Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Effect of a 12-Week Athletic Skills Model-Based Diversified Motor Skill Program on Vital Capacity in Primary School Students: A School-Based Non-Randomized Physical Education Intervention Study

Junhui Zhu
Universiti Kebangsaan Malaysia
Yan Bu
Yibin University
Mingling Zhao
Chengdu Polytechnic
Ling Xu
Sichuan Tianfu New Area No. 5 Primary School
Lin Zhu
670200865@qq.com

Sichuan University of Business and Technology

Article

Keywords: Athletic Skills Model, fundamental movement skills, motor competence, vital capacity, school physical education, children, non-randomized physical education intervention study, linear mixed-effects model

Posted Date: June 8th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9664669/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Version of Record: A version of this preprint was published at Scientific Reports on October 12th, 2026. See the published version at https://doi.org/10.1038/s41598-026-75561-6.

Abstract

Background

School-based physical education may improve children's health-related fitness, but evidence on diversified motor skill curricula and respiratory-related fitness indicators remains limited. This study examined whether a 12-week Athletic Skills Model (ASM)-based diversified motor skill program was associated with greater improvements in vital capacity than routine physical education among primary school students.

Methods

A school-based, two-group, non-randomized physical education intervention study with a pretest-posttest comparison was conducted in one primary school in Southwest China. After complete-case matching, 1,214 students were included, with 607 in the ASM group and 607 in the comparison group. The ASM group participated in a 12-week program embedded in regular physical education and after-school activity sessions, delivered three times per week for 40 minutes per session, whereas the comparison group continued routine physical education. Vital capacity was measured before and after the intervention. Paired- and independent-samples t tests, Hedges' g, and random-intercept linear mixed-effects models adjusted for age and sex were used to estimate changes and the group-by-time interaction. Subgroup analyses were conducted by tertiles of baseline vital capacity.

Results

Vital capacity increased from 1978.58 ± 401.65 mL to 2093.44 ± 473.41 mL in the ASM group (mean change: 114.86 ± 254.83 mL; $p < 0.001$; $dz = 0.45$) and from 1969.61 ± 397.01 mL to 2015.27 ± 480.91 mL in the comparison group (mean change: 45.66 ± 257.91 mL; $p < 0.001$; $dz = 0.18$). The between-group difference in change was 69.20 mL (95% CI: 40.33 to 98.08; $p < 0.001$; Hedges' $g = 0.27$). The adjusted model showed a significant group-by-time interaction ($\beta = 69.20$ mL; 95% CI: 40.38 to 98.02; $p < 0.001$). Positive net changes were observed across low-, intermediate-, and high-baseline subgroups.

Conclusion

A 12-week ASM-based diversified motor skill program was associated with a small but statistically significant additional improvement in field-based vital capacity compared with routine physical education. These findings support integrating diversified motor skill content into primary school physical education, although randomized or cluster-randomized studies including growth, maturation, activity-dose, and motor competence measures are needed to strengthen causal inference. Trial registration: This school-based non-randomized physical education intervention was not prospectively registered in a

public clinical trial registry because it was designed, approved, and implemented as a school physical education curriculum intervention rather than as a medical, drug, device, or patient-care clinical trial. The absence of prospective trial registration is acknowledged as a reporting limitation.

Trial registration

This school-based non-randomized physical education intervention was not prospectively registered in a public clinical trial registry because it was designed, approved, and implemented as a school physical education curriculum intervention rather than as a medical, drug, device, or patient-care clinical trial. The absence of prospective trial registration has been acknowledged as a reporting limitation.

1. Introduction

Physical fitness surveillance in children and adolescents increasingly emphasizes the interaction between movement competence, physical activity participation, and health-related fitness rather than isolated test-item performance alone. In China, school-based fitness testing remains an important source of information on children's physical development, yet concerns about insufficient physical activity and sedentary behavior indicate that physical education should not be reduced to test preparation. Recent evidence from Chinese children indicates that insufficient physical activity and sedentary behavior remain important concerns in school-age populations [3]. School-based physical activity programmes may improve physical activity and fitness outcomes in children and adolescents [4]. Different types and frequencies of physical activity are associated with physical fitness among Chinese children and adolescents [21]. Recent regional evidence from China suggests that physical activity, sedentary time, and physical fitness in children and adolescents have changed across recent school years [22].

Vital capacity, as assessed in school physical fitness testing, is a field-based indicator of respiratory-related fitness. It reflects, to some extent, lung volume, thoracic mobility, respiratory effort, and test cooperation, and it is also influenced by growth, sex, body size, maturation, posture, and habitual physical activity [5]. Long-term evidence from Chinese children and adolescents suggests that forced vital capacity and weight-adjusted forced vital capacity show important temporal and distributional changes [24]. Environmental exposure may also modify the association between physical activity and lung function in Chinese children [7]. Because vital capacity is not a direct clinical assessment of pulmonary function, changes in this outcome should be interpreted cautiously. Nevertheless, in school settings it remains a practical indicator for monitoring group-level physical fitness and may help evaluate whether physical education programs provide adequate movement stimulation.

Many primary school physical education programs rely heavily on repetitive running, jumping, throwing, ball games, or direct preparation for fitness-test items. Such activities may improve specific test performance, but they may offer limited opportunities for children to acquire diverse movement experiences, solve movement problems, and adapt to variable environments. Evidence from school-

based physical activity interventions suggests that structured activity time, moderate-to-vigorous physical activity, and motor competence are all relevant to children's physical fitness development [4, 12].

The Athletic Skills Model (ASM) provides a pedagogical framework for developing broad athletic ability through varied, multi-context, and transferable movement experiences. Instead of promoting early specialization, the ASM emphasizes a balanced development of sport participation, health, and performance through diversified movement tasks [1, 2]. In primary school physical education, ASM-informed content can integrate locomotor skills, balance, object control, climbing, rotating, rhythm, reaction, agility, and low-load strength tasks into coherent lesson structures.

