all observed matches. Statistical comparisons showed significant reductions in total and submaximal running distances between halves, while sprint-related variables remained stable. These findings indicate an adaptive pacing mechanism characterized by selective regulation of physical effort under tropical match conditions. Detailed results are presented in Tables 1–3 and Figures 1–3, which illustrate the distribution of workload intensity, spatial movement patterns, and positional adaptations across match halves.

*1. Total Distance Covered and Sprint-Related Variables*

A significant reduction in total distance covered (TDC) was observed between halves ($p = 0.03$), as shown in Table 1 and Figure 1. The effect size was large (Cohen's d = 0.96), confirming a meaningful reduction in overall running volume. Conversely, no significant changes were found in high-intensity metrics, including total sprint distance (TSD), number of sprints (ToS), and maximum speed (TMS) (all $p > 0.05$). These findings indicate that while total workload decreased, players successfully maintained

**Table 1.** Comparison of total and sprint-related variables between match halves.

| Variable | First half (Mean ± SD) | Second half (Mean ± SD) | p-value |
|---|---|---|---|
| Total distance covered (TDC, m) | 4,070.24 ± 856.86 | 3,270.99 ± 805.50 | 0.03* |
| Total sprint distance (TSD, m) | 32.19 ± 15.77 | 31.08 ± 15.81 | 0.35 |
| Number of sprints (ToS) | 11.11 ± 3.95 | 10.87 ± 2.81 | 0.14 |
| Maximum speed (TMS, km/h) | 26.66 ± 3.39 | 25.63 ± 4.91 | 0.14 |

Note: Values are Mean ± SD. *p ≤ 0.05 indicates a statistically significant difference between halves. TDC = total distance covered; TSD = total sprint distance; ToS = number of sprints; TMS = total maximum speed.

**Table 2.** Overall distribution of running distances by intensity zone.

| Zone of intensity | Distance (m, Mean ± SD) | Relative distance (m/min, Mean ± SD) |
|---|---|---|
| Zone 1 | 2,779.00 ± 459.36 | 20.14 ± 2.99 |
| Zone 2 | 2,384.38 ± 289.24 | 26.68 ± 3.09 |
| Zone 3 | 773.15 ± 136.56 | 6.02 ± 1.07 |
| Zone 4 | 254.52 ± 74.60 | 2.20 ± 0.64 |
| Zone 5 | 57.31 ± 26.64 | 0.07 ± 0.02 |

Note: Values are Mean ± SD. Running distances are reported across five intensity zones. p ≤ 0.05.

**Table 3.** Comparison of distances across intensity zones between halves.

| Zone of intensity | First half (Mean ± SD) | Second half (Mean ± SD) | p-value | 95% CI (Lower–Upper) |
|---|---|---|---|---|
| Zone 1 (m) | 1,777.00 ± 85.51 | 1,487.00 ± 80.38 | 0.02* | -526.90 – -53.25 |
| Zone 2 (m) | 1,608.00 ± 71.56 | 1,201.00 ± 61.83 | 0.00* | -597.60 – -215.90 |
| Zone 3 (m) | 495.60 ± 24.34 | 410.60 ± 23.53 | 0.02* | -153.30 – -16.63 |
| Zone 4 (m) | 156.40 ± 10.72 | 140.20 ± 10.12 | 0.28 | -45.98 – 13.74 |
| Zone 5 (m) | 33.79 ± 3.49 | 32.38 ± 3.46 | 0.78 | -11.33 – 8.52 |

Note: Values are Mean ± SD. CI = confidence interval. *p ≤ 0.05 indicates a statistically significant difference between halves.
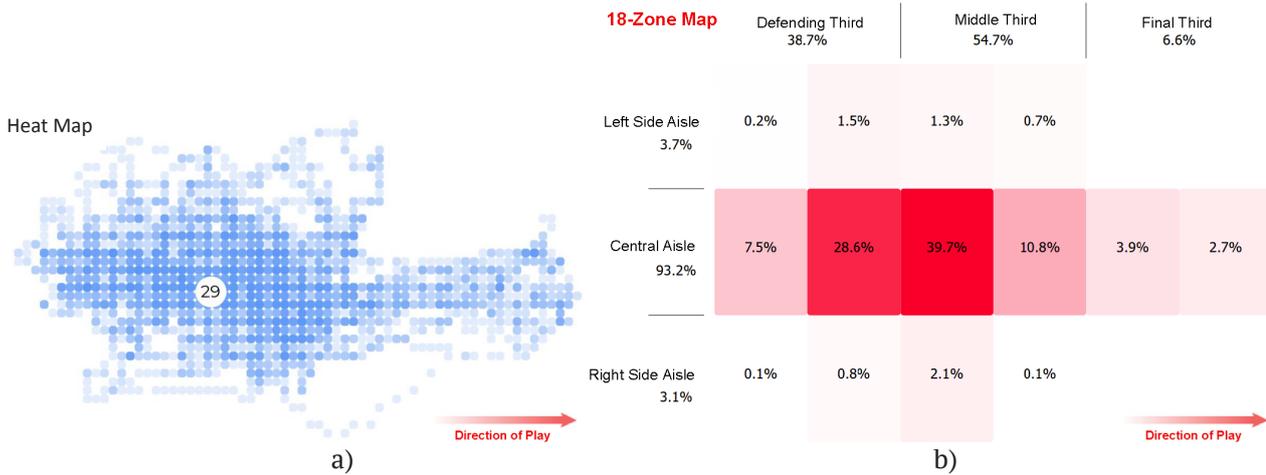


**Figure 1.** Heat map and 18-zone activity distribution of defenders, showing high concentration in the defensive and central thirds of the field.
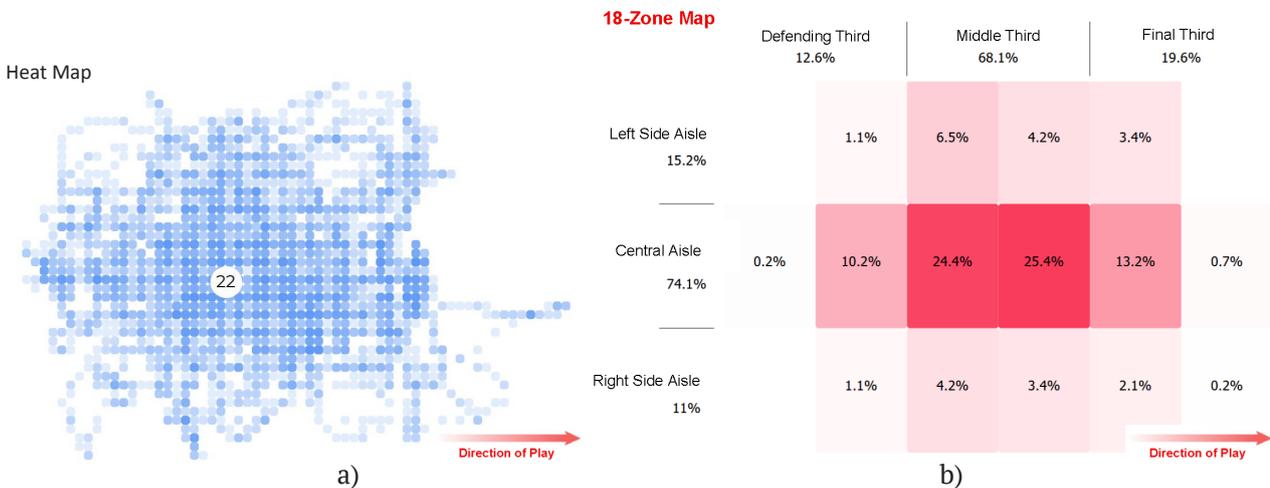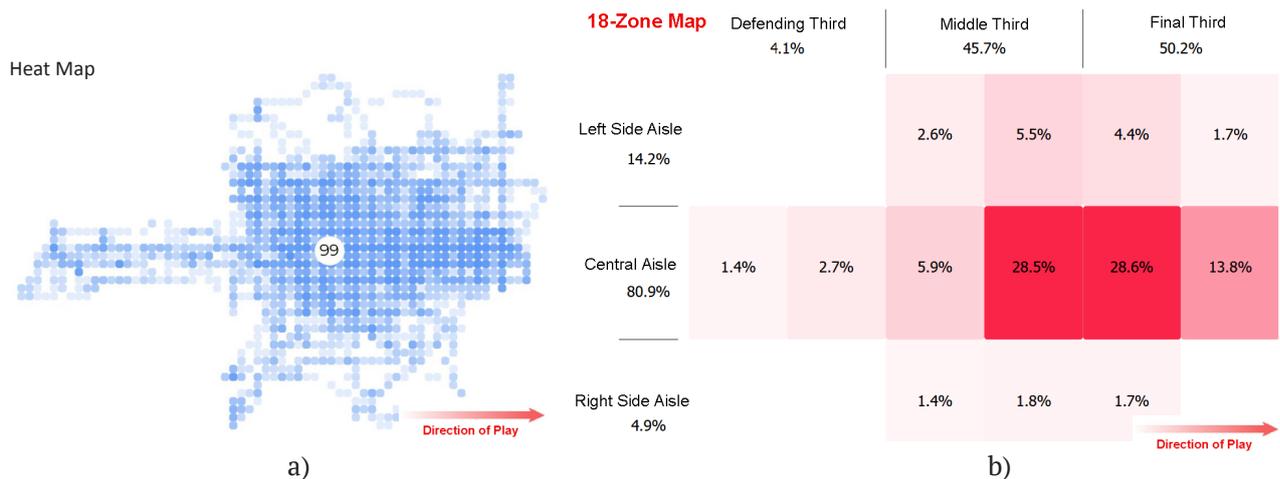


**Figure 2.** Heat map and 18-zone activity distribution of midfielders, with dominant movement in the middle third and balanced coverage across lateral corridors.

sprint capacity and peak speed, suggesting efficient energy management under competitive conditions.

*2. Adaptive Pacing Strategy Across Intensity Zones*

The distribution of running distances across five predefined intensity zones is summarized in Table 2, with half-time comparisons presented in Table 3 and visualized in Figures 2–3. Most activity occurred in low-intensity zones (Zones 1–2), accounting for nearly 80% of total movement and confirming the predominance of aerobic metabolism during match play. Significant reductions were observed in the lower intensity zones (Zones 1–3), while no significant differences were found in higher intensity zones (Zones 4–5). This indicates that players selectively reduced low-to-moderate intensity efforts while maintaining high-speed running, reflecting an adaptive pacing response to accumulated fatigue and environmental stress. As shown in Figures 1–3, the spatial and intensity-

**Figure 3.** Heat map and 18-zone activity distribution of forwards, indicating activity focused in the attacking and wide areas.

related analyses provide visual confirmation of the quantitative results. The 18-zone maps (Figures 1a, 2a, and 3a) demonstrate that player activity was primarily concentrated in the central and middle thirds of the field, highlighting controlled positional play and efficient use of space. Corresponding heat maps (Figures 1b, 2b, and 3b) reveal dense activity clusters within these areas, reflecting players' tendency to conserve energy by limiting unnecessary off-ball movement while maintaining tactical balance. Collectively, these spatial patterns illustrate an adaptive pacing response under tropical match conditions, where players strategically adjusted movement intensity to preserve high-speed performance and sustain overall effectiveness throughout the match.

