RESEARCH ARTICLE

Multidimensional analysis of the impact of physical education on adolescents' body mass index and related mechanisms in sports biomechanics

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Received: July 31, 2025; **accepted:** December 4, 2025.

Amid the current nationwide fitness trend, adolescent health dynamics have become a focal point of societal concern. Issues such as inadequate physical performance during school sports events and rising rates of obesity and myopia in health examination reports highlight growing health alarms among adolescents. Previous discussions on adolescent health have predominantly focused on superficial lifestyle aspects such as advocating reduced screen time and promoting healthy diets. However, physical education as an integral component of youth development possesses significant yet underexplored potential in comprehensively influencing adolescents' physical functions, particularly in regulating body mass index (BMI) and biomechanical mechanisms of movement. Meanwhile, despite numerous breakthroughs in the field of sports biomechanics, few studies have effectively integrated these cutting-edge findings into practical adolescent physical education. This study focused on the impact of physical education on adolescents' BMI and related sports biomechanics mechanisms, aiming to provide data support for optimizing adolescent physical education and promoting the comprehensive improvement of their physical functions. Forty track and field athletic major students (20 male and 20 female), aged 16 to 20, were selected and randomly divided into an experimental group and a control group using a random number table with 20 students in each group. The experimental group followed a training program integrated with physical education knowledge, covering multiple modules such as speed and agility, lower limb strength, and balance and stability with each session providing in-depth explanations of sports biomechanics principles, while the control group implemented a conventional training program, consisting only of basic warm-ups and auxiliary exercises with minimal knowledge instructions. The results showed that, in terms of physical indicators, the two groups had similar baseline levels before training. After training, the experimental group showed greater increases in height, weight, and BMI than that of control group. Regarding pulmonary function indicators, the experimental group's vital capacity and vital capacity-to-weight ratio were significantly higher than those of the control group after training (*P* < 0.05). Grip strength decreased in both groups after training, but the difference was not statistically significant. In terms of sports biomechanics indicators, significant differences in joint angles were observed between the groups at initial foot-ground contact and at the moment of maximum impact, whereas ground reaction force values were generally similar between groups with the experimental group showing potential for optimization. This study confirmed the importance of scientific and systematic physical education for adolescent development and provided data support for optimizing physical education.

Keywords: physical education; sports biomechanics; BMI; vital capacity indicators.

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Introduction

Amid the ongoing implementation of the national fitness strategy, the physical health of adolescents faces significant challenges [1]. Frequent issues such as declining physical performance in school sports activities and persistently rising rates of obesity and myopia in health screenings highlight the practical difficulties in adolescents' physical development, thereby increasing attention on the interventional value of physical education in improving adolescent health [2, 3].

In recent years, numerous studies have explored physical education and adolescent health [4-7]. Some systematic reviews indicated that regular physical training could significantly enhance cardiorespiratory function and body composition in adolescents [8]. Diao *et al*., through a randomized controlled trial (RCT), demonstrated that targeted sports interventions could improve muscle strength and motor coordination in adolescents [9], while Cai *et al*. found that integrating biomechanical knowledge into physical education helped adolescents optimize movement postures and reduce injury risks [10]. However, existing research still has notable limitations, which include that most studies focus on isolated physical indicators such as body mass index (BMI) and vital capacity, lacking in-depth analysis of associations with sports biomechanical mechanisms such as joint angles and ground reaction forces. Moreover, few studies incorporate the specific athletic backgrounds of adolescent sports majors, resulting in limited relevance and applicability of findings to practical physical education, and insufficient guidance for optimizing physical education programs [11-13].

This study focused on the interventional effect of physical education on adolescents' BMI and related sports biomechanics mechanisms by selecting 40 track and field major students with 20 males and 20 females, aged 16-20 years old as research subjects. The participants were equally divided into an experimental group and a control group by using a randomized controlled trial design with the experimental group undergoing a multi-module training program integrated with sports biomechanics knowledge including speed-agility and lower limb strength training coupled with theoretical explanation of principles, while the control group receiving conventional training. By comparatively analyzing indicators of height, weight, BMI, vital capacity, joint angles at foot-ground contact, and ground reaction forces between the two groups, this study aimed to investigate the interventional effects of scientific physical education. This research addressed a gap in research integrating physical education with sports biomechanical mechanisms, provided empirical evidence for analyzing the intrinsic logic of how physical education influenced adolescent physical functions. Further, the findings of this research could directly inform the optimization of curriculum design and development of targeted training programs in sports institutions, thereby enhancing the scientific validity and effectiveness of adolescent physical education, which held significant importance for advancing both research and practice in the field of adolescent physical health.

