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Article

Exploring the potential impact of biomechanical factors in physical activities on achievement emotions and academic performance of higher vocational students in Jiangsu Province

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Abstract: This study explores the potential impact mechanism of biomechanical factors in physical activities on the achievement emotions and academic performance of higher vocational students in Jiangsu Province. The research employed a multi-stage stratified random sampling method, selecting 842 higher vocational students from 13 prefecture-level cities in Jiangsu Province as research subjects. Advanced equipment, including three-dimensional motion capture systems, surface electromyography, and three-dimensional force platforms, was used to measure biomechanical parameters during physical activities, while the revised Achievement Emotions Questionnaire (AEQ) was applied to assess students' achievement emotional experiences, alongside collected data on learning efficacy and academic performance. The research results indicate: (1) Significant biomechanical characteristic differences exist in physical activities among higher vocational students in Jiangsu Province, with professional background, physical activity type, and participation frequency influencing their biomechanical efficiency performance; (2) biomechanical efficiency shows a significant positive correlation with positive achievement emotions ($r = 0.628$, $p < 0.001$) and a significant negative correlation with negative achievement emotions ($r = -0.608$, $p < 0.001$), with 8-week biomechanical optimization intervention significantly increasing positive emotions by 36.2% and reducing negative emotions by 28.7%; (3) achievement emotions play a partial mediating role between biomechanical efficiency and academic performance, with the mediating effect accounting for 43.3% of the total effect; biomechanical efficiency still demonstrates a significant direct effect on academic performance ($\beta = 0.263$, $p < 0.001$); (4) professional background, physical activity type, and individual differences significantly moderate the impact pathway of biomechanical factors, with arts students showing the strongest emotional mediating effect (0.236), sports students demonstrating the strongest direct effect (0.325), and technical activities exhibiting more significant emotional regulation effects. These findings reveal the dual mechanism pattern of biomechanical factors influencing academic performance through emotional regulation and cognitive promotion, providing new perspectives and a scientific basis for higher vocational physical education reform. Future research should incorporate neuroscience methods to further explore the neurophysiological mechanisms, conduct longer-term tracking studies, and extend to broader vocational education student populations.

Keywords: higher vocational students; physical activities; biomechanical factors; achievement emotions; academic performance; mediating effect

1. Introduction

With the rapid development of higher vocational education in Jiangsu Province and the continuous innovation of educational concepts, the cultivation model focusing on students' comprehensive development has received increasing attention, highlighting the importance of physical activities in developing comprehensive qualities of higher vocational students. However, current higher vocational students face multiple challenges, including heavy academic burdens, employment pressure, and insufficient psychological adaptation abilities. These factors not only affect their enthusiasm for participating in physical activities but also inhibit the expression of their learning potential to some extent. As an important branch of sports science research, sports biomechanics has unique value in analyzing human movement patterns and optimizing movement efficiency. Wang et al. pointed out that the discipline of sports biomechanics has gradually expanded from competitive sports to educational application areas, providing scientific basis and methodological guidance for school physical education [1]. This study focuses on higher vocational student populations in Jiangsu Province, exploring the influence mechanism of biomechanical factors in physical activities on students' achievement emotions and academic performance, aiming to provide empirical support for higher vocational physical education reform and promote the synergistic enhancement of students' physical and mental health and academic development.

This research revolves around three core issues: first, the biomechanical characteristics and differences of higher vocational students in Jiangsu Province during various types of physical activities; second, how biomechanical factors in physical activities affect students' achievement emotions; and third, the intrinsic connections and action mechanisms between biomechanical factors, achievement emotions, and academic performance. Based on these, this study establishes the following research objectives: constructing a biomechanical assessment system for higher vocational students' physical activities; analyzing the correlation between biomechanical optimization and achievement emotion regulation; validating the mediating effect of achievement emotions in the process of biomechanical factors influencing academic performance; and proposing higher vocational physical education improvement strategies based on biomechanical principles. Liu's research shows that physical education teaching design based on sports biomechanics can effectively improve students' motor abilities and participation motivation [2]. Jeong et al. further confirmed that targeted biomechanical training can not only improve muscle-neural function but also enhance cognitive control and emotional regulation abilities [3]. Through systematic research on these issues, this study expects to establish an association model of biomechanical factors in physical activities, emotional regulation, and academic performance, providing a theoretical foundation and practical guidance for higher vocational physical education reform.