Overall, the findings revealed a significant reduction in total distance and low-to-moderate intensity activity between halves, while sprint-related and high-speed efforts were maintained. These outcomes confirm that players used adaptive pacing, strategically adjusting workload to sustain decisive actions despite accumulating fatigue. The evidence shows that Thai professional players effectively managed physical and cognitive demands under tropical environmental stress, providing a solid empirical basis for further pedagogical and physiological interpretation.

## Discussion

The present study aimed to examine half-time differences, analyze intensity-zone distribution, and test the adaptive pacing hypothesis in professional soccer players competing under tropical environmental conditions. The analysis revealed significant reductions in total and submaximal running distances between halves, while sprint-related and high-speed efforts were maintained. These results confirm the presence of an adaptive pacing mechanism, indicating that players strategically regulated their physical output to preserve decisive actions despite fatigue accumulation. The observed spatial and intensity-related patterns further demonstrated that Thai professional players effectively managed physical and cognitive demands, maintaining tactical stability and performance efficiency throughout the match.

The significant reduction in total distance covered during the second half (Cohen's d ≈ 0.96) confirms that Thai professional players experienced progressive fatigue over the course of the match. However, the stability of sprint distance, sprint frequency, and maximum speed indicates that players maintained their ability to perform decisive high-intensity actions even under fatigue. This reflects a deliberate redistribution of physical effort rather than a simple physical decline. In line with the adaptive pacing model, athletes appear to regulate running intensity strategically, reserving metabolic energy for critical phases of the game [15]. From a physiological perspective, this balance between conserving energy and producing explosive actions demonstrates effective self-regulation of aerobic and anaerobic systems, allowing players to sustain performance efficiency throughout the match.

When compared with international standards, the total running distance recorded in this study was lower than values typically reported in European professional leagues [16]. However, this should not be interpreted as evidence of inferior physical conditioning but rather as a rational adjustment to local environmental and tactical contexts. Matches were played under tropical heat averaging 30.2 °C and humidity exceeding 70%, conditions known to accelerate cardiovascular strain and glycogen depletion [8]. Under such circumstances, players likely adapt by minimizing unnecessary low-intensity movements to prevent early exhaustion

while maintaining energy reserves for high-speed play. The pattern observed in this dataset therefore represents optimized pacing behavior shaped by the climatic and tactical realities of Thai soccer.

The analysis across intensity zones supports the existence of the adaptive pacing mechanism. Distances in Zones 1–3 declined significantly between halves, while Zones 4 and 5, representing high-speed and sprint activities, remained statistically unchanged. This selective adjustment suggests that players consciously reduced submaximal efforts to preserve the physiological and cognitive resources necessary for sprinting. In modern soccer, this reflects a dynamic interaction between physical capacity and tactical decision-making, where players continuously assess energy expenditure in relation to situational demands [17]. Rather than representing fatigue-induced decline, this controlled modulation of pace reveals an advanced behavioral adaptation that enables players to sustain performance quality throughout the match.

From a pedagogical perspective, these findings emphasize the importance of incorporating pacing education into training programs. Coaches and conditioning staff should use GPS-derived data not only as performance tracking tools but also as instructional resources to teach players energy regulation and situational awareness. Training should prioritize the quality of effort over total volume, replicating match-specific fatigue profiles to build tolerance for maintaining sprint output under constrained conditions. Periodization strategies should include sessions that reproduce the physical decay observed after halftime while reinforcing the cognitive skills required to judge when and how to perform high-intensity actions [18]. This approach aligns with the pedagogical trend toward ecologically valid training design, where the objective is to simulate realistic decision–action couplings rather than isolated physical drills.

The heat maps revealed clear positional differences consistent with tactical specialization. Defenders primarily operated within the defensive and middle thirds, engaging in short, controlled movements associated with positional discipline and recovery actions. Midfielders displayed broader spatial coverage across central corridors, reflecting their transitional role in linking defense and attack, while forwards concentrated their activity in attacking zones, executing repeated high-speed actions near the opponent's goal. These spatial distinctions confirm that physical demands are role-dependent and cannot be generalized across positions. Recognizing these unique movement patterns enables coaches to design position-specific conditioning programs that replicate the

physiological load and tactical responsibilities of each role [12].

The practical value of these results lies in their application to tactical organization and match management. Knowledge of where and when players engage in high-intensity actions helps coaches plan substitutions more effectively, structure recovery periods, and balance training loads according to positional roles. Using GPS data alongside tactical observations allows for a more precise interpretation of player activity during different phases of the game. In the context of Thai professional soccer, such data serve as a starting point for building practical models that reflect real playing conditions and support informed coaching decisions.

The study confirmed that Thai professional soccer players adjust their pacing according to the tactical flow of the game and the challenges of a tropical environment. Despite a reduction in total running distance, the players maintained sprint capacity and high-intensity actions, demonstrating an effective balance between effort and recovery. These outcomes highlight a functional adaptation that allows athletes to sustain performance quality under heat stress. The findings can be used by coaches to design training sessions that reflect match-specific fatigue patterns and promote efficient energy management throughout competition.

*Limitations and Future Research*

While the findings provide valuable insights, certain limitations should be acknowledged. The study involved a single professional team of sixteen players, which limits generalization to the broader Thai Premier League. In addition, the analysis focused solely on external workload variables, excluding internal indicators such as heart rate, perceived exertion, or hormonal markers that could clarify the physiological mechanisms underlying adaptive pacing. These limitations restrict the interpretation of whether the observed behaviors were primarily influenced by thermoregulatory stress or tactical intent.

Future studies should address these constraints by including multi-team and multi-season datasets that combine both internal and external load parameters. Such approaches would enhance ecological validity and support the creation of predictive performance models. The use of machine learning with GPS data could also allow early identification of overtraining or injury risk, aiding data-driven decisions in training management [19]. Moreover, examining psychological factors such as self-regulation, perceived effort, and tactical awareness under environmental stress may provide a more integrated view of adaptive pacing as a combined physiological and cognitive process in professional soccer.

## Conclusions

The study confirmed that Thai professional soccer players regulate their pacing to maintain performance efficiency under tropical match conditions. Although total and submaximal running distances decreased in the second half, players sustained sprint capacity and high-speed actions. This indicates a controlled distribution of effort that reflects physiological and tactical adaptation to heat and fatigue. The results support the adaptive pacing model, showing that players balance endurance and decision-making demands to preserve effective performance. From a practical perspective, these findings emphasize the importance of situational pacing and position-specific conditioning that prioritize the timing and quality of high-intensity actions rather than total running volume.

## Conflict of Interest

The authors declare no conflicts of interest related to this study.

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# Psychological and physiological integration in developing futsal passing skills among students

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## Abstract

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| *Background and Study Aim* | Passing accuracy in futsal depends on both physical abilities and psychological readiness, which together determine the effectiveness of decision-making and execution during play. Although various training approaches combine technical and psychological preparation, their relative effectiveness in enhancing passing performance remains of practical interest. This study aimed to examine the integration of physiological (power) and psychological (emotional intelligence) factors in the development of futsal passing skills among student-athletes. |
| *Material and Methods* | A total of 30 male futsal players were recruited through purposive sampling. Instruments included the Standing Broad Jump to measure lower-limb power, an emotional intelligence questionnaire, and the Triple Box Pass Test for passing accuracy. Data were analyzed using descriptive statistics, Pearson's correlation, simple and multiple regression, and hypothesis testing through t- and F-tests at a 0.05 significance level. |
| *Results* | The findings revealed significant positive correlations between power and passing skills ($r = 0.644$, $t = 4.170$, $p < 0.05$), and between emotional intelligence and passing skills ($r = 0.630$, $t = 4.015$, $p < 0.05$). Moreover, the combined effect of power and emotional intelligence produced a strong correlation with passing skills ($R = 0.796$, $F = 23.334$, $p < 0.05$), accounting for 63.3% of the variance in performance. |
| *Conclusions* | The study concludes that both physiological (power) and psychological (emotional intelligence) aspects significantly influence futsal passing skills. Integrating physical conditioning with emotional intelligence training is therefore essential in designing comprehensive programs to enhance players' technical performance. |
| **Keywords**: | futsal performance, passing skills, physiological factors, psychological factors, student-athletes. |

## Introduction

Futsal is a dynamic team sport that requires a complex interaction of technical precision, tactical awareness, physical conditioning, and psychological control. Successful passing, as one of its fundamental skills, depends not only on motor coordination and physical power but also on cognitive and emotional factors that affect decision-making under pressure. The high tempo and spatial constraints of the game increase the demands on players' perception, anticipation, and regulation of emotions during performance. Physiological and psychological factors together influence the effectiveness of training strategies aimed at improving the quality and consistency of passing in futsal.

Futsal has become one of the fastest-growing indoor sports worldwide, attracting both male and female participants at both professional and amateur levels [1]. Its popularity continues to expand due to its dynamic nature, accessibility, and suitability for diverse age groups. In Indonesia, the sport is governed by the Federasi Futsal Indonesia

(FFI), which organizes national and regional tournaments and promotes futsal development from schools to university teams [2]. Such initiatives have contributed to increasing participation and improving competitive standards, creating a strong platform for studying technical and psychological aspects of player performance. These organizational efforts emphasize the need to explore how various training elements contribute to player development in competitive futsal.

As a high-intensity sport, futsal demands rapid transitions, quick decision-making, and precise ball control within confined spaces, where technical proficiency becomes a critical determinant of success [3]. According to Mendes et al. [3], elite-level futsal players are distinguished by their ability to maintain performance consistency under time pressure and limited space. Among the fundamental technical skills, passing plays a pivotal role in sustaining possession, creating scoring opportunities, and maintaining tactical cohesion within the team [4]. Wang et al. [4] identified passing as one of the key performance indicators influencing match outcomes through ball-possession dynamics. Consequently, mastering passing techniques remains a central

objective in futsal training programs aimed at improving offensive efficiency and teamwork.

Effective passing is not restricted to mechanical precision; it also depends on timing, coordination, and the ability to make quick and accurate decisions during play [5]. Hameed [5] emphasized that biomechanical and anthropometric factors can affect both the speed and accuracy of ball transmission, reflecting the complex interaction between physical and cognitive elements. Sekulic et al. [6] confirmed that futsal performance is a multidimensional construct influenced by physiological capacities and psychological preparedness. These findings suggest that optimal performance in passing requires not only technical training but also the development of power and emotional control that enable players to perform effectively under pressure.

Physiological parameters, particularly muscular power, play a central role in the execution of strong and precise passes. Power, defined as the product of strength and speed, enables explosive movements that enhance both short and long passing accuracy [7]. Widiastuti [7] noted that higher lower-limb power contributes to more forceful and faster passes, making them difficult to intercept. Such integration of physiological and psychological preparation provides a comprehensive foundation for improving technical skills in futsal players and serves as the conceptual basis for the present study.