Fundamental movement skills (FMS) and motor competence are important foundations for children's participation in more complex physical activities and organized sport. School-based neuromuscular training has been reported to improve fundamental movement skills and physical fitness in children [6]. Functional training may also have positive effects on fundamental motor skills among children [13]. Physical activity programmes have shown beneficial effects on fundamental movement skills in young children [14]. Physical activity interventions in early childhood may contribute to both fundamental movement skills and cognitive function [15]. Evidence from preschool populations suggests that active play alone may not fully replace skill-oriented physical education for improving fundamental movement skills [16]. Movement skill competence has also been linked to cognitive skills in primary school children [8]. These findings support the idea that diversified movement experiences may contribute not only to skill development but also to health-related fitness through increased engagement, movement confidence, and physical activity exposure.

The relationship between diversified motor skill training and vital capacity is likely indirect. Dynamic running and jumping, agility tasks, postural control, core stability, rhythmic movement, and game-based activities may increase ventilatory demand, involve trunk and respiratory musculature, and encourage fuller breathing patterns during activity. School-based activity programs have reported favorable changes in children's pulmonary-related outcomes, and exercise interventions in pediatric populations have been associated with improvements in selected lung function indicators [9, 10]. However, whether an ASM-based diversified motor skill program can improve school-based vital capacity in primary school students remains insufficiently examined.

Therefore, the present study developed a 12-week ASM-based diversified motor skill program embedded in routine school physical education and evaluated its association with changes in vital capacity among primary school students. The aims were to: (1) compare pretest-posttest changes in vital capacity between the ASM group and a routine physical education comparison group; (2) estimate the adjusted group-by-time interaction using a linear mixed-effects model; and (3) explore whether the intervention effect differed across baseline vital capacity levels. We hypothesized that students exposed to the ASM-based program would show greater improvement in vital capacity than students receiving routine physical education, while recognizing that the non-randomized design limits causal interpretation.

2. Materials and Methods

2.1 Study Design

This study was designed as a school-based, two-group, non-randomized physical education intervention study with a pretest-posttest comparison. The intervention was conducted within the routine school physical education and after-school activity context rather than in a medical, hospital, patient-care, drug, or device trial setting. Because school timetabling, teacher allocation, and class management were organized in stable educational units, individual randomization was not feasible. Therefore, classes or instructional units, rather than individual students, were assigned to either the Athletic Skills Model (ASM)-based diversified motor skill program or the routine physical education comparison condition. The study evaluated changes in a school-based physical fitness indicator, vital capacity, before and after the 12-week curriculum intervention. Participants were recruited from one primary school in China and were students in Grades 3 to 5. A total of 28 classes participated in the study, including 14 classes assigned to the ASM group and 14 classes assigned to the comparison group. Students in the ASM group received a diversified motor skill program embedded in regular school physical education, whereas students in the comparison group continued the school's routine physical education program.

2.2 Protocol, Reporting Guideline, and Trial Registration

The intervention protocol was developed before implementation and reviewed as part of the institutional ethics approval process. The protocol specified the study rationale, participant eligibility, class-level allocation procedure, intervention content, comparison condition, outcome measure, testing procedure, safety management, data anonymization, and planned statistical analysis. A separate protocol document is provided as a Related Manuscript File for editorial and peer review.

This study was not a medical clinical trial involving patients, diagnosis, treatment, drugs, medical devices, or clinical care pathways. It was a school-based sports science and physical education intervention implemented within routine curriculum and after-school activity arrangements. However, because the study involved allocation of classes/students to an exercise-based intervention and comparison condition and assessed a health-related fitness outcome, the manuscript has been revised to follow CONSORT 2010 reporting principles where applicable to a non-randomized intervention design. A completed CONSORT 2010 checklist, with non-applicable randomization-related items clearly marked, is provided as a Related Manuscript File.

This study was not prospectively registered in a public clinical trial registry because it was originally designed and approved as a school physical education curriculum intervention rather than as a medical clinical trial. The absence of prospective trial registration is explicitly acknowledged in the Abstract, Discussion, and Declarations.

2.3 Ethical Approval and Consent to Participate

The study protocol was approved by the Technology Ethics Committee of Yibin University before participant recruitment and intervention implementation (approval No. YBULLKY26042101). The study was conducted in accordance with the Declaration of Helsinki and the principles of informed consent, minimal risk, voluntary participation, and data anonymization. Written informed consent was obtained from the students' parents or legal guardians before participation. In addition, students were informed of the study purpose, activity content, testing procedures, and their right to withdraw at any time in age-appropriate language by the research team and physical education teachers. Only students who provided verbal assent and had guardian consent participated in the study. Identifiable information was removed after data export, and all analyses were conducted using de-identified data at the group level.

2.4 Participants and Inclusion Criteria

Participants were primary school students from one school in Southwest China. Students were recruited from Grades 3 to 5 across 28 participating classes, including 14 classes in the ASM group and 14 classes in the comparison group. All students in the participating classes were considered eligible if they were able to take part in regular physical education classes and low- to moderate-intensity physical activity and had written guardian consent. Students were excluded from the analytic sample if they had an acute cardiopulmonary condition or medical restriction that made physical activity inappropriate, experienced physical discomfort on the testing day that invalidated the test, or lacked paired valid pretest and posttest vital capacity records. The analytic dataset was constructed by matching valid pretest and posttest vital capacity records from the ASM and comparison groups. After complete-case matching, 607 students were included in the ASM group and 607 students were included in the comparison group, yielding a final analytic sample of 1,214 students.

Recruitment, guardian consent, baseline testing, intervention delivery, and post-intervention testing were completed within the school semester according to the school-approved physical education intervention protocol. Baseline testing was conducted during the week before the intervention, the 12-week ASM-based curriculum intervention was implemented during regular school physical education and after-school activity sessions, and post-intervention testing was conducted within the week after completion of the program.