Materials and methods

Research subjects

A total of 40 students with 20 males and 20 females, aged 16-20 years old, majoring in physical education from the School of Physical Education, Luoyang Normal University (Luoyang, Henan, China) were recruited in this research. All participants were track and field athletes specializing in sprinting, jumping, and throwing events. The inclusion criteria included that the participant was in good health with no history of major chronic diseases such as cardiovascular disease, diabetes, or severe musculoskeletal disorders and no major sports injuries in the past year and no less than 10 hours per week for sports training. All procedures of this study were approved by the Ethics Review Committee of Luoyang Normal University (Luoyang, Henan, China) (Approval number: Lynu-IRB-2024-035).

Physical training programs

The participants were randomly divided into experimental and control groups with 20 people in each group. Both groups underwent a 12-week training program, consisting of three 90-minute sessions per week scheduled consistently on Monday, Wednesday, and Friday afternoons, following the identical training field arrangements, warm-up protocols (5 minutes of joint mobility exercises and 5 minutes of jogging), and cool-down routines (5 minutes of static stretching). The training contents were divided into three modules including speed and agility training, lower limb strength training, and balance and stability training with each module lasting 25 minutes per session. Speed and agility training included 30-meter sprints and shuttle runs with directional changes. The core training contents, however, differed between the two groups with the experimental group following a comprehensive training program integrated with sports biomechanics knowledge. Prior to training, animations were used to explain the biomechanical principles of running posture and center of gravity transfer, instructing students to adjust stride frequency and foot strike angle to reduce energy loss. Lower limb strength training primarily involved squats and lunges combined with resistance band exercises. The knowledge education focused on explaining the muscle activation sequence and joint force distribution during knee flexion and extension to prevent sports injuries. Balance and stability training employed single leg stands and balance pad support exercises, concurrently analyzing joint angle changes during body sway to help students master balance control techniques. During each session, coaches provided real-time corrections based on student movements to ensure compliance with biomechanical standards. The control group followed a conventional training program without any sports biomechanics instructions. The core training focused on basic physical exercises, consisting of 20 minutes of endurance running of 1,000-meter jog, 25 minutes of basic strength training including push-ups and sit-ups, and 20 minutes of ball activities of basketball dribbling and volleyball bumping. During training, only movement demonstrations were provided with no theoretical explanations or individualized movement adjustments. The primary objective was completion of the training volume.

BMI measurement

Height and weight were measured using a calibrated electronic stadiometer and scale with the accuracy of 0.1 cm and 0.1 kg, respectively. BMI was calculated using the formula below.

$$BMI = Weight\ (kg) / (height\ (m))^2$$

All measurements were repeated three times and averaged.

Vital capacity-weight index measurement

Vital capacity was measured using a Contec SP10W electronic spirometer with accuracy of 1 mL (Contec Medical System, Qinhuangdao, Hebei, China) following manufacturer's instruction. Each subject performed three tests with the highest value recorded as the final vital capacity. Subsequently, the vital capacity-body weight index was calculated by diving body weight (kg) from vital capacity (mL) with results rounded to one decimal place.

Grip strength-weight index measurement

Grip strength was measured using a Tekscan T400 electronic dynamometer (Tekscan, New York, NY, USA) with the accuracy of 0.1 kg. Subjects stood naturally with feet shoulder-width apart and the elbow flexed at 90° and the forearm horizontal. The maximum force was exerted for 2 - 3 seconds. Three trials were performed for each hand with 30 seconds intervals. The highest value from either hand was recorded as the result.