In addition to physical readiness, psychological attributes play an essential role in determining the quality of technical execution in futsal. Emotional intelligence, defined as the capacity to perceive, regulate, and manage emotions in oneself and others, has been identified as a crucial factor supporting stable performance under pressure [8, 9]. Didymus et al. [8] emphasized that athletes with higher emotional awareness demonstrate greater control of stress responses, which helps maintain optimal focus during competition. Similarly, Haney Aguirre-Loaiza [9] noted that emotional regulation enhances decision-making and interpersonal communication, both of which are vital in high-intensity, team-based sports such as futsal. These findings underline the psychological complexity of maintaining technical precision in a fast-paced and demanding environment.

During matches characterized by rapid tempo and frequent stress exposure, fluctuations in emotional state can disrupt concentration and motor control. However, athletes with well-developed emotional intelligence are more capable of sustaining composure, ensuring consistent decision-making and passing accuracy even under intense pressure [9, 10]. Abarghoueinejad et al. [10] observed that athletes with balanced psychological development demonstrate superior adaptability, allowing them to adjust efficiently to situational challenges on the court. This connection highlights that technical stability in futsal relies as much on emotional control as on physical conditioning.

Although previous research has independently addressed the influence of muscular power on futsal performance [11], few studies have combined this physiological aspect with psychological readiness in an integrated analytical framework. Belo et al. [11] showed that power and motor skills differentiate athletes across competitive levels, yet the interaction between these physical determinants and emotional factors remains insufficiently examined.

Analysis of research findings has shown that both physiological power and psychological attributes, particularly emotional intelligence, are decisive factors in determining technical performance in futsal. Researchers emphasize that effective skill execution depends on the coordinated development of physical conditioning and emotional regulation, which together influence stability and accuracy under competitive stress. At the same time, scholars highlight that the interaction between these two domains remains complex, as their combined influence on passing performance is shaped by situational demands and training conditions. This conceptual gap continues to limit a comprehensive view of how integrated physical and psychological preparation can improve the effectiveness of passing skills in futsal players.

In the context of the above considerations, the following research hypothesis is proposed: It is hypothesized that (1) power positively correlates with futsal passing skills, (2) emotional intelligence positively correlates with futsal passing skills, and (3) the integration of power and emotional intelligence provides a stronger predictive model for passing performance than either factor alone. In accordance with this hypothesis, the study focuses on examining how the integration of physiological (power) and psychological (emotional intelligence) factors contributes to the development of passing skills among student-athletes in futsal.

## Materials and Methods

*Participants*

A purposive sampling technique was used to recruit 30 male futsal student-athletes from Tadulako University, Palu (Central Sulawesi), aged 18–22 years. All participants were actively involved in university-level futsal competitions and had at least two years of consistent training experience. The inclusion criteria required that participants be physically healthy, free from injury during the study period, and willing to participate voluntarily. Recruitment was carried out through team coaches, and each participant received a detailed information sheet before providing written informed consent.

Ethical approval for this study was obtained from the Research Ethics Committee of Universitas

Tadulako, Palu, Indonesia (Approval No. 1538.a/ UN28.16/KP.10.00/2025, dated July 17, 2025). All participants were informed about the study procedures and objectives before signing the consent form.

### Research Design

Emotional intelligence was measured using the Schutte SelfReport Emotional Intelligence Test (SSEIT) [12], which comprises 33 items distributed across four subscales: emotion perception, managing self-emotions, managing others' emotions, and utilizing emotions. Responses were rated on a 5-point Likert scale ranging from 1 ("strongly disagree") to 5 ("strongly agree"). The Indonesian version of this instrument demonstrated acceptable reliability, with a Cronbach's alpha coefficient of 0.86, indicating consistent internal consistency.

Passing performance was assessed using the Triple Box Pass Test (TBPT), a standardized measure of futsal passing accuracy. The setup consisted of three target boxes measuring 1 m × 1 m each, positioned 5 m apart. Participants performed three sets of passes, aiming to consecutively hit the target boxes within 30 s. The final score represented the total number of successful passes. The TBPT has been applied in futsal skill assessment and demonstrated high reliability (r = 0.89) [Abd Rahman2018].

Prior to testing, all participants completed a standardized 10-minute warm-up session to ensure readiness and prevent injury. The tests were conducted indoors on a wooden futsal court under consistent environmental conditions, with a maintained temperature of approximately 26 °C and stable lighting. To minimize fatigue and order effects, the testing sequence was randomized, and a 3-minute rest interval was provided between tests.

### Statistical Analysis

The data collected in this study were analyzed using quantitative statistical methods with the assistance of SPSS software. Descriptive statistics, including means, standard deviations, and frequency distributions, were used to summarize participant characteristics and variable distributions. Pearson's product–moment correlation analysis was performed to determine the strength and direction of associations between power, emotional intelligence, and passing skills. Simple linear regression was used to assess the individual contribution of power and emotional intelligence to passing performance. Multiple regression analysis was then conducted to evaluate the combined influence of both independent variables on passing skills. The statistical significance of these relationships was tested using t-tests for individual predictors and an F-test for the overall regression model. A 95% confidence level ($\alpha = 0.05$) was set as the criterion for statistical significance.

## Results

Preliminary analyses were conducted to verify that the data met the required statistical assumptions. The Kolmogorov–Smirnov test confirmed normal distribution for all variables—power, emotional intelligence, and passing skills ($p > 0.05$). Scatterplot inspection indicated linear relationships between the independent variables (power and emotional intelligence) and the dependent variable (passing skills). The tolerance values above 0.10 and Variance Inflation Factors (VIF) below 10 showed the absence of multicollinearity. Thus, the dataset met all assumptions for correlation and regression analyses.

The reliability of the instruments used in this study was also confirmed. The Schutte Self-Report Emotional Intelligence Test (SSEIT; [12]) demonstrated strong internal consistency in the Indonesian version, with a Cronbach's alpha coefficient of 0.86. The Triple Box Pass Test (TBPT), adapted from Rahman and Shaharudin [13], showed comparable reliability for assessing futsal passing performance (r = 0.87). These results indicate that both instruments provided consistent and valid measures for the study variables.

Statistical analysis showed significant relationships between the independent variables (power and emotional intelligence) and the dependent variable (passing skills) among futsal players. A positive correlation was found between lower-limb power and passing performance (r = 0.644). The regression equation $Y = 0.485 + 0.022X_1$ indicated that players with greater power achieved higher passing accuracy. The obtained t-value (t = 4.170) exceeded the critical threshold (t = 2.048; $p < 0.05$), confirming a significant relationship between power and passing skills (Table 1).

A significant positive correlation was also observed between emotional intelligence and passing performance (r = 0.630). The regression equation $Y = -1.951 + 0.078X_2$ showed that higher emotional intelligence scores were associated with more consistent and accurate passing. The t-test result (t = 4.015 > 2.048; $p < 0.05$) supported the significance of this relationship (Table 1), indicating that psychological readiness contributes meaningfully to the precision of technical performance in futsal.

When both predictors were analyzed together, multiple regression results demonstrated that power and emotional intelligence jointly influenced passing performance. The combined model $Y = -3.795 + 0.018X_1 + 0.061X_2$ produced a multiple correlation coefficient of R = 0.796, indicating a strong positive association. The model's F-value (F = 23.334) was higher than the critical value (F = 3.34; $p < 0.05$), confirming overall significance (Table 2). The coefficient of determination ($R^2 = 0.633$) revealed that both predictors together explained

**Table 1.** Correlation and Regression Analysis between Independent Variables (Power and Emotional Intelligence) and Passing Skills

| Independent Variable | Correlation (r) | Regression Equation | t-value | p-value |
|---|---|---|---|---|
| Power | 0.644 | $Y = 0.485 + 0.022X_1$ | 4.170 | $< 0.05$ |
| Emotional Intelligence | 0.630 | $Y = -1.951 + 0.078X_2$ | 4.015 | $< 0.05$ |

**Table 2.** Multiple Regression Analysis of Power and Emotional Intelligence on Futsal Passing Skills

| Predictor Variables | Multiple Correlation (R) | Regression Equation | F-value | p-value | $R^2$ (Coefficient of Determination) | Interpretation |
|---|---|---|---|---|---|---|
| Power & Emotional Intelligence | 0.796 | $Y = -3.795 + 0.018X_1 + 0.061X_2$ | 23.334 | $< 0.001$ | 0.633 | Model significant |

63.3 % of the variance in passing performance, while the remaining 36.7 % was attributed to other unmeasured influences.

The results showed that passing performance in futsal was affected by both muscular power and emotional intelligence. Players with higher muscular power demonstrated greater passing accuracy, strength, and speed. Those with higher emotional intelligence maintained focus and consistent performance under game pressure. When both variables were included in the model, their combined effect explained a larger proportion of variance in passing performance than either factor alone.

## Discussion

This study aimed to examine the relationship between physiological and psychological factors in the development of passing performance among futsal players. The results showed that both muscular power and emotional intelligence significantly contributed to the accuracy and stability of passing skills. Higher lower-limb power was associated with faster and more precise passes, while higher emotional intelligence corresponded with improved focus and decision-making under pressure. When analyzed together, these two variables explained a substantial proportion of the variance in passing performance, indicating that their combined influence was stronger than the effect of each factor considered separately.

The findings of this study align with the biopsychosocial framework, which explains athletic performance as a result of the interaction between physical, psychological, and social factors. The combined influence of muscular power and emotional intelligence observed in this research reflects the multidimensional nature of futsal performance. This integration provides a clearer view of how physical strength and emotional regulation together support the precision and consistency of passing. In the Indonesian context, the results may also reflect specific training conditions of university futsal players, who often have limited exposure to structured psychological preparation. The diverse cultural and environmental backgrounds of the athletes from coastal and mountainous regions could further influence their adaptation and performance characteristics, giving this study a distinct contextual perspective compared with previous international research.

In addition, the results showed that both physiological and psychological factors played important roles in the development of futsal passing skills. The significant positive relationship between power and passing performance is consistent with previous research emphasizing the contribution of muscular strength and explosive ability to technical execution in futsal and other ball games [6, 7, 11]. Power, defined as the interaction between strength and speed, is essential for generating effective movements in high-intensity sports, enabling players to perform faster and more accurate passes [3, 6]. Athletes with greater lower-limb power demonstrate higher precision and stability in passing, confirming the findings of earlier studies that identified leg explosive power as a determinant of performance accuracy [4, 11].

These findings also support the importance of psychological readiness, particularly emotional control, in enhancing motor performance. As reported in studies addressing stress regulation and emotional functioning in sports [8, 9, 10], emotional intelligence allows athletes to sustain focus and make correct decisions under competitive pressure. Overall, the combined evidence highlights that the efficiency of passing performance in futsal depends on both physical conditioning and emotional regulation, confirming the multidimensional character of skill development in this sport.

Equally important is the influence of emotional intelligence on futsal passing skills. The strong correlation observed in this study supports the view that emotional intelligence, through dimensions such as self-regulation, motivation, empathy, and social awareness, enhances decision-making under pressure [14, 15, 16, 17]. Given the fast-paced and

dynamic nature of futsal, emotional intelligence enables players to remain composed, coordinate effectively with teammates, and maintain focus on tactical execution. This finding is consistent with Suhartati and Indrawati [17], who emphasized the role of emotional intelligence in maintaining performance stability, and with Udayar et al. [19], who demonstrated that higher emotional intelligence is associated with better performance in a stressful task via enhanced self-efficacy.