2.5 Design of the ASM-Based Diversified Motor Skill Intervention

The ASM group received a 12-week intervention delivered three times per week for 40 minutes per session, for a total of 36 planned sessions. The program was embedded into two regular physical education classes and one after-school physical activity session each week. Each session included approximately 8 minutes of dynamic warm-up, 25 minutes of ASM-themed motor skill activities, 5 minutes of small-group challenges or cooperative games, and 2 minutes of cool-down and feedback. Attendance was recorded by physical education teachers using class attendance sheets. The effective attendance threshold was defined as participation in at least 80% of the planned sessions.

Students who were included in the final analytic sample had valid paired pretest and posttest vital capacity records and participated in the school-based intervention under routine class management. Implementation fidelity was supported through a standardized 12-week teaching plan, consistent lesson structure, teacher-led delivery, and regular checking of whether the planned ASM-themed activities were completed during each session.

The intervention was designed around three interacting components: fundamental movement skills, coordination abilities, and movement conditions. Weeks 1–2 focused on adaptation, safety rules, spatial awareness, basic running, jumping, throwing, and balance games. Weeks 3–5 expanded the movement repertoire through climbing, rolling, rotating, low-height obstacle crossing, and rhythmic movement. Weeks 6–8 emphasized coordination integration, including reaction, agile changes of direction, partner cooperation, and multitask movement. Weeks 9–11 focused on movement-condition enhancement through low-load strength, short circuit stations, speed-strength tasks, and core stability. Week 12 was used for consolidation and preparation for posttesting, with reduced training volume while maintaining movement quality and participation interest.

Intensity was managed through teacher observation and children's perceived exertion. The target intensity was predominantly moderate, with short bouts of higher-intensity activity embedded in game-based tasks. The program avoided heavy resistance exercise and prolonged monotonous endurance running. Example tasks included movement maze, reaction color gates, balance and target throwing, rhythmic grid jumping, low-bar climbing relay, orientation running after rotation, partner mirror movement, and small-group carrying challenges.

2.6 Control Group Instruction

The comparison group continued the school's routine physical education curriculum, including warm-up activities, formation practice, running, jumping and throwing exercises, ball games or general games, and physical fitness test-related practice. The comparison group did not receive systematic ASM modules, cross-sport transfer tasks, or a progressive movement-repertoire structure. Classes in the comparison group followed the same routine school timetable and were managed by the school's physical education teachers under standard teaching and safety procedures. The scheduled lesson frequency and overall school-based activity exposure were kept comparable to those of the ASM group at the class level, but the content differed in that the comparison group received conventional physical education rather than a structured ASM-based diversified motor skill program. Attendance and safety incidents were recorded according to routine school physical education management procedures.

2.7 Outcome Measure and Testing Procedure

The primary outcome was vital capacity, measured in milliliters using the school physical fitness testing procedure. Testing was conducted with reference to the National Student Physical Fitness Standard. Vital capacity was assessed using an electronic vital capacity tester routinely used for school physical fitness assessment. Before each testing session, the device was checked and zeroed according to the manufacturer's instructions and the school testing protocol to ensure normal operation. Disposable or

individually assigned mouthpieces were used where applicable, and basic hygiene procedures were followed between participants. Each student received standardized verbal instructions and a brief demonstration before testing. Students maintained a stable standing or seated posture according to the school protocol, inhaled deeply, and then exhaled steadily with maximal effort until completion. Each student completed two valid trials, with an adequate rest interval between trials. If coughing, air leakage, premature termination, poor mouthpiece sealing, or obvious insufficient effort occurred, the trial was considered invalid and was repeated according to the testing protocol. The higher value from the valid trials was retained for analysis. The pretest was conducted during the week before the intervention, and the posttest was conducted within the week after completion of the 12-week program to reduce bias related to semester timing.

2.8 Statistical Analysis

Continuous variables were summarized as mean ± standard deviation, and categorical variables as frequencies and percentages. Baseline differences were examined using independent-samples t tests or chi-square tests, as appropriate. Within-group pretest–posttest changes were assessed using paired-samples t tests, and between-group differences in change scores were assessed using independent-samples t tests with Hedges' g as the standardized effect size. A random-intercept linear mixed-effects model was fitted with vital capacity as the dependent variable; fixed effects included time, group, time × group interaction, age, and sex, with participant as a random intercept. The time × group interaction was the primary effect estimate. Subgroup analyses were conducted according to tertiles of baseline vital capacity. Missing data were handled using complete-case analysis based on valid paired pretest and posttest records. Model assumptions were checked using residual diagnostics. Statistical significance was set at two-sided $p < 0.05$. All analyses were performed using IBM SPSS Statistics version 27.0.

Figure 1 summarizes the sample flow, intervention structure, and statistical analysis pathway. Because the study was embedded in a real school curriculum and did not use individual randomization, the flow diagram should report initial eligibility, allocation at the class or instructional-unit level, exclusions, paired complete cases, and reasons for missing data. The figure should also clarify that the ASM program was a structured curriculum intervention integrating movement breadth, coordination challenges, and movement-condition enhancement rather than a collection of isolated exercises.

(Figure 1. **about here)**

3 Results

3.1 Sample Characteristics

After data cleaning and pretest-posttest matching, 607 students were included in the ASM group and 607 in the comparison group. Baseline age, sex distribution, and vital capacity were similar between groups. The ASM group included 309 boys and 298 girls, and the comparison group included 315 boys and 292 girls. Mean age was 9.28 +/- 1.38 years in the ASM group and 9.21 +/- 1.39 years in the

comparison group. Baseline vital capacity was 1978.58 +/- 401.65 mL in the ASM group and 1969.61 +/- 397.01 mL in the comparison group (Table 1).