Kinematic and kinetic indicators

A Mocap Pro V10 three-dimensional motion capture system (Beijing Duoliang Technology Co., Ltd., Beijing, China) with sampling frequency of 100 Hz and a Kistler 9286AA force platform (Kistler Group, Stuttgart, Baden-Württemberg, Germany) with sampling frequency of 1,000 Hz were synchronized for data acquisition. The system's built-in MotionAnalysis 3D algorithm was used to reconstruct human motion models. Subjects wore tight-fitting suits with reflective markers attached to key joints on head, shoulders, hips, knees, and ankles. During the standing long jump, the system captured the positional changes of the markers in real time, automatically reconstructed the human motion model, and simultaneously recorded knee and ankle joint angles at the moments of initial foot-ground contact (first contact with the force platform) and maximum impact (peak vertical ground reaction force), as well as the corresponding ground reaction force values. Each subject performed three valid jump trials with correct execution and no marker loss. The average of the three trials was used for subsequent analysis.

Statistical analysis

The data was processed using SPSS 25.0 software (IBM, Armonk, NY, USA). Descriptive statistical analysis was performed on the basic demographic information of both groups with continuous variables presented as mean ± standard deviation and categorical variables as frequencies and percentages. When comparing the BMI and other indicator data between the groups before and after intervention, the Shapiro-Wilk test was first used to assess normality. For normally distributed data, independent samples t-tests and paired samples t-tests were used to analyze baseline differences before intervention and group differences after intervention, respectively. For non-normally distributed data, the Mann-Whitney U test and Wilcoxon signed-rank test were applied. Repeated measurement data were analyzed using repeated measures ANOVA. Pearson or Spearman correlation analysis was also used to explore the correlations between indicators. *P* value less than 0.05 was considered statistically significant.

Results and discussion

BMI changes before and after training

Before training, the average height, weight, and BMI of experimental group were 173.2 ± 4.1 cm, 62.5 ± 5.3 kg, and 21.3 ± 1.2 kg/m², respectively, while the control group demonstrated the average height, weight, and BMI as 172.8 ± 3.9 cm, 62.8 ± 5.1 kg, and 21.5 ± 1.1 kg/m², respectively. There were no statistically significant differences in these initial values between the two groups, indicating consistent baseline levels. After 12 weeks of training, the experimental group showed the mean values of height, weight, and BMI as 173.7 ± 4.0 cm, 64.0 ± 5.2 kg, and 21.8 ± 1.1 kg/m², while the control group showed the mean values of height, weight, and BMI as 173.1 ± 3.8 cm, 63.6 ± 5.0 kg, and 21.6 ± 1.0 kg/m², respectively. The results indicated that the changes in height, weight, and BMI before and after training were not statistically significant in either group, suggesting that the 12-week training program did not produce statistically reliable changes in the subjects' basic physical indicators. From the data trends, the absolute increases in height and weight in the experimental group were slightly greater than those in the control group, which might be related to improved participant engagement and optimized energy intake-expenditure balance resulting from the integration of biomechanical guidance in the training. However, due to the lack of statistical significance, it cannot be inferred that this difference stems from a systematic advantage of the training protocol itself.

Changes and analysis of vital capacity and vital capacity BMI before and after training

The mean value of vital capacity indicator in the experimental group was 2,588.52 ± 390.55 mL before the training and soared to 3,114.69 ± 467.21 mL after training with a significant increase of 526.17 mL ($P < 0.05$). The control group showed a pre-training value of 2,636.15 ± 280.84 mL and increased to 2,925.35 ± 291.78 mL after training with a 289.2 mL increase ($P < 0.05$). In terms of the vital capacity-weight index, the experimental group jumped from 38.07 ± 4.25 to 44.82 ± 6.08 with an increase of 6.75 ($P < 0.05$), while the control group changed from 39.23 ±