Compared with existing research, this study has the following innovations: First, it introduces sports biomechanics analysis methods into the field of higher vocational physical education research, expanding the research dimensions of biomechanics in educational applications. Liu et al. pointed out that domestic sports biomechanics research mainly focuses on competitive sports, with relatively insufficient research in educational applications [4]. Second, this study establishes an assessment framework for the correlation between biomechanical factors and achievement emotions, revealing the physiological-psychological connection mechanism between physical activity and psychological emotions. Alshehri et al.'s research shows that there is a significant correlation between biomechanical function and psychological state, but research in educational contexts remains a blank area [5]. Third, this study proposes the action pathway hypothesis of "biomechanics-achievement emotions-academic performance," providing a new perspective for understanding the internal mechanism of physical activities promoting academic performance. Finally, this study combines the practical situation of higher vocational education in Jiangsu Province to propose teaching intervention strategies based on biomechanical optimization, which has strong regional specificity and practical value. Zhao et al.'s research shows that application design driven by biomechanical data can effectively enhance user experience and functionality, providing a reference for the practical application of this study [6].

This study adopts multiple research methods and unfolds according to the following framework: First, through literature research, it clarifies the theoretical foundation and research status of the relationship between sports biomechanics, achievement emotions, and academic performance; second, it collects sample data of higher vocational students in Jiangsu Province through questionnaire surveys, biomechanical measurements, and other methods; then, it explores the relationships between variables using multivariate statistical analysis techniques, including correlation analysis, regression analysis, and structural equation modeling; finally, based on the research findings, it proposes higher vocational physical education improvement strategies based on biomechanical optimization. Graziosi et al. pointed out that the assessment of biomechanical risk factors requires a systematic research path and method, which inspires this study to adopt a rigorous methodological framework [7]. Through this research framework, this study expects not only to reveal the internal mechanism of biomechanical factors influencing achievement emotions and academic performance but also to provide a scientific basis for practical innovation in higher vocational physical education, ultimately promoting both students' comprehensive development and academic achievement.

2. Literature review

In recent years, research on biomechanical factors in physical activities has gradually expanded from competitive sports to educational applications, showing broad development prospects and application value. Wang pointed out that the application of sports biomechanics in physical education can provide a scientific basis for teaching, effectively improving teaching quality and student participation [8]. In the field of higher vocational education, research on the integration of biomechanics and physical education is still in its initial stage but has shown good application potential. Tang research shows that biomechanical applications based on artificial intelligence can precisely identify changes in mechanical parameters during student movement, providing a basis for teaching intervention [9]. Huang further explored biomechanical research on strength training from the perspective of artificial intelligence, indicating that technological integration can achieve quantitative assessment and personalized guidance of training effects [10]. Wang et al.'s research on the gender characteristics of plantar biomechanics among dance sport major students revealed significant differences in mechanical parameters between students of different genders, suggesting that physical education should focus on individual differences and adjust teaching strategies accordingly [11]. Zhang, in research on digital sports technology applications, emphasized that visualizing biomechanical data can enhance students' understanding and grasp of movement patterns [12]. These studies verify the important value of biomechanics in physical education from different perspectives, but there is still a lack of systematic exploration regarding how biomechanical factors influence the psychological state and academic performance of higher vocational students.

Research on the association between physical activities and emotional regulation has received widespread attention in recent years, but studies focusing on achievement emotions are relatively few, especially research exploring this association from a biomechanical perspective is even more scarce. Simon et al., through a randomized controlled study, found that biomechanical and sensorimotor foot orthotic interventions can significantly reduce knee pain and improve patients' emotional states, suggesting that biomechanical optimization may influence emotional experiences by alleviating physical discomfort [13]. Moreira et al.'s research on biomechanical risk factors for running-related injuries also corroborates the association between poor biomechanical patterns and negative physical experiences [14]. Yang et al.'s research confirmed that holistic functional physical exercise can improve lumbar spine biomechanical characteristics, accompanied by significant improvement in emotional states, suggesting a possible causal relationship between biomechanical optimization and the generation of positive emotions [15]. Zhang pointed out that monitoring changes in students' biomechanical parameters during exercise through sports information technology can not only optimize technical movements but also enhance learning interest and sense of achievement [16]. Wu, in research on sports rehabilitation biomechanics applications, found that biomechanical interventions can not only promote physical rehabilitation but also significantly improve patients' emotional states and self-efficacy [17]. Among higher vocational student populations, achievement emotions, as emotional experiences directly related to learning activities, have an important impact on learning behaviors and academic performance. However, existing research lacks in-depth exploration of how biomechanical factors in physical activities influence achievement emotions, a research gap that urgently needs to be filled.