Table 1
Baseline Characteristics of the ASM and Comparison Groups

Variable	ASM group (n = 607)	Comparison group (n = 607)	p value
Sex, boys/girls	309/298	315/292	0.774
Age, years	9.28 +/- 1.38	9.21 +/- 1.39	0.384
Baseline vital capacity, mL	1978.58 +/- 401.65	1969.61 +/- 397.01	0.696
Baseline level, low/intermediate/high	199/210/198	207/193/207	0.584
Complete paired sample, n (%)	607 (100.0)	607 (100.0)	--

Note. Continuous variables are presented as mean +/- standard deviation, and categorical variables are presented as counts or count/count. Age was estimated using September 1, 2025 as the baseline date. Baseline vital capacity level was classified according to tertiles of the overall baseline distribution: low, <=1760 mL; intermediate, 1761–2087 mL; and high, > 2087 mL.

(Table 1. **about here)**

3.2 Pretest-Posttest Changes in Vital Capacity

Vital capacity increased by 114.86 +/- 254.83 mL in the ASM group and by 45.66 +/- 257.91 mL in the comparison group. The between-group difference in change was 69.20 mL (95% CI, 40.33 to 98.08; $p < 0.001$), indicating a greater increase in the ASM group than in the comparison group. The improvement observed in the comparison group may reflect growth, routine physical education, and test familiarization.

(Table 2. **about here)**

Table 2
Pretest-Posttest Changes in Vital Capacity and Effect Sizes

Group	n	Pretest (mL)	Posttest (mL)	Change (mL)	Paired t	p value	Effect size
ASM group	607	1978.58 +/- 401.65	2093.44 +/- 473.41	114.86 +/- 254.83	11.11	< 0.001	dz = 0.45
Comparison group	607	1969.61 +/- 397.01	2015.27 +/- 480.91	45.66 +/- 257.91	4.36	< 0.001	dz = 0.18
Between-group difference	--	--	--	69.20 (95% CI, 40.33 to 98.08)	4.70	< 0.001	Hedges' g = 0.27

Note. Values are mean +/- standard deviation unless otherwise indicated. dz denotes the paired standardized mean difference. Hedges' g denotes the standardized between-group effect size based on change scores. The between-group difference was calculated as the change in the ASM group minus the change in the comparison group.

The within-group standardized change was dz = 0.45 in the ASM group and dz = 0.18 in the comparison group. The between-group effect size for change scores was small (Hedges' g = 0.27). Therefore, the practical interpretation should emphasize a modest additional benefit at the group level rather than a large individual-level training effect.

Figure 2 presents the distributions of pretest and posttest vital capacity, paired trajectories for a random subset of participants, and 95% confidence intervals for group means. The ASM group showed a larger rightward shift in posttest values than the comparison group, although individual responses were heterogeneous. This pattern supports the need for adjusted model-based analysis and subgroup exploration.

(Fig. 2. **about here)**

3.3 Results of the Linear Mixed-Effects Model

The random-intercept linear mixed-effects model showed a significant overall increase in vital capacity over time. The group-by-time interaction remained significant after adjustment for age and sex (beta = 69.20 mL; 95% CI, 40.38 to 98.02; p < 0.001), indicating that the ASM group had a greater pretest-posttest increase than the comparison group (Table 3).

Table 3
Fixed Effects From the Linear Mixed-Effects Model

Fixed effect	beta	SE	95% CI	Test statistic	p value
Intercept	-507.19	29.47	-564.94 to -449.44	z = -17.21	< 0.001
Time (posttest vs. pretest)	45.66	10.40	25.28 to 66.04	z = 4.39	< 0.001
Group (ASM vs. comparison)	-4.19	11.18	-26.10 to 17.72	z = -0.38	0.708
Time x group	69.20	14.70	40.38 to 98.02	z = 4.71	< 0.001
Sex (boys vs. girls)	392.72	8.42	376.21 to 409.23	z = 46.62	< 0.001
Age, per 1-year increase	246.79	3.05	240.82 to 252.77	z = 80.98	< 0.001

Note. The dependent variable was vital capacity. Fixed effects included time, group, the group-by-time interaction, sex, and age, with individual participants specified as random intercepts.

Age and sex were strongly associated with vital capacity. Boys had higher vital capacity than girls on average (beta = 392.72 mL; 95% CI, 376.21 to 409.23; $p < 0.001$), and each additional year of age was associated with higher vital capacity (beta = 246.79 mL; 95% CI, 240.82 to 252.77; $p < 0.001$). These associations are consistent with growth-related differences in lung volume and highlight the need to account for developmental factors when interpreting school-based vital capacity outcomes.

(Table 3. **about here)**

3.4 Subgroup Analysis by Baseline Level

Positive between-group differences in change were observed across low-, intermediate-, and high-baseline vital capacity subgroups, with net differences of 70.31 mL, 72.43 mL, and 60.21 mL, respectively.

(Table 4. **about here)**

Table 4
Exploratory Subgroup Analysis by Baseline Vital Capacity Level

Baseline vital capacity subgroup	Net between-group difference in change (mL)	95% CI	p value	Interpretation
Low	70.31	34.18 to 106.44	< 0.001	Positive net change
Intermediate	72.43	15.01 to 129.84	0.014	Positive net change
High	60.21	7.09 to 113.32	0.026	Positive net change

Note. Baseline vital capacity level was classified according to tertiles of the overall baseline distribution: low, ≤ 1760 mL; intermediate, 1761–2087 mL; and high, > 2087 mL.

Figure 3 displays the overall net intervention effect and subgroup-specific effects by baseline vital capacity level. The direction of the estimates was consistent across subgroups, suggesting that the ASM program may be applicable to students with different baseline levels.

(Fig. 3. **about here)**

4 Discussion

This study examined a 12-week ASM-based diversified motor skill program embedded in primary school physical education. The main finding was that students in the ASM group showed a greater increase in vital capacity than students in the routine physical education comparison group. The adjusted group-by-time interaction indicated an additional improvement of approximately 69 mL, with a small between-group effect size. These findings suggest that diversified motor skill content may contribute to modest improvements in a field-based respiratory-related fitness indicator when implemented within a school curriculum.