The integration of power and emotional intelligence provides a more comprehensive understanding of futsal performance. The regression model indicated that these two factors together explained 63.3% of the variance in passing skills, emphasizing the interdependence between physical and psychological components. This result supports the argument of Abarghoueinejad et al. [10] that psychological balance cannot be separated from physical readiness when determining athletic outcomes. By demonstrating their complementary contributions, the present study extends previous research, which has often examined these domains separately rather than in combination.

The novelty of this study lies in its contextual focus on the Indonesian futsal environment, particularly among university-level athletes. Whereas most previous research has concentrated on professional or youth football [1, 3, 6], the present findings contribute empirical data from higher education sports in Southeast Asia [2, 11], highlighting specific physical and psychological factors relevant to this setting.

From a practical standpoint, the results emphasize the value of training programs that integrate both physical and psychological components. Coaches should combine strength and plyometric exercises with activities that develop emotional intelligence, including stress management and teamwork strategies [8, 9, 10]. In addition, methods such as reflective practices and emotional awareness training have been shown to enhance social–emotional skills and improve overall performance stability [14, 15, 16, 17, 18]. Integrating these elements can help athletes improve technical proficiency and emotional control, thereby enhancing consistency and overall performance in competitive futsal.

These findings also have theoretical implications for understanding how physiological and psychological factors interact in sports performance. The results support the biopsychosocial perspective, which explains athletic outcomes as the result of combined influences of physical conditioning and psychological readiness. The relationship observed between muscular power and emotional intelligence emphasizes the need to consider multiple dimensions of performance rather than isolated variables. Integrating these factors provides a more comprehensive view of how physical and emotional components jointly contribute to skill execution in futsal. This theoretical contribution may guide future models aimed at explaining the mechanisms through which physiological and psychological readiness affect technical precision in high-intensity team sports.

*Limitations and Future Research*

This study has several limitations that should be considered. The sample was limited to one institution, which may reduce the generalizability of the results to other settings or populations. The use of self-reported questionnaires might also have introduced response bias, as participants could have given answers that appeared more favorable rather than fully accurate. Future studies should include participants from multiple institutions or regions to improve external validity. Longitudinal or mixed-method designs could also be used to examine causal relationships and provide a more detailed understanding of the interaction between physical and psychological factors in futsal performance.

## Conclusions

This study confirms the interaction between physiological and psychological factors in the development of futsal passing performance. The combined influence of muscular power and emotional intelligence illustrates the multidimensional nature of technical skills and highlights the importance of balanced preparation in university-level futsal. The results may serve as a reference for developing training approaches that integrate both physical and psychological readiness in competitive sport.

## Conflict of Interest

The authors declare no conflict of interest regarding the publication of this research. The study was conducted independently, and no financial or personal relationships influenced the results or their interpretation.

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# Development of gross motor skills and nutrition literacy among inclusive junior high school students

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## Abstract

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| *Background and Study Aim* | Slow learners in inclusive junior high schools often face difficulties in developing gross motor skills and possess limited nutritional literacy. Both aspects are essential for fostering independence in daily functioning and promoting a healthy lifestyle. This study aimed to evaluate the effectiveness of active physical education-based nutrition learning in improving gross motor skills and nutritional literacy among slow learners. |
| *Material and Methods* | This quasi-experimental study involved 40 slow learners from an inclusive junior high school. Participants were assigned to two balanced groups. The experimental group (n = 20; 10 females, 10 males) received active physical education-based nutrition learning. The control group (n = 20; 10 females, 10 males) received conventional instruction without treatment. Instruments included the Test of Gross Motor Development-2 (TGMD-2) to assess gross motor skills and a multiple-choice test to measure nutritional literacy. The prerequisite analyses included the Shapiro–Wilk test (normality), Levene's test (homogeneity of variance), and Box's M test (homogeneity of covariance). The hypotheses were tested using MANCOVA. |
| *Results* | The MANCOVA results showed a significant treatment effect on both gross motor skills and nutritional literacy, with substantial effect sizes (partial $\eta^2$ = 0.956 for TGMD-2 and 0.903 for nutritional literacy). The pre-test covariate for TGMD-2 significantly influenced motor skills (F = 59.23; p < 0.001), while the pre-test for nutritional literacy was not significant. |
| *Conclusions* | Active physical education-based nutrition learning effectively improves both gross motor skills and nutritional literacy among slow learners in junior high school. This approach is recommended as an integrative strategy in inclusive education to support physical and cognitive development. |
| **Keywords**: | gross motor skills, nutrition literacy, active physical education, slow learners, inclusive education. |

## Introduction

Inclusive education aims to ensure that every student, regardless of cognitive or physical ability, receives equal opportunities to learn, develop, and participate in physical and academic activities. Among students with learning difficulties, slow learners often encounter complex challenges that affect both their motor and cognitive development. Limited gross motor skills may hinder their ability to engage in physical education effectively, while low nutritional literacy can negatively influence their daily habits and overall health. These interrelated difficulties highlight the need for educational approaches that address physical competence and nutrition knowledge simultaneously within inclusive school environments.

Individuals with slower learning capabilities have distinct needs in the educational process, especially regarding cognitive and motor skills. They face challenges in understanding and remembering information and require additional time to master concepts compared to their peers [1]. In addition, motor skills also present difficulties, as delays in motor development affect their participation in physical activities and physical education [2]. If opportunities for motor development are not maximized, the consequences extend beyond physical delays, influencing emotional, social, and cognitive growth, which are crucial for pupils' overall development [3]. Therefore, educators play a key role in recognizing and addressing the needs of slow learners. By implementing an Individualized Education Plan (IEP), teachers can adapt instructional strategies to better meet the specific requirements of individual pupils [4].

Physical education in inclusive schools plays

a central role in cultivating healthy and active lifestyles. Integrating nutritional education with physical activities helps children improve their motor abilities and adopt healthier habits that promote both physical and cognitive growth. A comprehensive review and meta-analysis conducted in the United States indicated that collaboration between nutritionists and sports professionals is essential for encouraging healthy and active lifestyles among students [5]. Similarly, another study showed that interdisciplinary educational interventions significantly improved students' understanding of diet, nutrition, and physical activity, thereby confirming the effectiveness of integrating nutrition and health education in fostering student development, including within inclusive settings [6].

The 2018 Riskesdas report revealed alarming trends in adolescent dietary habits in Indonesia: 62.2% did not have breakfast, 95.5% consumed insufficient amounts of fruits and vegetables, and 75.7% frequently ate spicy foods. Moreover, 40.7% reported regular intake of fried, cholesterol-rich, and fatty foods, 26.2% consumed excessive salty foods, and 53.1% consumed excessive sugary foods, while 93.6% consumed inadequate fruits and vegetables [7]. These findings align with global data showing that approximately 390 million children and adolescents aged 5–19 years are overweight, while 160 million are classified as obese worldwide. Childhood obesity poses serious concerns for physical health and overall quality of life, as it is associated with increased morbidity and mortality [5]. Such statistics emphasize adolescents' low nutritional literacy and poor awareness of healthy dietary habits. This situation is further aggravated by low levels of physical activity. A systematic review found that children, regardless of gender, preferred sedentary activities such as video games and television over outdoor physical activities during leisure time, indicating a global shift toward sedentary lifestyles [8]. This trend is also evident among slow learners, who face the combined challenges of limited nutritional literacy and weak gross motor skills, placing them at greater risk of unhealthy lifestyle patterns that further impede motor and cognitive development.

In response, research suggests that slow learners are more engaged when learning activities incorporate games, as these foster motivation and active participation [9]. Game-based activities help develop fundamental motor skills such as running, jumping, and kicking a ball [10]. Consequently, physical education offers an effective approach, as game-based learning enables slow learners to experience concepts directly while simultaneously supporting both motor and cognitive development [11,12].

Other studies reinforce the importance of integrating nutrition and physical activity. Mafugu's research showed that students with slow learning conditions tend to have low nutritional literacy, which contributes to poor gross motor and overall physical development [13]. Without sufficient knowledge, students are less able to make healthy food choices, leading to unhealthy eating patterns [13]. Healthy lifestyle habits are therefore fundamental to supporting students' physical and cognitive growth [14,15]. Conversely, insufficient physical activity contributes to poor gross motor development, as limited exposure to movement hinders the acquisition of essential motor skills [16].

In practice, nutrition is often taught separately from physical education, preventing students from connecting theoretical knowledge with practical application. However, integrating nutrition into physical education through structured play has the potential to enhance understanding while simultaneously developing gross motor skills. Implementation challenges remain, as many teachers lack adequate training, knowledge of activity design, and access to sports equipment and facilities [5]. This issue aligns with a study showing that students understand and apply knowledge more effectively when engaged in interactive and practical learning experiences. Therefore, it is essential to use diverse, engaging, and experiential teaching methods that integrate nutrition education with physical activities to increase student interest and participation [17].

Analysis of research findings has shown that the integration of nutrition education with physical activity contributes to better motor development, healthier lifestyle choices, and improved cognitive outcomes among students. Researchers emphasize that combining theoretical and practical learning within inclusive educational environments helps slow learners overcome limitations in both motor and nutritional domains. However, challenges related to limited teacher preparation, insufficient adaptation of learning materials, and inadequate facilities continue to hinder the full implementation of such integrative approaches. This context underscores the importance of exploring effective models of active, nutrition-based physical education that can address the complex developmental needs of slow learners in inclusive settings.

Despite this evidence, challenges persist in inclusive schools. Slow learners often have a limited understanding of the importance of healthy eating and display weak gross motor skills. These limitations are compounded by a lack of variety in teaching methods. Nutrition is frequently taught through abstract student worksheets (*Lembar Kerja Siswa*, or student activity sheets) without real-world application, which reduces nutritional literacy. Many students also show little interest in theoretical classroom learning, preferring hands-on activities.

Unhealthy lifestyle habits, such as frequent fast-food consumption and low levels of physical activity, further worsen motor skill deficiencies, leading to negative effects on both physical and cognitive development.

Based on the preceding analysis, it is essential to develop an innovative learning approach that integrates nutrition education and physical activity within a unified framework. Such an approach would enable slow learners to not only understand nutritional concepts theoretically but also apply them through meaningful physical activities. The active physical education–based nutrition learning model is considered highly relevant, as it promotes experiential learning that simultaneously stimulates both cognitive and motor development. Although previous studies have examined nutrition education and physical activity, most have addressed these areas separately. Comprehensive approaches that combine both aspects, particularly in the context of inclusive schools in Indonesia, remain scarce.

Therefore, this study introduces a contextual and interactive active physical education–based nutrition learning intervention designed to address the limitations identified in prior research. This approach integrates nutrition education and physical education within a single experiential learning framework aimed at enhancing gross motor skills and nutritional literacy among slow learners in inclusive junior high schools.

## Materials and Methods

*Participants*

The participants were 8th-grade students from an inclusive junior high school in Yogyakarta, Indonesia, aged 13–15 years. A purposive sampling technique was applied with the following inclusion criteria: (1) students identified as slow learners based on psychological assessment or diagnosis, (2) aged 13–15 years, (3) non-athletes, (4) physically healthy and able to participate in light-to-moderate physical activities (verified by a doctor's certificate), and (5) obtained parental or guardian consent. Exclusion criteria included: (1) students with severe physical disabilities, (2) students with chronic illnesses, and (3) students who participated in less than 80% of the program.