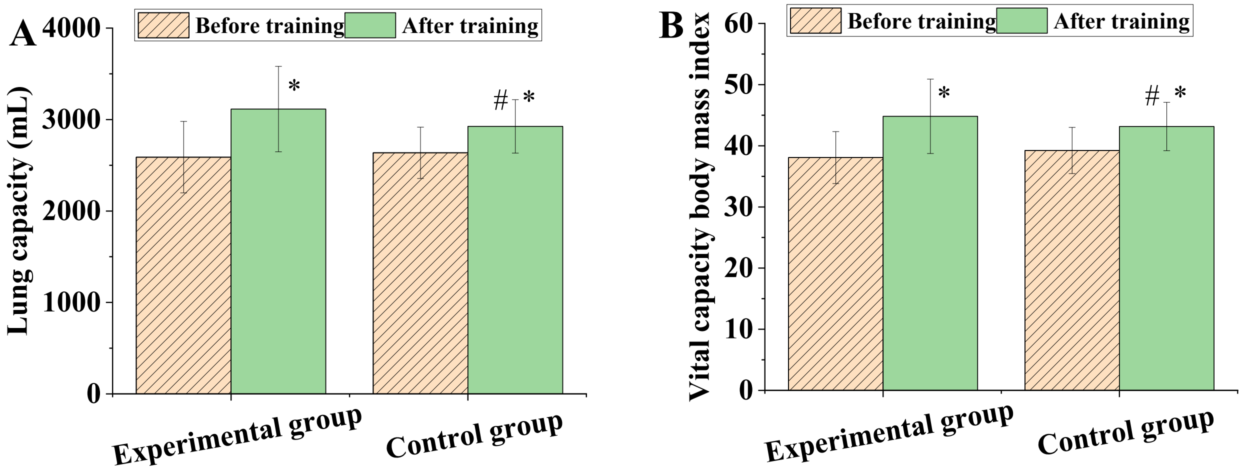

Figure 1. Changes in vital capacity indicators of the experimental and control groups before and after training. **A.** Vital capacity. **B.** Vital capacity-weight index. *: a significant difference (P < 0.05) compared to before training. #: a significant difference (P < 0.05) compared to the experimental group.

3.78 to 43.15 ± 3.95 with an increase of 3.92 (P < 0.05). A significant difference was also observed between the experimental and control groups after training (P < 0.05) (Figure 1). Traditional physical education courses in control group often neglected specific breathing technique guidance, making it difficult for students' spontaneous breathing to meet the demands of high-intensity training. However, the experimental group was different. In various training modules such as before the speed and agility and plyometric exercise modules, key points of breathing rhythm coordination were integrated into the knowledge explanation, enabling students to master scientific breathing methods during training, fully mobilizing the respiratory muscles, and achieving a significant increase in vital capacity. The control group, lacking such detailed guidance, lagged significantly compared to experimental group [14, 15].

Grip strength changes of two groups before and after training

The mean grip strength of the experimental group decreased from 24.83 ± 2.12 kg before training to 24.59 ± 1.64 kg after training with a reduction of 0.24 kg, while the grip strength-weight index also decreased from 36.51 ± 3.86 to 35.38 ± 3.14 with a decline of 1.13. In the control group, grip strength decreased from 25.06 ± 1.28 kg before training to 24.88 ± 3.35 kg after training with a drop of 0.18 kg. The grip strength-weight index changed from 37.29 ± 4.05 to 36.70 ± 2.92 with a decrease of 0.59. Overall, both groups experienced a decline in mean grip strength and grip strength-weight index after training with a slightly larger decrease in the experimental group, although the difference was not significant (P > 0.05). Conventionally, grip strength improvement relies on direct hand strength training such as frequent use of hand grippers. However, in this research, the experimental group focused on enhancing comprehensive physical movement capabilities with a reduced proportion of specialized hand training in the short term, leading to a redistribution of body strength and resulting in grip strength fluctuations [16, 17]. Similarly, the control group failed to maintain stable grip strength due to the lack of targeted training and insufficient overall intensity, reflecting the need for a balanced and coordinated approach to strength training in physical education that integrates both whole-body and localized efforts [18].