The ASM framework may support higher-quality physical activity participation by expanding children's movement repertoire. Compared with repetitive test-item practice, the present program combined locomotor, balance, object-control, climbing, rotating, rhythmic, reaction, agility, and low-load strength tasks. These activities required students to adapt movement patterns under different spatial, temporal, and postural constraints. Such variation may increase engagement and provide a broader stimulus for motor competence development, which is consistent with the rationale of ASM and FMS-oriented interventions. School-based motor competence interventions have also been reported to be feasible and acceptable in primary-school contexts [11].

The observed improvement in vital capacity should be interpreted cautiously. The intervention did not directly train respiratory muscles or measure clinical pulmonary function. Instead, the association may reflect indirect pathways, including increased movement exposure, greater ventilatory demand during active games, improved trunk control, and better cooperation during the field-based vital capacity test.

Another possible explanation is that the ASM curriculum increased effective movement density and reduced monotony in physical education classes. Game-based challenges and cooperative tasks may help children sustain participation while experiencing short bouts of higher-intensity activity within a predominantly moderate-intensity lesson. A 12-week game-based afterschool physical activity programme has been shown to improve physical fitness in children aged 9–10 years [17]. Integrative neuromuscular training may improve muscular fitness in young children, supporting the inclusion of low-load strength and coordination tasks in school-based programmes [18]. Meta-analytic evidence in young athletes suggests that integrative neuromuscular training can improve selected physical performance outcomes, although that population differs from the present school sample [19]. Integrative neuromuscular training delivered within physical education classes has been reported to improve strength and speed performance [20].

The subgroup findings suggest that students with low, intermediate, and high baseline vital capacity all showed positive net changes in the ASM group relative to the comparison group. However, these analyses should be considered exploratory unless confidence intervals, interaction tests, and adjustment for multiple testing are fully reported. Students with lower baseline values may have had more room for improvement, whereas students with higher baseline values may have benefited from increased movement complexity.

This study has several limitations. First, the non-randomized design limits causal inference, and unmeasured differences in class context, teacher characteristics, extracurricular sport participation, family activity environment, and growth may have influenced the results. Second, the study was not prospectively registered in a public clinical trial registry because it was originally designed and approved as a school-based physical education curriculum intervention rather than as a medical clinical trial. Nevertheless, given that the intervention involved allocation to an exercise-based curriculum and assessment of a health-related fitness outcome, the absence of prospective registration should be considered a reporting limitation. Third, vital capacity was measured as a school fitness-test indicator rather than as a comprehensive pulmonary function assessment. Fourth, height, weight, BMI, maturation status, and respiratory health history were not included, although these factors are relevant to vital capacity. Population-based evidence from Chinese children indicates that physical fitness is associated with multiple individual and contextual determinants [23].

Future research should use class-randomized or school-randomized designs when feasible and should report the study in accordance with appropriate non-randomized or cluster-intervention reporting guidelines. For prospective interventional studies involving exercise-based allocation and health-related outcomes, public trial registration should be completed before participant recruitment where required by the target journal or registry policy. Additional measurements of height, weight, BMI, maturity, habitual physical activity, motor competence, coordination ability, and exercise intensity would help clarify mechanisms.

5 Conclusion

A 12-week Athletic Skills Model-based diversified motor skill program embedded in primary school physical education was associated with a greater improvement in school-based vital capacity than routine physical education. The net effect was statistically significant but small, indicating that the program may provide modest group-level benefits rather than large individual-level changes. These findings support the feasibility of integrating diversified motor skill content into school physical education, while stronger randomized or cluster-randomized studies with growth, maturation, motor competence, and activity-dose measures are needed before firm causal conclusions can be drawn.

Declarations

Ethics approval and consent to participate

The study was conducted in accordance with the Declaration of Helsinki and was approved by the Technology Ethics Committee of Yibin University (approval No. YBULLKY26042101). Written informed consent from parents or legal guardians and assent from participating children were obtained.

Consent for publication

Not applicable. This manuscript does not include identifiable individual-level images, videos, or personal data.

Competing interests

The authors declare that they have no competing interests.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Author Contribution

YB, JHZ, and LZ: Conceptualization, Methodology, Software, Writing-Original draft preparation, Writing-Reviewing and Editing, Critical Review, and data collection.MLZ: Data analysis. YB, JHZ, and LZ: Writing-Original draft preparation, Writing-Reviewing and Editing. JHZ, and LX: Software and Visualization. All authors read and approved the final manuscript.

Acknowledgements

Not applicable.

Data Availability

he datasets analysed during the current study are not publicly available because they contain school-based assessment data from children and are subject to institutional governance, ethical approval, and privacy-protection requirements. De-identified data and intervention materials may be made available from the corresponding author upon reasonable request and with permission from the relevant institution and ethics committee.