A total of 50 students were screened, and 40 met the eligibility criteria. The eligible participants were proportionally assigned to two groups: the experimental group (n = 20; 10 females, 10 males), which received the Active Physical Education–Based Nutrition Learning intervention, and the control group (n = 20; 10 females, 10 males), which received conventional instruction without the intervention.

Ethical clearance and an official university approval letter were obtained (No. B/679/UN34.16/PT.06.01/2025). Written parental or guardian consent was also secured before participation.

*Research Design*

This study employed a quasi-experimental design with a pretest–posttest control group, as illustrated in Figure 1. The experimental group received the Active Physical Education–Based Nutrition Learning intervention for 16 weeks, while
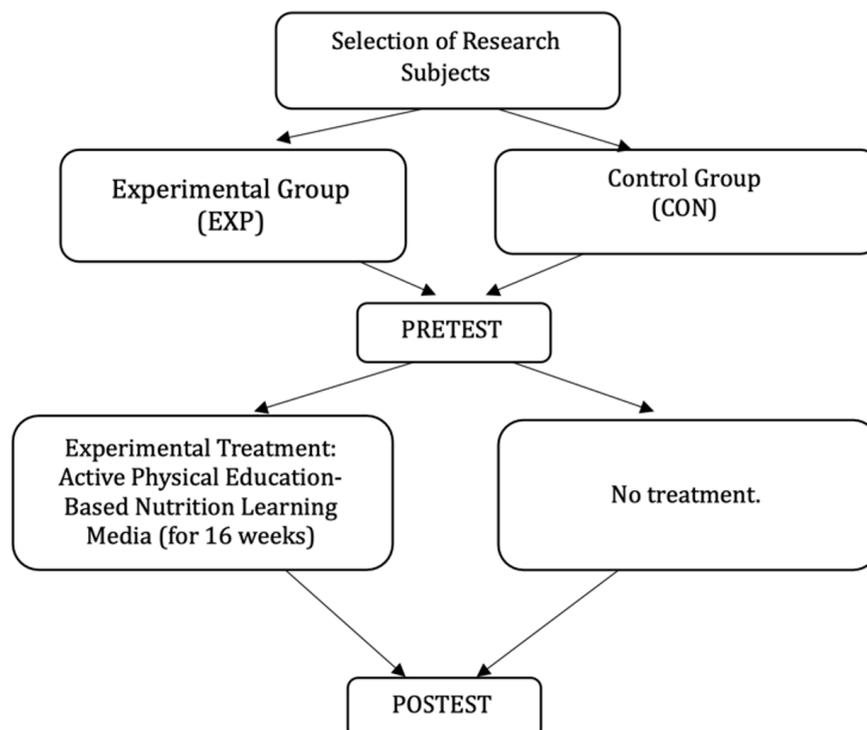


**Figure 1.** Research flow.

the control group received no treatment.

*Procedure*

*Experimental Group (EXP)*

The experimental group participated in the Active Physical Education–Based Nutrition Learning program, which consisted of 12 sessions. Each session lasted 3 × 40 minutes (120 minutes), following the inclusive school physical education schedule, and included three main phases: warm-up (10–15 minutes), main activity (80–90 minutes), and cool-down (10–15 minutes). The exercise intensity was maintained at a moderate level according to the Borg Rating of Perceived Exertion (RPE) scale (11–13), indicating that students perceived the activities as "somewhat hard" but still manageable. This intensity was chosen to ensure safe, inclusive, and meaningful participation, particularly for slow learners. The Borg RPE scale has been widely used in studies involving children's physical activity, including research on participants aged 11–14 years, which confirmed that they could reliably regulate their physical effort corresponding to RPE levels 9, 13, and 17 [18]. Each session consisted of 3–5 repetitions of movements, interspersed with 2-minute rest intervals between sets. Instructions were delivered briefly and clearly, supported by visual media such as food images, color symbols, and nutrition-category cards to facilitate students' understanding.

The intervention consisted of structured physical activities that integrated nutrition education through weekly games and movement-based sessions, as outlined below:

1. Week 1 (Orientation): Introduction to program objectives, procedures, and benefits, followed by pretests (TGMD-2 and nutritional literacy).
2. Weeks 2–3 (Understanding nutrients and their types): Nutrition Relay — a relay race in which students categorized food cards into nutrient groups (carbohydrates, protein, fat, vitamins, minerals, water).
3. Weeks 4–5 (Nutritional functions): Nutritional Ball Throw — students threw food-labeled balls into baskets representing nutritional functions (energy source, body-building, and protective materials).
4. Weeks 6–7 (Grouping foods by nutrients): Food Basket Game — an obstacle course combined with the categorization of food-labeled balls. Students ran through zigzag obstacles, crawled, jumped, and then threw plastic balls with food pictures into baskets according to their nutritional content.
5. Weeks 8–9 (Linking food to energy needs): Energy Race — students performed movements on two track lines (high energy = 20 m sprint; low energy = leisurely walk or light jumps). After completing the exercise, they attached food pictures corresponding to the energy lines.
6. Weeks 10–11 (Connecting food with health benefits): Nutrition Strike Ball — students hit or kicked food-labeled balls into health-related categories (e.g., milk → healthy bones; fish → strong muscles; fruit → body resistance; sweet potato → energy).
7. Week 12 (Evaluation): Post-tests (TGMD-2 and nutritional literacy). The experimental group then conducted a program evaluation, discussed challenges and solutions, and received reinforcement on maintaining a balanced diet and regular physical activity.

*Learning Program Intervention*

The Active Physical Education–Based Nutrition Learning program was developed and validated through an expert evaluation process involving seven specialists. The expert panel included three specialists in teaching materials, three experts in special needs education (slow learners), and one expert in learning media. Each expert independently assessed the program's content accuracy, instructional clarity, and suitability for slow learners. Their evaluations were used to refine the structure, activities, and visual components of the learning materials.

To enhance the transparency and reproducibility of this study, sample learning materials were developed, including:

(1) student worksheets containing task instructions and reflection prompts;

(2) game rules and activity guidelines describing session flow, duration, and objectives;

(3) visual aids used throughout the intervention sessions.

All these elements were compiled into the Teaching Module "Active Physical Education–Based Nutrition Learning, «which provides a complete description of the instructional design, learning objectives, teaching media, and step-by-step session implementation.

The reliability of the Active Physical Education–Based Nutrition Learning program was assessed using Cronbach's Alpha coefficients, all of which exceeded the minimum acceptable value of 0.60, confirming the program's internal consistency and dependability [19,20].

Teaching Module "Active Physical Education–Based Nutrition Learning"

Learning Achievements: Students are able to demonstrate their ability to perform sports movements and develop healthy lifestyle behavior patterns through fun and meaningful physical activities.

Learning Objectives:

1. To understand the concept of nutrition and the function of nutrients through active physical activities.

2. To categorize foods based on their nutritional content.
3. To relate different types of food to energy needs and health benefits.
4. To demonstrate improvement in gross motor skills through physical activity–based games and nutrition education.

Subject: Physical Education.

Curriculum: Independent Curriculum.

Class: Phase D – Junior High School (Grade VII).

Time Allocation: 12 meetings × 120 minutes (3 × 40 minutes).

A. Material Description

The learning materials integrate physical education and nutrition education through activity-based games designed to strengthen understanding of nutrition concepts (nutrient types, functions, energy, and health benefits) and to develop basic motor skills (locomotor, non-locomotor, and manipulative).

B. Teaching Media
- Food picture cards (carbohydrates, proteins, fats, vitamins, minerals, water)
- Food-labeled plastic balls
- Baskets or basketball rings labeled with nutritional functions
- Energy images (high and low)
- Whistles, ropes, cones, a scoreboard, and reflection papers

C. Learning Steps

1.Meeting 1: Program Orientation and Pretest

Objective: To introduce the program, explain the objectives and benefits of the activities, and conduct pretests on motor skills (TGMD-2) and nutritional literacy.

Time: 120 minutes

Main Activity (80–90 minutes): Explanation of objectives and procedures, completion of the nutritional literacy instrument, and implementation of the TGMD-2 test (locomotor and object control).

Cool-down (10–15 minutes): Light muscle relaxation and brief reflection on the importance of maintaining an active and nutritionally balanced lifestyle.

2.Sessions 2–3: "Nutrition Relay" Game

Objective: To identify groups of nutrients (carbohydrates, proteins, fats, vitamins, minerals, water).

Equipment: Food picture cards, colored nutrient category boards, and track cones.

Teaching Media: The visual teaching media used in this activity are shown in Figure 2.

Rules (Summary):
- Each team lines up at the starting line.
- The teacher announces a nutrient category (e.g., carbohydrates).
- One student runs to pick the corresponding food card and attaches it to the correct category board.
- The fastest and most accurate team earns points.
- Warm-up (10–15 minutes): Light jogging around the field and dynamic stretching.
- Main Activity (80–90 minutes): Implementation of the "Nutrition Relay" game according to the rules, repeated for 3 sets × 5 minutes with a 2-minute rest between sets, varying the nutrient categories in each round.
- Cool-down (10–15 minutes): Easy walking and static stretching while reviewing examples of nutritious foods.

3. Sessions 4–5: "Nutritional Ball Throw" Game

Objective: To relate food types to their nutritional functions (energy, building, and protection).

Equipment: Food picture balls and baskets labeled with nutritional functions.

Media: The visual teaching media used in this activity are shown in Figure 3.

Rules (Summary):
- Students throw food picture balls into baskets corresponding to the correct nutritional function.
- Each correct throw earns one point.
- The team with the highest score wins.
- Warm-up (10–15 minutes): Throw-and-catch pairing and arm stretching exercises.
- Main Activity (80–90 minutes): Implementation of the "Nutritional Ball Throw" game in group
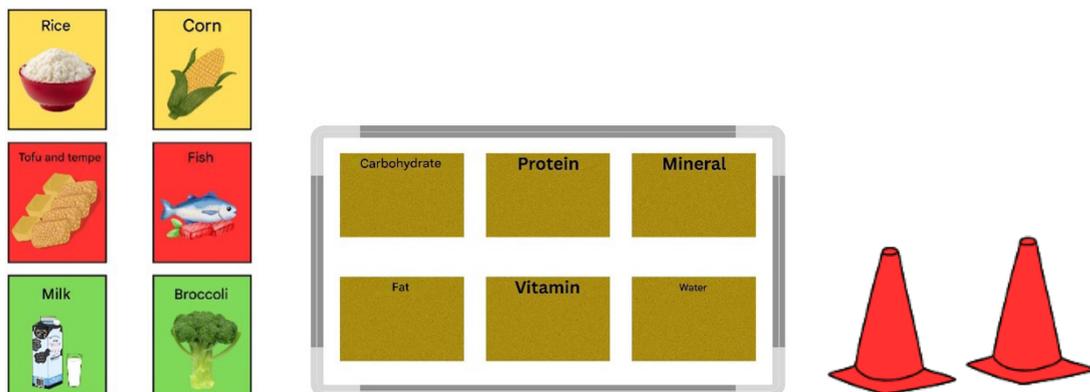


**Figure 2.** Visual teaching media used in the "Nutrition Relay" game.

format, with variations in distance and ball size. The game is repeated for 3 sets × 5 minutes, with a 2-minute rest between sets.