Biomechanical indexes of two groups before and after training

(1) Joint motion index at the time of foot contact with the ground

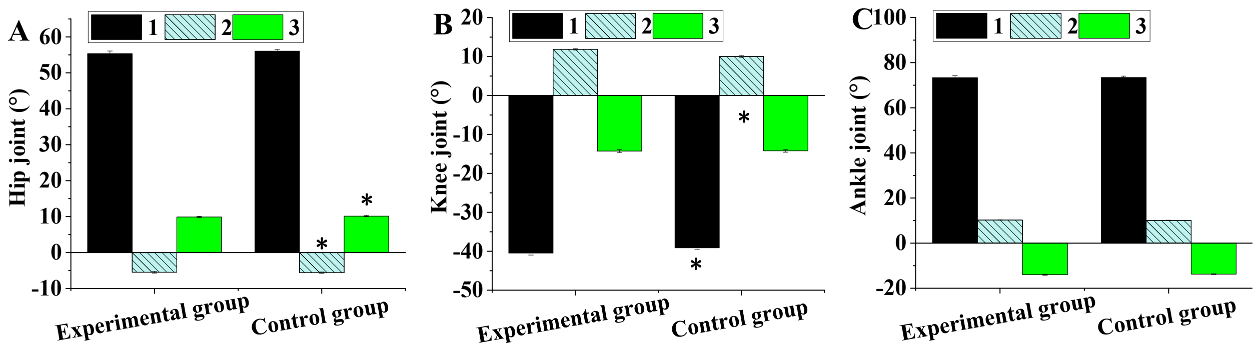

Figure 2. Joint motion indexes of experimental group and control group at the time of foot contact with the ground. Numbers 1 to 3 represented flexion/extension, adduction/abduction, internal/external rotation, respectively. A to C represented hip, knee, and ankle joints, respectively. *: $P < 0.05$ compared to the experimental group.

The results showed that, at the moment of foot-ground contact, the experimental group exhibited significantly smaller hip adduction/abduction angles and significantly larger internal/external rotation angles compared to that in the control group ($P < 0.05$). In conventional sports training, coaches rarely delve into the biomechanical principles of optimizing hip joint angles during the starting phase. Students often rely on intuition to exert force. In contrast, through systematic physical education such as in the explanation of starting techniques, the experimental group analyzed the biomechanics of hip joint angles at the moment of starting, which enabled students to precisely adjust their postures, making hip movements more in line with mechanical principles and improving efficiency in the initial phase of movement, forming a stark contrast with the control group. Additionally, the experimental group showed significantly smaller knee flexion/extension angles and significantly larger knee adduction/abduction angles compared to the control group ($P < 0.05$) (Figure 2). Routine training seldom focuses on the importance of fine adjustments in knee joint angles during different movement tasks. Based on specific training needs, the experimental group was taught to adjust knee angles according to speed and rhythm during midway running, thus distributing forces more reasonably [19]. The control group, lacking such detailed guidance, exhibited a relatively less efficient knee movement pattern. No significant differences were observed in the angles of ankle flexion/extension, adduction/abduction, and internal/external rotation in the experimental group compared to the control group, which suggested that, in the early stages of basic sports training, ankle movement patterns were more influenced by conventional training and had commonalities without significant differentiation due to the specialized education of the experimental group. Further advanced training is needed to explore and enhance potential improvements [20].

(2) Joint motion index at the maximum collision time of foot contact with the ground

At the moment of maximum impact, the experimental group showed no significant differences in hip joint flexion/extension, adduction/abduction, and internal/external rotation angles compared to the control group, which suggested that, at this critical movement node, the hip joint motion in both groups was influenced by prior training, exhibiting similar basic mechanical performance. Conventional training had already ensured a certain foundation, but the experimental group could further optimize details through deeper knowledge understanding. The experimental group had significantly smaller knee flexion/extension angles and significantly larger adduction/abduction angles at the moment of maximum impact compared to the control group