References

1. Savelsbergh, G. J. & Wormhoudt, R. The athletic skills model: Enhancing physical literacy across the lifespan. InNonlinear Pedagogy and the Athletic Skills Model 2021 Jun 27 (pp. 102–110). Routledge. 10.4324/9781003025375-7
2. Rudd, J. et al. *Nonlinear Pedagogy and the Athletic Skills Model: The Importance of Play in Supporting Physical Literacy* (Routledge, 2021).
3. Yang, X., Leung, A. W., Jago, R., Yu, S. C. & Zhao, W. H. Physical Activity and Sedentary Behaviors among Chinese Children: Recent Trends and Correlates. *Biomed. Environ. Sci.* **34** (6), 425–438. 10.3967/bes2021.059 (2021).
4. Neil-Sztramko, S. E., Caldwell, H. & Dobbins, M. School-based physical activity programmes for promoting physical activity and fitness in children and adolescents aged 6 to 18. *Cochrane Database Syst. Reviews*. **9** (9), CD007651. 10.1002/14651858.CD007651.pub3 (2021).
5. Gan, X., Yu, K., Wen, X. & Lu, Y. Longitudinal Association of Economic Growth with lung function of Chinese children and adolescents over 30 years: evidence from seven successive national surveys. *Int. J. Environ. Res. Public Health*. **18** (12), 6592. 10.3390/ijerph18126592 (2021).
6. Lin, J., Zhang, R., Shen, J. & Zhou, A. Effects of school-based neuromuscular training on fundamental movement skills and physical fitness in children: a systematic review. *PeerJ* **10**, e13726. 10.7717/peerj.13726 (2022).
7. Guo, Q. et al. Identifying the threshold of outdoor PM2. 5 reversing the beneficial association between physical activity and lung function: A national longitudinal study in China. *Sci. Total Environ.* **839**, 156138. 10.1016/j.scitotenv.2022.156138 (2022).
8. O'Hagan, A. D. et al. Do our movement skills impact our cognitive skills? Exploring the relationship between cognitive function and fundamental movement skills in primary school children. *J. Sci. Med. Sport*. **25** (11), 871–877. 10.1016/j.jsams.2022.08.001 (2022).
9. Mainous, A. G. 3 et al. The Daily Mile: The Impact of an Elementary School-Based Exercise Program on Pulmonary Function. *Fam. Med.* **55** (10), 677–679. 10.22454/FamMed.2023.976789 (2023).
10. Jing, Z. et al. Effects of physical activity on lung function and quality of life in asthmatic children: An updated systematic review and meta-analysis. *Front. Pead.* **11**, 1074429. 10.3389/fped.2023.1074429 (2023).

11. Fairclough, S. J. et al. Move Well, Feel Good: Feasibility and acceptability of a school-based motor competence intervention to promote positive mental health. *PLoS One*. **19** (6), e0303033. 10.1371/journal.pone.0303033 (2024).
12. Costa, J. A. et al. A school-based physical activity intervention in primary school: effects on physical activity, sleep, aerobic fitness, and motor competence. *Front. Public. Health*. **12**, 1365782. 10.3389/fpubh.2024.1365782 (2024).
13. Zhang, D. et al. Effect of functional training on fundamental motor skills among children: A systematic review. *Heliyon* **10** (23), e39531. 10.1016/j.heliyon.2024.e39531 (2024).
14. Yang, Y., Mao, X., Li, W., Wang, B. & Fan, L. A meta-analysis of the effect of physical activity programs on fundamental movement skills in 3–7-year-old children. *Front. Public. Health*. **12**, 1489141. 10.3389/fpubh.2024.1489141 (2025).
15. Jiang, S. et al. Effects of physical activity interventions on fundamental movement skills and cognitive function in early childhood: A systematic review and network meta-analysis. *J. Sport Health Sci.* **15**, 101085. 10.1016/j.jshs.2025.101085 (2025).
16. Liu, B., Yan, Y., Jia, J. & Liu, Y. Can active play replace skill-oriented physical education in enhancing fundamental movement skills among preschool children? A systematic review and meta-analysis. *BMC Public. Health*. **25**, 1399. 10.1186/s12889-025-22398-9 (2025).
17. Onarici Gungor, E., Yaliz Solmaz, D., Guven, G. & Gurol, B. A 12-week afterschool game-based physical activity program improves physical fitness of 9–10-year-old children: a randomized controlled study. *Sci. Rep.* **15**, 44013. 10.1038/s41598-025-31429-9 (2025).
18. Wang, Z., Zang, J., Wang, Z., Fong, D. T. P. & Wang, D. Effects of 12-week integrative neuromuscular training on muscular fitness and sex differences in response to intervention in five- to six-year-old preschoolers. *PeerJ* **13**, e19417. 10.7717/peerj.19417 (2025).
19. Wan, K., Dai, Z., Wong, P., Ho, R. & Tam, B. T. Comparing the Effects of Integrative Neuromuscular Training and Traditional Physical Fitness Training on Physical Performance Outcomes in Young Athletes: A Systematic Review and Meta-Analysis. *Sports Med. - Open.* **11**, 15. 10.1186/s40798-025-00811-2 (2025).
20. Alonso-Aubin, D. A., Moya del Saz, I., Martínez-Guardado, I. & Chulvi-Medrano, I. An Integrative Neuromuscular Training Program in Physical Education Classes Improves Strength and Speed Performance. *Healthcare* **13** (12), 1372. 10.3390/healthcare13121372 (2025).
21. Wei, L., Li, Z. & Sun, Y. Types and Frequencies of Physical Activity Associated with Physical Fitness in Chinese Children and Adolescents: A National Cross-Sectional Study. InHealthcare 2025 Sep 24 (Vol. 13, 19, p. 2400). *MDPI* 10.3390/healthcare13192400
22. Zhang, L. et al. Comparison of physical activity, sedentary time, and physical fitness among Chinese children and adolescents in Qinghai between 2019 and 2023. *Sci. Rep.* **15**, 15995. 10.1038/s41598-025-99046-0 (2025).
23. Wang, W. et al. Physical fitness status and associated determinants among Chinese children aged 9–12 years in Shandong province: a population-based cross-sectional study. *Sci. Rep.* **15** (1), 29221.

10.1038/s41598-025-13319-2 (2025).

24. Li, C. & Gu, J. Trends and Distributional Characteristics of Forced Vital Capacity and Forced Vital Capacity Adjusted for Weight Among Chinese Children and Adolescents Over the Three Decades. *Iran. J. Public. Health*. **55** (1), 133–142. 10.18502/ijph.v55i1.20979 (2026).