- Cool-down (10–15 minutes): Breathing exercises and discussion about the functions of food in the body.

4.Sessions 6–7: "Food Basket Game"

Purpose: To develop basic movement skills and reinforce understanding of nutrient groupings.

Equipment: Food balls, nutrition baskets, and obstacles (cones, ropes, low bars).

Media: The visual teaching media used in this activity are shown in Figure 4.

Rules (Summary):
- Students complete the obstacle track (running, jumping, crawling).
- They collect food balls and place them in baskets according to the correct nutrient group.
- Scores are based on speed and accuracy.
- Warm-up (10–15 minutes): Zigzag running, jumping on the spot, and dynamic stretching.
- Main Activity (80–90 minutes): Implementation of the "Food Basket Game" with obstacle variations. The game is repeated for 3 sets × 5 minutes with a 2-minute rest between sets.
- Cool-down (10–15 minutes): Slow walking and full-body stretching.

5.Sessions 8–9: "Energy Race" Game

Objective: To understand the concept of food energy and its relationship to physical activity.

Equipment: Food images with energy values, and two marked paths — one for "high energy" and one for "low energy."

Media: The visual teaching media used in this activity are shown in Figure 5.

Rules (Summary):
- Students select a food picture.
- If the food represents high energy → they perform a 20 m sprint; if it represents low energy → they walk leisurely.
- After completing the movement, students attach the food image to the corresponding energy path.
- Warm-up (10–15 minutes): Light jogging and dynamic stretching.
- Main Activity (80–90 minutes): Implementation of the "Energy Race" game with rotation of student roles. The game is repeated for 3 sets × 5 minutes, with a 2-minute rest between sets.



**Figure 3.** Visual teaching media used in the "Nutritional Ball Throw" game.



**Figure 4.** Visual teaching media used in the "Food Basket Game."

- Cool-down (10–15 minutes): Leisurely walking, relaxation, and discussion about balanced energy in daily nutrition.

6.Sessions 10–11: "Nutrition Strike Ball" Game

Objective: To link food items with their corresponding health benefits.

Equipment: Food picture balls and a target board with health benefit categories.

Media: The visual teaching media used in this activity are shown in Figure 6.

Rules (Summary):
- Students kick or hit food picture balls toward target areas that correspond to the appropriate health benefit (e.g., milk → healthy bones).
- Scores are based on accuracy in direction and benefit classification.
- Warm-up (10–15 minutes): Light kicking and punching movements, followed by dynamic stretching.
- Main Activity (80–90 minutes): Implementation of the "Nutrition Strike Ball" game in groups. The game is repeated for 3 sets × 5 minutes with a 2-minute rest break between sets.
- Cool-down (10–15 minutes): Stretching of leg and arm muscles and reflection on the health benefits of food.

7.Meeting 12: Posttest and Reflection

Objective: To assess improvements in motor skills (TGMD-2) and nutritional literacy, and to reinforce students' commitment to a healthy lifestyle.
- Warm-up (10–15 minutes): Light exercise and joint stretching performed together.
- Main Activity (80–90 minutes):
  – Administration of posttests on gross motor skills (TGMD-2) and nutritional literacy.
  – Discussion of learning outcomes and evaluation of students' experiences during the program.
- Cool-down (10–15 minutes): Relaxation and breathing exercises, followed by affirmation of commitment to maintaining an active and nutritionally balanced lifestyle.

D. Evaluation

The evaluation covered two main aspects:
1. Cognitive: Nutritional literacy test (20 multiple-choice questions).
2. Psychomotor: Assessment of gross motor skills using the Test of Gross Motor Development–2 (TGMD-2).

E. Attachment
1. Student Worksheets (LKPD)
2. Active Physical Education–Based Nutrition Learning
3. Phase: D (Grade VII)
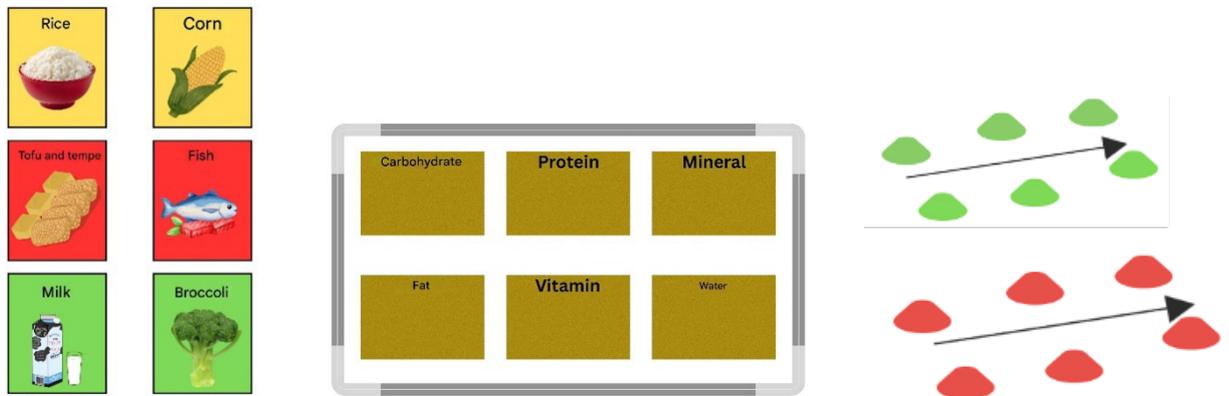4. Time Allocation: 12 meetings (3 × 40 minutes per meeting)



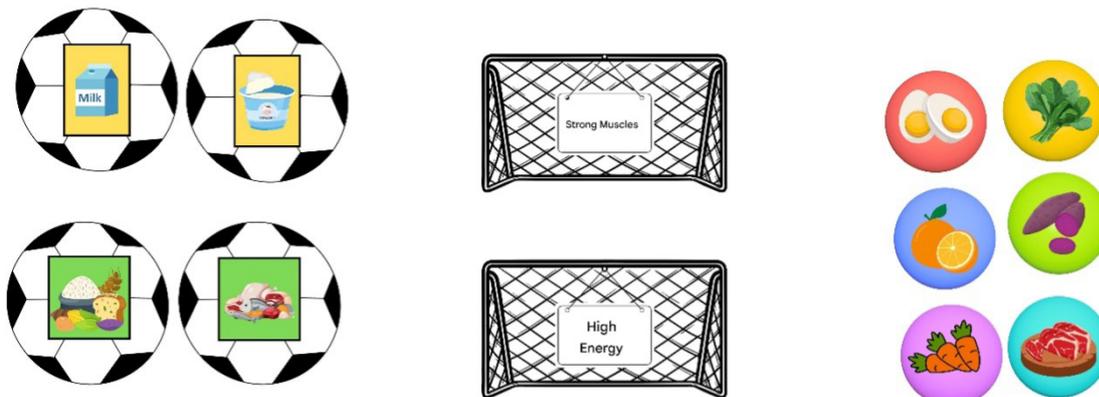**Figure 5.** Visual teaching media used in the "Energy Race" game.



**Figure 6.** Visual teaching media used in the "Nutrition Strike Ball" game.

*General Instructions*

Part A: Game Activities and Self-Observation

The student worksheet for recording movements, recognized foods, and perceived benefits during each game activity is presented in Table 1.

Part B: Self-Reflection

Students reflected on their understanding of nutrition concepts and their participation in activities by answering the following questions:

· Give two examples of foods that belong to the carbohydrate group.
· What are the benefits of protein for your body?
· When does your body need high energy?
· Name two healthy eating habits you want to maintain after participating in this activity.
· Rate your level of activity during this session by ticking (✔).

The categories used for student self-assessment are presented in Table 2.

*Facilitators, Training, and Fidelity Monitoring*

All activities in the experimental group were facilitated by Physical Education (PE) teachers who held at least a bachelor's degree in Physical Education and were either certified civil servants (ASN) or had a minimum of two years of teaching experience in inclusive schools. These criteria ensured that facilitators possessed sufficient pedagogical competence and experience working with students with special educational needs.

Before the intervention, all PE teachers participated in a two-week intensive training program to ensure instructional consistency and adaptive teaching competence when working with slow learners. The training included workshops, microteaching sessions, and guided simulations focusing on three core competencies:

(1) delivering adaptive verbal and visual instructions;

(2) using visual learning media such as food cards, color symbols, and nutrition-category boards;

(3) applying a structured fidelity checklist to monitor adherence to the intervention protocol.

During the intervention, weekly fidelity monitoring was conducted by the research team using a standardized observation sheet that assessed session duration, clarity of instruction, activity flow, and student engagement. This systematic monitoring ensured consistent implementation of all sessions according to the intended design of the intervention.

*Control Group (CON)*

The control group (CON) participated in traditional nutrition learning sessions integrated within conventional physical education classes. The program was conducted over 12 sessions of 120 minutes each (3 × 40 minutes), consistent with the schedule of the experimental group. Each session included a brief lecture and a question–answer segment delivered by the PE teacher, focusing on the same nutrition topics as those taught in the experimental group (e.g., types of nutrients, their functions, and healthy food choices). No physical activity–based learning methods or interactive games were applied.

The instructional format emphasized teacher explanation, note-taking, and verbal recall exercises, representing a passive learning condition. The exercise intensity during the physical activity components was maintained at a moderate level (Borg scale 11–13) to ensure comparable physical engagement across groups. During the first and final

**Table 1.** Student worksheet for game activities and self-observation

| No. | Game Name | Type of Movement Performed | Examples of Foods Recognized | Benefits of Activities for the Body |
|---|---|---|---|---|
| 1 | Nutrition Relay | Sprinting, grabbing, sticking | Rice, bread, tempeh | Improves speed and nutritional knowledge |
| 2 | Nutritional Ball Throw | ..................... | ..................... | ..................... |
| 3 | Food Basket Game | ..................... | ..................... | ..................... |
| 4 | Energy Race | ..................... | ..................... | ..................... |
| 5 | Nutrition Strike Ball | ..................... | ..................... | ..................... |

**Table 2.** Student self-assessment of activity participation level

| Category | Description | Choice |
|---|---|---|
| Active | Participated fully, showed enthusiasm, and cooperated well with friends | ☐ |
| Moderately Active | Participated but occasionally lacked focus | ☐ |
| Needs Guidance | Often passive and required teacher encouragement | ☐ |

weeks, participants completed pretest and posttest assessments (TGMD-2 and nutritional literacy tests) to allow for equitable comparison. After the intervention, the control group was offered the opportunity to participate in the Active Physical Education–Based Nutrition Learning program as a delayed intervention, ensuring ethical equity in participation.

*Instruments*

*Nutrition Literacy Test*

Nutritional literacy was assessed using a 20-item multiple-choice test covering five key indicators.

The indicators and corresponding item numbers were as follows:
1. Understanding nutrition concepts — items 1–4.
2. Identifying nutrient functions — items 5–8.
3. Grouping foods based on nutrient content — items 9–12.
4. Linking food to energy needs — items 13–16.
5. Linking food to health benefits — items 17–20.