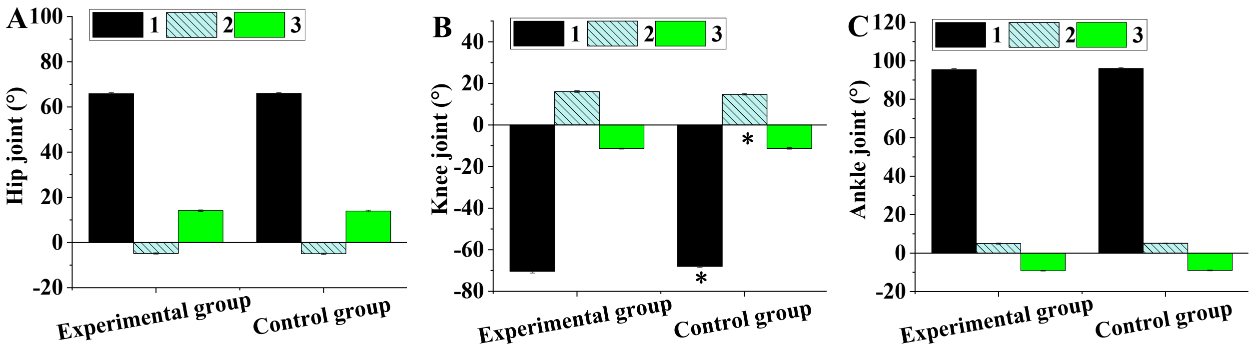

Figure 3. Joint motion indexes of the experimental group and control group at the maximum collision time. Numbers 1 to 3 represented flexion/extension, adduction/abduction, internal/external rotation, respectively. A to C represented hip, knee, and ankle joints, respectively. *: $P < 0.05$ compared to the experimental group.

($P < 0.05$), which reflected that the experimental group was benefited from specialized physical education such as emphasizing body posture and force application during sprint training to optimize knee joint force and movement posture at the moment of maximum impact and make the knee joint movement more adapted to high-intensity impacts and improve sports performance [21], while the control group needed urgent improvement in this regard. No significant differences were observed in the ankle joint flexion/extension, adduction/abduction, and internal/external rotation angles at the moment of maximum impact between the two groups (Figure 3), which once again indicated that the movement pattern of the ankle joint had strong commonality under the existing training system. Future research can explore how to break the routine and achieve differentiated improvements through physical education [22].

(3) Ground reaction force at the moment when the foot touched the ground or at the moment of maximum collision

At the initial foot-ground contact, on the horizontal direction, the mean ground reaction force was 0.27 ± 0.03 in the experimental group and 0.28 ± 0.02 in the control group with a mean difference of only 0.01, showing no statistically significant intergroup difference. On the vertical direction, the mean values were 0.56 ± 0.01 in the experimental group and 0.59 ± 0.03 in the control group with a mean difference of 0.03, showing no statistically significant intergroup difference too. At the moment of maximum impact, on the horizontal direction, the mean ground reaction force was 0.19 ± 0.02 in the experimental group and 0.21 ± 0.04 in the control group with a mean difference of 0.02, showing no statistically significant intergroup difference. On the vertical direction, the mean values were 2.53 ± 0.03 in the experimental group and 2.61 ± 0.06 in the control group with a mean difference of 0.08, showing no statistically significant intergroup difference either. The results indicated that, in terms of basic perception and response to sports biomechanics, conventional physical education training had already endowed students with basic capabilities to maintain a relatively stable state when subjected to forces in both vertical and horizontal directions. However, with in-depth physical education, the experimental group that had profoundly understood the principles of force application demonstrated the potential to more flexibly and skillfully utilize ground reaction forces in subsequent training, accurately converting them into propulsive forces or key supportive forces for maintaining balance, thereby laying a solid foundation for advanced sports performance [23, 24].

Conclusion

Based on the 12-week training intervention and indicator analysis results of this study, the scientifically systematic physical education integrated with sports biomechanics knowledge demonstrated differentiated advantages in its interventional value for adolescent physical fitness and athletic ability compared with conventional physical training. It effectively enhanced cardiopulmonary function and helped adolescents develop movement patterns more aligned with biomechanical principles, thereby optimizing movement efficiency and safety. However, its short-term impact on basic physical indicators of height, weight, and BMI in healthy adolescents of physical education majors was limited and required balancing the synergy between whole-body training and localized strength training to avoid fluctuations in specific muscle strength indicators. Meanwhile, fundamental sports training had already exerted a certain degree of common influence on adolescent ankle joint movement patterns, while the optimization of indicators such as ground reaction forces required longer intervention periods or advanced training designs. The findings of this study provided empirical reference for sports institutions to optimize curriculum systems and develop targeted adolescent sports training programs. Future research could further explore the underlying mechanisms of physical education in developing adolescent athletic potential by expanding sample size and extending the training intervention period.

Acknowledgements

This work was supported by Henan Science and Technology Research Project (Grant No. 252102321135 and 222102320342).

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