Figures

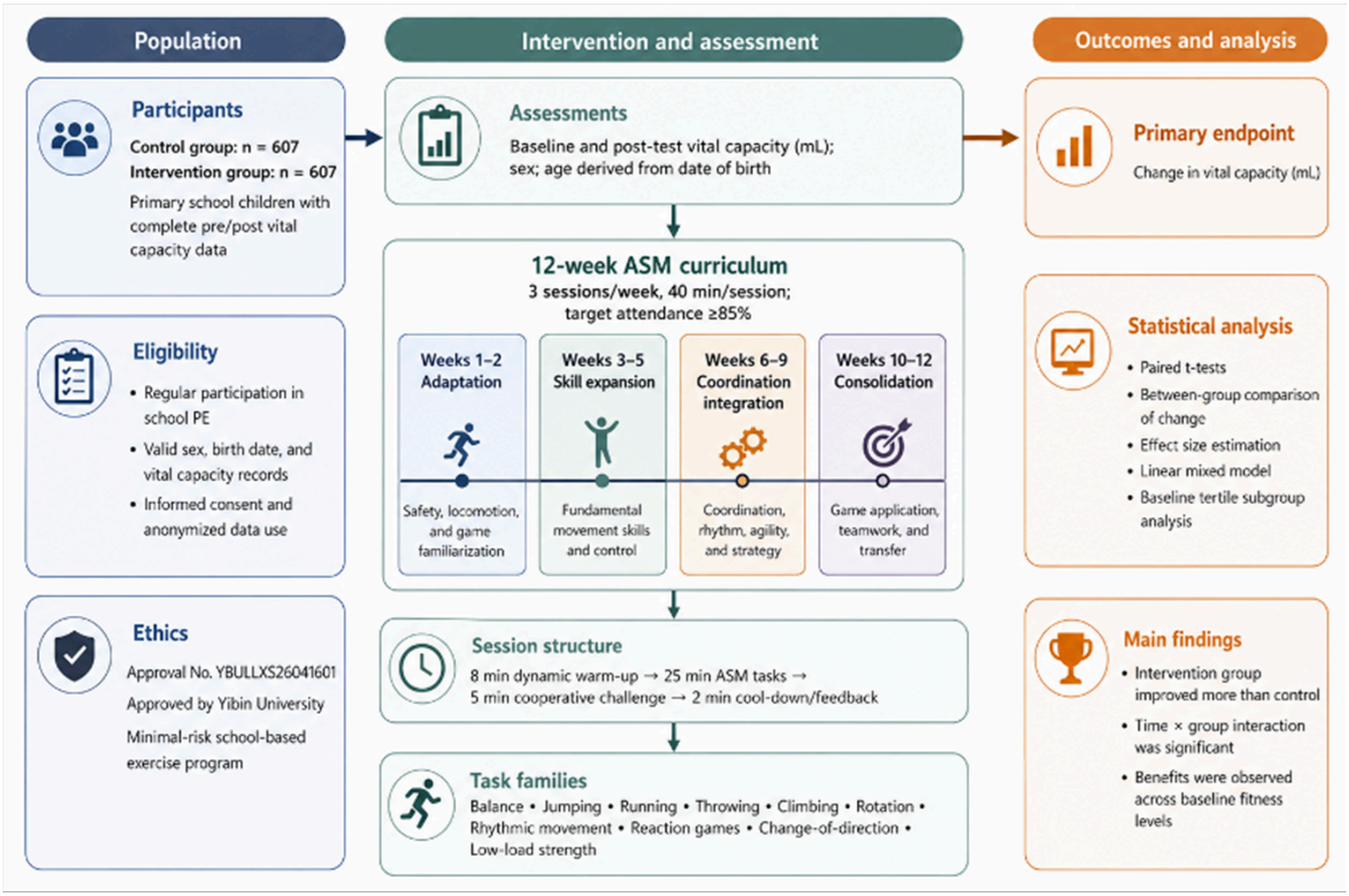


Figure 1

Sample flow, ASM intervention structure, and statistical analysis pathway.