After developing the multiple-choice instrument, content validation and reliability testing were carried out. The validation was performed by seven experts using the Aiken's V method, and the reliability was tested using Cronbach's Alpha. The results showed satisfactory validity (V = 0.78) and high internal consistency (α = 0.833 for 12 items), confirming that the instrument was appropriate for assessing nutritional literacy among inclusive junior high school students.

Gross Motor Skills Test

Gross motor skills were assessed using the Test of Gross Motor Development, Second Edition (TGMD-2). This standardized instrument is designed to measure fundamental movement skills in children aged 3 to 10 years [21].

The justification for using this test in the present study is based on recommendations found in previous research [22, 23], which indicate that the TGMD-2 is appropriate for individuals with special needs or developmental delays who may be older than 10 years. The gross motor profiles of students with learning difficulties are often comparable to those of younger children, particularly in locomotor skills (running, leaping, hopping) and object control skills (throwing, catching, kicking) [21, 22, 23]. The TGMD-2 demonstrates strong psychometric properties and has been widely applied in studies involving children with various motor or developmental challenges [22].

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics for Windows, version 30 (IBM Corp., Armonk, NY, USA). The Shapiro–Wilk test was applied to assess data normality, as the sample size was fewer than 20 participants [23]. The Levene's test was used to examine the homogeneity of variance, while Box's M test was employed to verify the homogeneity of covariance matrices. Normalized gain (N-gain) scores were calculated and classified according to Hake's criteria to determine the improvement in gross motor skills and nutritional literacy. Multivariate Analysis of Covariance (MANCOVA) was used to test the study hypotheses, with pretest scores included as covariates. This analytical approach was chosen because the study involved two related dependent variables and required controlling for baseline differences between groups. MANCOVA was considered appropriate as it allows for simultaneous testing of treatment effects, increases statistical power, and provides more reliable results than univariate analyses [24].

## Results

The program's validity and reliability were analyzed using the Content Validity Index (CVI) and Cronbach's Alpha. The combined results of the media and material expert assessments are presented in Table 3.

Based on the validation results summarized in Table 3, all evaluated aspects met the very feasible criteria. For the media expert assessment, the aspects of visual clarity and movement representation, media safety and suitability, and ease of use were all rated very feasible. Likewise, the material expert evaluation showed that integration of nutrition content with physical activity, quality of learning materials, and usefulness were each categorized as very feasible. Therefore, the Active Physical Education–Based Nutrition Learning program was determined to be highly feasible for implementation in inclusive school settings.

The reliability of the Active Physical Education–Based Nutrition Learning program was evaluated using Cronbach's Alpha to determine the internal consistency of each assessment aspect. The summary of the reliability test results is presented in Table 4.

As shown in Table 4, all Cronbach's Alpha coefficients exceeded the minimum threshold of 0.60, indicating high internal consistency and stability of the learning program. According to previous research, coefficients above 0.60 are considered acceptable for reliability [19,20]. Therefore, the Active Physical Education–Based Nutrition Learning program was confirmed to be both valid and reliable for implementation.

The content validation of the nutrition literacy instrument was conducted by seven expert raters using the Aiken's V coefficient. The evaluation covered twelve rated aspects, focusing on content relevance, clarity, sequencing, and language suitability for inclusive junior high school students. The detailed results of the validation process are presented in Table 5.

**Table 3.** Expert Validation Results for the Active Physical Education–Based Nutrition Learning Program

| No. | Aspects of Assessment | Total Score | Average Score | Percentage (%) | Category |
|---|---|---|---|---|---|
| **Media Expert Evaluation** | | | | | |
| 1 | Visual Clarity & Movement Representation | 161 | 3.83 | 95.83 | Very Feasible |
| 2 | Media Safety and Suitability | 196 | 3.50 | 87.50 | Very Feasible |
| 3 | Media Ease of Use | 175 | 3.57 | 89.29 | Very Feasible |
| **Subtotal (Media Experts)** | | | **3.63** | **90.87** | **Very Feasible** |
| **Material Expert Evaluation** | | | | | |
| 1 | Integration of Nutrition Materials with Physical Activity | 84 | 3.50 | 87.50 | Very Feasible |
| 2 | Quality of Learning Materials | 89 | 3.59 | 89.77 | Very Feasible |
| 3 | Usefulness | 82 | 3.49 | 86.54 | Very Feasible |
| **Subtotal (Material Experts)** | | | **3.53** | **87.94** | **Very Feasible** |

**Table 4.** Reliability Test Results of the Active Physical Education–Based Nutrition Learning Program

| No. | Eligibility Aspects | Cronbach's Alpha | Status |
|---|---|---|---|
| 1 | Visual Clarity & Movement Representation | 0.856 | Reliable |
| 2 | Media Safety and Suitability | 0.808 | Reliable |
| 3 | Media Ease of Use | 0.821 | Reliable |
| 4 | Integration of Nutrition Materials with Physical Activity | 0.838 | Reliable |
| 5 | Quality of Learning Materials | 0.884 | Reliable |
| 6 | Usefulness | 0.871 | Reliable |

As shown in Table 5, all twelve rated aspects achieved Aiken's V values exceeding the minimum threshold of 0.74, with an average coefficient of 0.78.

This study generated data that were systematically analyzed using several statistical procedures, including descriptive analysis, assumption testing (normality, homogeneity of variance, and homogeneity of covariance), calculation of normalized gain (N-gain), and the main analysis employing MANCOVA on the variables of gross motor skills and nutritional literacy among slow learners in inclusive junior high schools.

The presentation of results was organized sequentially, beginning with descriptive statistics, followed by assumption testing, effectiveness estimation using N-gain, and concluding with hypothesis testing.

The descriptive findings for both the TGMD-2 (gross motor skills) and Nutrition Literacy tests are presented in Table 6.

According to Table 6, the descriptive findings of the TGMD-2 test indicate that the experimental group achieved a pre-test mean score of 88.80 (range 79–98), showing that their initial gross motor abilities were within this range. After the intervention, the mean score increased markedly to 117.15 (range 111–126), indicating a substantial improvement in fundamental motor skills.

The control group exhibited a pre-test mean score of 88.90 (range 80–95) and a post-test mean of 93.20 (range 84–98), reflecting only a slight improvement. These results suggest that the intervention was effective in enhancing gross motor abilities compared with the untreated group.

Similarly, the descriptive statistics for the Nutrition Literacy test show that the experimental group's mean score rose from 40.00 (range 30–55) at pre-test to 79.00 (range 70–90) at post-test, indicating a significant improvement in nutrition knowledge. The control group's mean score increased only slightly, from 43.25 (range 30–55) to

**Table 5.** Validation of the Nutrition Literacy Question Instrument

| No. | Rated Aspect | Σs | V | Description |
|---|---|---|---|---|
| 1 | The questions presented cover the concept of nutrition. | 21 | 0.75 | Accepted |
| 2 | The questions aim to improve the nutritional literacy of inclusive junior high school students. | 21 | 0.75 | Accepted |
| 3 | The questions are presented sequentially, from easy to difficult. | 22 | 0.79 | Accepted |
| 4 | The questions cover the concept of nutrition. | 24 | 0.86 | Accepted |
| 5 | The questions cover the functions of nutrients. | 21 | 0.75 | Accepted |
| 6 | The questions cover nutritious food groups. | 21 | 0.75 | Accepted |
| 7 | The questions cover nutritional needs. | 22 | 0.79 | Accepted |
| 8 | The questions cover the benefits of nutritious foods. | 21 | 0.75 | Accepted |
| 9 | The questions are neither too easy nor too difficult. | 22 | 0.79 | Accepted |
| 10 | The questions comply with the curriculum standards for inclusive junior high school students. | 16 | 0.80 | Accepted |
| 11 | The vocabulary used is appropriate for the students' comprehension level. | 22 | 0.79 | Accepted |
| 12 | The language used follows PUEBI (The Indonesian Spelling System General Manual). | 22 | 0.79 | Accepted |
| Average | | 21 | 0.78 | Accepted |

Note. V for rater = 7; at a 5% error rate, a minimum value of 0.74 is considered acceptable.

**Table 6.** Descriptive Results of TGMD-2 and Nutrition Literacy Tests

| Test Type | Group | N | Mean | SD | Min | Max |
|---|---|---|---|---|---|---|
| TGMD-2 (Gross Motor Skills) | Pre-Test Experimental | 20 | 88.80 | 5.207 | 79 | 98 |
| | Post-Test Experimental | 20 | 117.15 | 4.568 | 111 | 126 |
| | Pre-Test Control | 20 | 88.90 | 3.582 | 80 | 95 |
| | Post-Test Control | 20 | 93.20 | 3.708 | 84 | 98 |
| Nutrition Literacy | Pre-Test Experimental | 20 | 40.00 | 6.882 | 30 | 55 |
| | Post-Test Experimental | 20 | 79.00 | 5.282 | 70 | 90 |
| | Pre-Test Control | 20 | 43.25 | 6.742 | 30 | 55 |
| | Post-Test Control | 20 | 45.00 | 6.489 | 35 | 55 |

45.00 (range 35–55), demonstrating that meaningful gains in nutritional literacy occurred primarily in the experimental group following the intervention.

*Normality Test Results*

The assumption of normality was tested using the Shapiro–Wilk test for both dependent variables — TGMD-2 (gross motor skills) and Nutrition Literacy.

The results demonstrated that all significance values for both the experimental and control groups, in pre-test and post-test conditions, were greater than 0.05, confirming that the data were normally distributed.

The detailed outcomes of the normality test for both variables are presented in Table 7.

As shown in Table 7, all significance values for both TGMD-2 and Nutrition Literacy exceeded 0.05, indicating that the data met the assumption of normality across all groups and testing phases.

Homogeneity of Variance Test Results

The homogeneity of variance assumption was examined using Levene's Test for both dependent variables — TGMD-2 (gross motor skills) and Nutrition Literacy.

The results confirmed that all significance values exceeded 0.05, indicating that the variance across groups was homogeneous.

The detailed findings of Levene's Test for both variables are presented in Table 8.

As shown in Table 8, both TGMD-2 and Nutrition Literacy variables produced significance values greater than 0.05 (0.166 and 0.480, respectively), confirming that the homogeneity of variance assumption was satisfied for both datasets.

Homogeneity of Covariance Test Results

The homogeneity of covariance was examined using Box's M Test.

The analysis produced a Box's M value of 12.583 with a significance level of 0.082 (p > 0.05), indicating that the covariance matrices across groups were homogeneous.

Therefore, the assumption of homogeneity of covariance was satisfied.