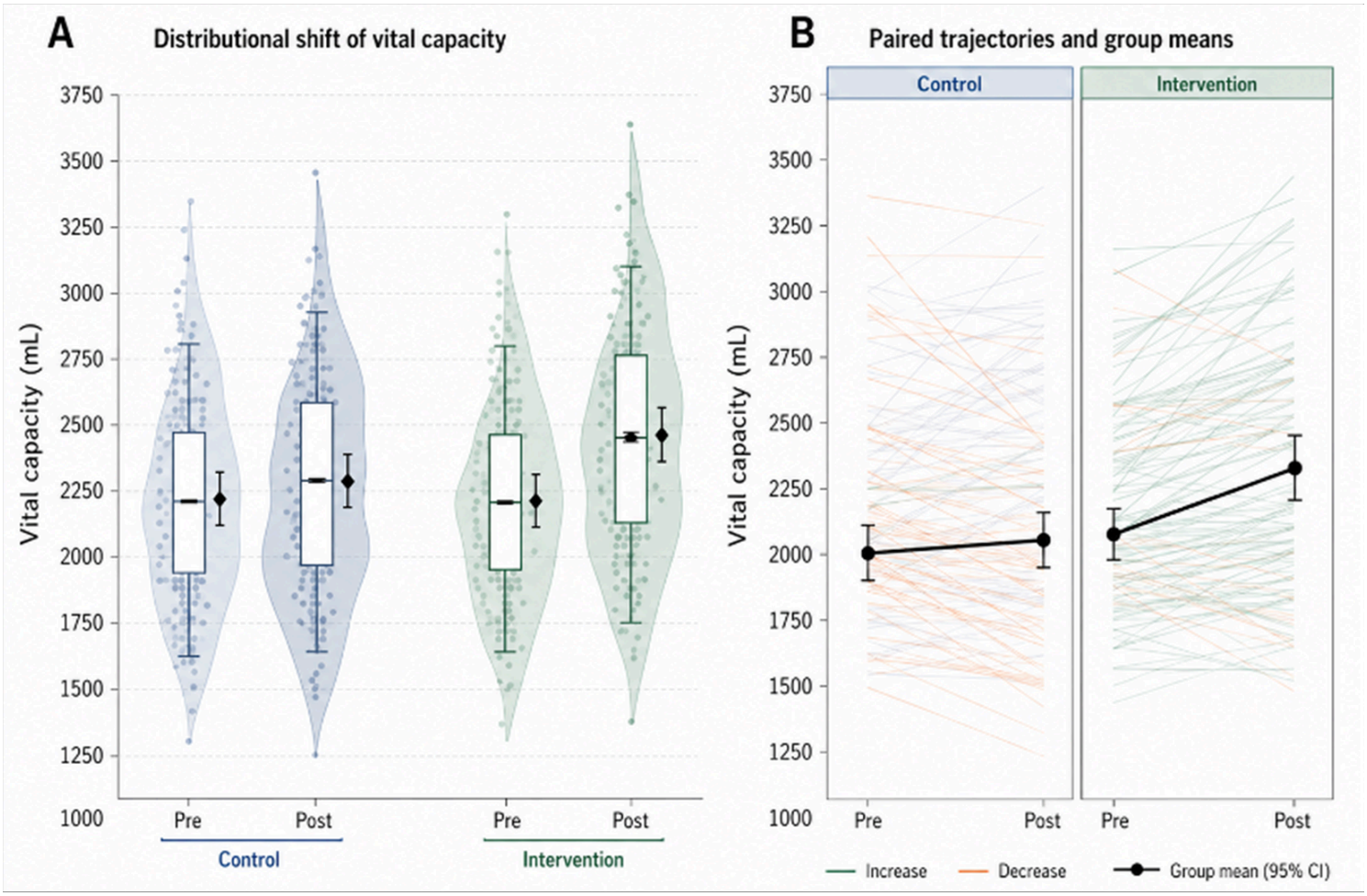


Figure 2

Individual paired changes, distributional patterns, and 95% confidence intervals for mean vital capacity in the ASM and comparison groups.

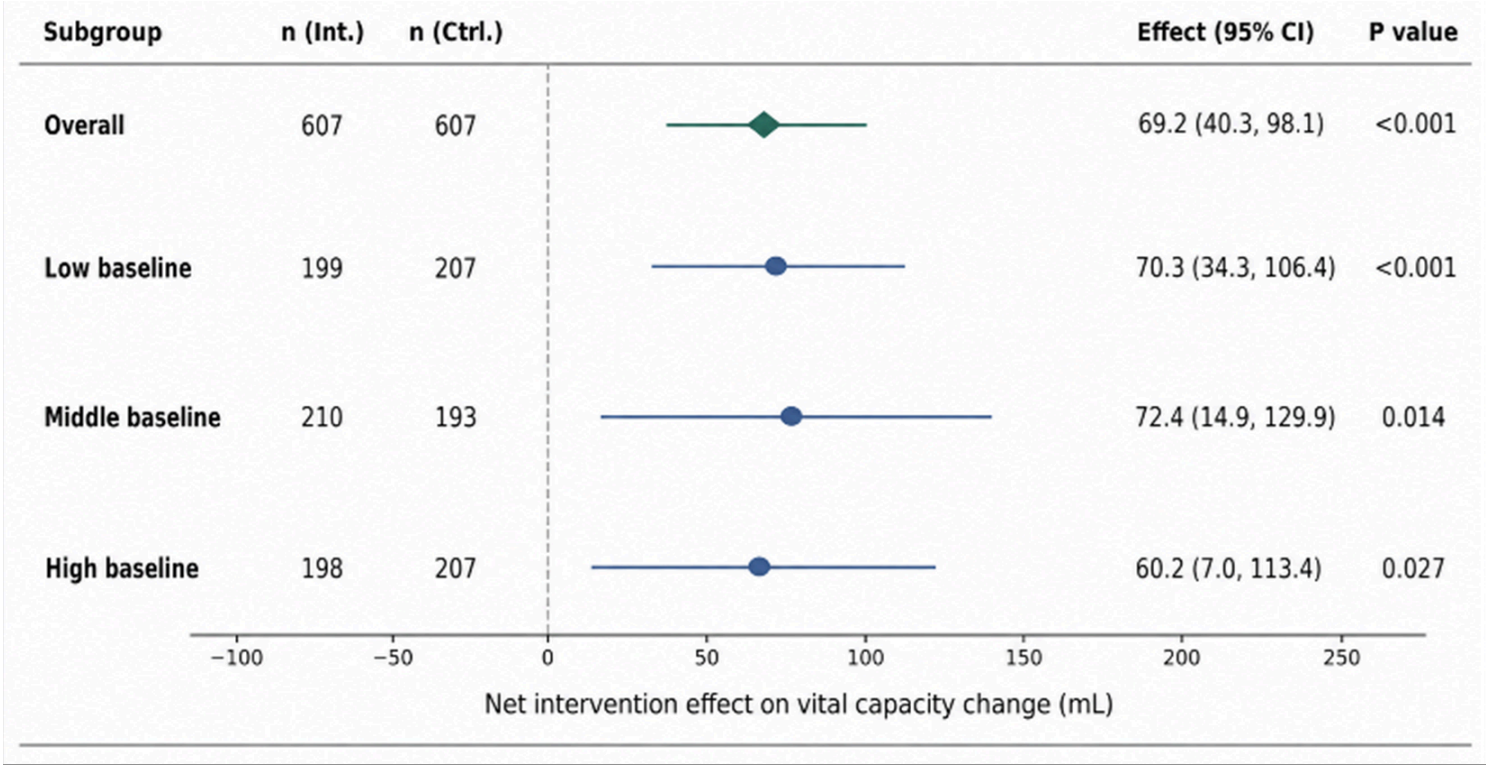


Figure 3

Forest plot of the overall net intervention effect and exploratory subgroup effects by baseline vital capacitylevel.