N-Gain Results

**Table 7.** Normality Test Results of TGMD-2 and Nutrition Literacy

| Test Type | Group | Sig. (Shapiro–Wilk) | Interpretation |
|---|---|---|---|
| TGMD-2 (Gross Motor Skills) | Pre-Test Experimental | 0.948 | Normal |
| | Post-Test Experimental | 0.074 | Normal |
| | Pre-Test Control | 0.358 | Normal |
| | Post-Test Control | 0.102 | Normal |
| Nutrition Literacy | Pre-Test Experimental | 0.157 | Normal |
| | Post-Test Experimental | 0.128 | Normal |
| | Pre-Test Control | 0.380 | Normal |
| | Post-Test Control | 0.101 | Normal |

**Table 8.** Results of Homogeneity of Variance Test for TGMD-2 and Nutrition Literacy

| Test Type | F | df1 | df2 | Sig. | Interpretation |
|---|---|---|---|---|---|
| TGMD-2 (Gross Motor Skills) | 1.992 | 1 | 38 | 0.166 | Homogeneous variance ($p > 0.05$) |
| Nutrition Literacy | 0.510 | 1 | 38 | 0.480 | Homogeneous variance ($p > 0.05$) |

**Table 9.** N-Gain Results for TGMD-2 and Nutrition Literacy

| Test Type | Group | Pre | Post | N-Gain | Percentage (%) | Category |
|---|---|---|---|---|---|---|
| TGMD-2 (Gross Motor Skills) | Experimental | 88.80 | 117.15 | 28.35 | 72.32 | Moderately effective |
| | Control | 88.90 | 93.20 | 4.30 | 10.99 | Not effective |
| Nutrition Literacy | Experimental | 40.00 | 79.00 | 39.00 | 65.00 | Moderately effective |
| | Control | 43.25 | 45.00 | 1.75 | 3.08 | Not effective |

The normalized gain (N-Gain) analysis was conducted to measure the relative improvement in both gross motor skills (TGMD-2) and nutrition literacy between the pre-test and post-test phases.

The results showed that the experimental group experienced substantial increases across both variables, while the control group demonstrated minimal changes.

The detailed N-Gain results for both tests are presented in Table 9.

As shown in Table 9, the experimental group achieved markedly higher N-Gain percentages in both TGMD-2 (72.32%) and nutrition literacy (65.00%), indicating a moderate level of effectiveness for the intervention.

In contrast, the control group demonstrated only marginal gains of 10.99% and 3.08%, respectively, classified as not effective.

These findings confirm that the Active Physical Education–Based Nutrition Learning program substantially improved both gross motor skills and nutrition literacy among slow learners compared with conventional instruction.

*MANCOVA Hypothesis Testing Results*

The MANCOVA analysis was conducted to examine the overall effect of the Active Physical Education–Based Nutrition Learning intervention on the combined dependent variables [gross motor skills (TGMD-2) and nutrition literacy] while controlling for pre-test scores. The multivariate test results using Pillai's Trace are presented in Table 10.

As shown in Table 10, the MANCOVA results revealed a statistically significant multivariate effect of group on the combined dependent variables ($p < 0.001$), indicating that the intervention had a substantial influence on both outcomes even after controlling for pre-test scores. The analysis also confirmed that only the TGMD covariate was significant, while the nutrition literacy covariate was not. These findings demonstrate that the applied learning intervention effectively improved both gross motor skills and nutrition literacy among slow learners.

The univariate results were analyzed to identify the specific effects of the intervention on each dependent variable [gross motor skills (Post-TGMD) and nutrition literacy (Post-Literacy)] after controlling for the pre-test covariates. The results of the univariate MANCOVA tests are presented in Table 11.

As shown in Table 11, both dependent variables — gross motor skills and nutrition literacy — demonstrated statistically significant improvements following the intervention ($p < 0.05$). The large effect sizes indicate that the applied program had a powerful influence on students' development across both domains. The covariate Pre-TGMD was significant only for the motor skill outcome, confirming that initial motor ability partially influenced post-intervention performance, while

**Table 10.** Multivariate MANCOVA Results (Pillai's Trace)

| Effect | Statistics | Value | F | Sig. | Partial $\eta^2$ | Category | Interpretation |
|---|---|---|---|---|---|---|---|
| Group | Pillai's Trace | 0.973 | 628.0 | 0.000 | 0.973 | Large | Significant effect of group on combined DVs |
| Pre-TGMD | Pillai's Trace | 0.644 | 31.64 | 0.000 | 0.644 | Large | Significant effect of TGMD covariate |
| Pre-Literacy | Pillai's Trace | 0.048 | 0.884 | 0.422 | 0.048 | Small | Nutrition literacy covariate not significant |

Note. According to Cohen, effect sizes are interpreted as small ($\eta^2 = 0.01$), medium ($\eta^2 = 0.06$), and large ($\eta^2 = 0.14$).

**Table 11.** Univariate MANCOVA Results on Dependent Variables

| Source | DV | F | Sig. | Partial $\eta^2$ | Category | Interpretation |
|---|---|---|---|---|---|---|
| Group | Post-TGMD | 791.11 | 0.000 | 0.956 | Large | Significant difference, large effect |
| Group | Post-Literacy | 333.89 | 0.000 | 0.903 | Large | Significant difference, large effect |
| Pre-TGMD | Post-TGMD | 59.23 | 0.000 | 0.622 | Large | Significant covariate |
| Pre-TGMD | Post-Literacy | 1.77 | 0.191 | 0.047 | Small | Not significant |
| Pre-Literacy | Post-TGMD | 0.00 | 0.996 | 0.000 | None | Not significant |
| Pre-Literacy | Post-Literacy | 1.79 | 0.190 | 0.047 | Small | Not significant |

Note. According to Cohen, effect sizes are interpreted as small ($\eta^2 = 0.01$), medium ($\eta^2 = 0.06$), and large ($\eta^2 = 0.14$).

Pre-Literacy did not significantly affect the results.

Overall, the findings confirm that the Active Physical Education–Based Nutrition Learning program effectively enhanced both motor and cognitive aspects of student development within the inclusive school setting.

Taken together, these findings provide robust evidence that the culturally adapted and physically active nutrition education model was highly effective for slow learners in inclusive junior high school settings. The magnitude of the effects demonstrates the program's potential for replication and its practical relevance in improving students' holistic health literacy and physical competence.

## Discussion

This study aimed to evaluate the effectiveness of active physical education–based nutrition learning in improving gross motor skills and nutritional literacy among slow learners. The findings showed that incorporating nutrition instruction into active physical education lessons in inclusive junior high schools significantly enhanced both gross motor abilities and nutritional literacy among students with learning difficulties. The MANCOVA results confirmed this effectiveness, revealing a substantial impact on both dependent variables, as reflected by the high partial $\eta^2$ values (0.956 for TGMD-2 and 0.903 for nutritional literacy). These outcomes demonstrate that the intervention successfully improved both motor and cognitive domains.

This study aligns with prior studies. One study indicated that organized physical exercise significantly influences pupils' gross motor development, especially for those with special needs [25]. Another study revealed that children participating in both unstructured and organized play have enhanced motor coordination. However, this requires intentional teaching tactics to maximize advantages [10]. Moreover, WHO recommendations emphasize that physical exercise is crucial for physical and mental health as well as for motor development [26]. These studies collectively demonstrate that systematic physical exercise treatments enhance motor abilities, physical fitness, and academic and cognitive areas.

Beyond motor development, this study also reinforces the importance of innovative strategies to improve nutritional literacy. Balanced nutrition podcasts enhance student engagement and understanding [27]. Nutrition education programs significantly improved adolescents' nutritional knowledge and practices [28]. Another study found that animated media effectively increased knowledge and promoted healthier eating behaviors [29]. These studies emphasize that diverse and interactive learning strategies foster active participation and meaningful learning outcomes.

Taken together, these findings suggest that integrating nutrition education with active physical education creates a dual impact. It enhances gross motor skills while simultaneously improving nutrition literacy. These domains are crucial for inclusive students, as motor development supports independence in daily activities, builds self-confidence, and encourages active engagement in physical environments [30]. Nutrition literacy equips students with the knowledge and habits

necessary to maintain a healthy lifestyle. It enables them to make informed dietary choices that promote long-term well-being [31, 32, 33, 34]. Strengthening these two aspects simultaneously is particularly important for inclusive education, as it fosters both physical independence and consistent health-promoting behaviors.

Covariate analysis revealed that initial TGMD-2 scores (Pre-TGMD) significantly predicted post-intervention gross motor outcomes (F = 59.23; $p < 0.001$; partial $\eta^2 = 0.622$). This indicates that baseline motor competence plays a crucial role in subsequent development. It aligns with several studies that confirmed the lasting influence of early motor competence on later achievement [35, 36, 37]. Conversely, initial nutritional literacy scores did not significantly influence post-test outcomes ($p > 0.05$; partial $\eta^2 < 0.05$). This suggests that the intervention itself primarily drove improvements. This finding is consistent with previous studies emphasizing that comprehensive and practical nutrition education programs can improve dietary practices regardless of students' prior knowledge [38, 39].

These findings are theoretically substantiated by Piaget's theory of learning through play, Bandura's social learning theory, and Vygotsky's constructivist framework. These theories emphasize the significance of direct experience, social interaction, and cooperation in the learning process. Numerous studies indicate that interactive and collaborative learning environments enhance both motivation and the application of information [40, 41, 42].

This study contributes to inclusive physical education by presenting a pedagogical model that combines gross motor learning and nutrition literacy within an active learning framework. The model connects physical and cognitive development, enabling students to acquire nutrition concepts through movement-based experiences. It also overcomes the limitations of traditional methods that separate nutrition and physical education into distinct domains.

The findings show that integrating physical activity with nutrition literacy is both feasible and effective for slow learners in inclusive schools when teachers act as adaptive facilitators. Physical education teachers are responsible for modifying tasks, adjusting activity intensity, and providing clear visual instructions suited to students' abilities. Through this adaptive approach, students not only learn nutrition concepts but also develop healthy habits through direct physical engagement.

This integrated model can help reduce learning gaps in both areas and may be applicable beyond Indonesia. This integrated model may also contribute to the development of inclusive education practices consistent with constructivist and experiential learning approaches. It provides a practical framework for improving both nutrition literacy and motor competence among inclusive learners.

*Limitations of the Study*

Several limitations should be noted. The relatively small sample size limits the generalizability of the results. The short duration of the intervention prevents conclusions about long-term effects. Gender differences were not analyzed, so it remains unclear whether outcomes varied between male and female students. In addition, the study was conducted in a specific cultural and educational context, an Indonesian inclusive junior high school, which may restrict the applicability of the findings to other educational systems.

Future research should involve larger samples, use longitudinal designs, include gender-based comparisons, and test the intervention at different educational levels. Further studies could also examine how teachers implement this model across various schools and teaching contexts, focusing on fidelity, student engagement, and program sustainability. In addition, it may be useful to explore the use of digital or game-based tools to support participation and adaptive learning for slow learners.

## Conclusions

The study confirmed that integrating nutrition learning into physical education lessons can effectively support the comprehensive development of students with learning difficulties in inclusive settings. The approach promotes both physical competence and awareness of healthy lifestyle habits. Such integration provides a meaningful learning framework where movement and knowledge complement each other, supporting the goals of inclusive education and fostering active participation of all students.

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## Conflict of Interest

The authors declare no conflict of interest regarding the authorship or the findings of this study.

## AI Tools Usage

In preparing this manuscript, the authors used ChatGPT (OpenAI, San Francisco, CA) to refine sentence structure and improve language clarity. The entire content was thoroughly reviewed, edited, and validated by the authors and a language expert. The authors assume full responsibility for the accuracy, originality, and integrity of the manuscript.

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