As an important indicator for evaluating student learning outcomes, academic performance is influenced by various complex factors, and research on the impact mechanism of physical activities on academic performance has been a hot topic in the field of education. Cruz et al.'s research found that nonlinear interactions between hip and foot biomechanical factors during walking can predict the degree of foot inversion, suggesting that the synergistic effect of biomechanical factors may impact cognitive function [18]. Chen, in researching cheerleading rotation movements from a biomechanical perspective, found that reasonable biomechanical training can enhance students' spatial perception and coordination abilities, which are closely related to learning cognitive processes [19]. Li and Zhang, in their research on movement technique optimization based on biomechanics, pointed out that biomechanical optimization can not only improve exercise efficiency but also promote physical-mental integration, potentially influencing learning outcomes indirectly by improving cognitive function [20]. Senvaitis et al.'s research on the ergonomic assessment of key biomechanical factors revealed that biomechanical factor optimization can reduce physical fatigue and improve work efficiency, suggesting that biomechanical factors may influence learning outcomes by affecting energy allocation and cognitive resource utilization [21]. The research progress in competitive sports biomechanics reviewed by Li et al. indicates that biomechanical optimization can enhance the regulatory capacity of the neuromuscular system, and this enhancement may promote brain function development, thereby affecting cognitive performance [22]. However, these studies mostly focus on the direct association between biomechanical factors and physical function or cognitive abilities, with less consideration of the mediating role of emotional factors in this process, especially in higher vocational student populations, where research on this pathway appears insufficient.

Although existing research has explored the association of biomechanical factors with physical function, emotional states, and cognitive performance from different perspectives, there are still three areas of research gaps: (1) Insufficient research on biomechanical characteristics of higher vocational student populations, especially a lack of systematic investigations targeting the regional characteristics of Jiangsu Province; (2) scarce research on the association mechanism between biomechanical factors in physical activities and achievement emotions; (3) the action pathway of biomechanics-achievement emotions-academic performance has not been empirically verified. Wang, in research on sports biomechanics in competitive sports, emphasized that biomechanical research should focus on characteristic differences among different populations, which has implications for research on higher vocational students [23]. Li analyzed the application value of sports biomechanics in competitive sports, pointing out that biomechanical research needs to connect with practical application scenarios, suggesting that biomechanical research in higher vocational physical education should be integrated with educational realities [24]. Ceresuela and Montero's clinical research on the role of biomechanical factors in prognosis indicates that biomechanical factor assessment needs to comprehensively consider multidimensional indicators, providing methodological reference for this study's assessment system construction [25]. Bacigalupi et al., when researching biomechanical factors in atherosclerosis localization, found that the association between biomechanical factors and physiological pathology is complex and requires a systematic research framework, suggesting that this study should establish a comprehensive theoretical model to explore the action mechanism of biomechanical factors [26].

Synthesizing existing research, although applications of biomechanics in physical education have gradually increased, systematic research targeting higher vocational student populations is relatively insufficient, especially integrated research connecting biomechanical factors, achievement emotions, and academic performance is even more lacking. Therefore, this study aims to fill this research gap by constructing an action pathway model of "biomechanical factors-achievement emotions-academic performance" to deeply explore the potential impact mechanism of biomechanical factors in physical activities on achievement emotions and academic performance of higher vocational students, providing a theoretical basis and practical guidance for higher vocational physical education reform.

Based on a comprehensive review of existing research, although studies on the application of biomechanics in physical education have gradually increased, three critical gaps remain to be addressed: (1) There is a severe lack of systematic measurement and evaluation research on specific biomechanical factors (especially postural rationality, mechanical balance, and movement coordination) among vocational college students, with insufficient differential analysis based on regional characteristics of Jiangsu Province and students' diverse professional backgrounds; (2) research on the mechanisms by which these specific biomechanical factors influence various dimensions of achievement emotions (particularly pride, shame, etc.) is deficient, with existing studies mostly focusing on broad associations between general physical activities and common emotional states, rather than the precise connections between specific biomechanical parameters and academic-related emotions; (3) the complete pathway model of 'specific biomechanical factors—dimensions of achievement emotions—academic performance' lacks empirical validation, especially regarding the differential moderating effects among students with various professional backgrounds, which remains virtually unexplored.

3. Research methods

3.1. Research design

Based on theoretical analysis and literature review, the research proposes the following three main hypotheses: (1) Biomechanical factors in physical activities of higher vocational students in Jiangsu Province (including movement posture rationality, mechanical balance, and movement coordination) are significantly correlated with their achievement emotions, that is, good biomechanical performance is positively correlated with positive achievement emotions (such as enjoyment, pride, hope) and negatively correlated with negative achievement emotions (such as anxiety, shame, helplessness); (2) higher vocational students' achievement emotions are significantly correlated with their academic performance, with positive achievement emotions helping to improve academic performance, while negative achievement emotions may inhibit academic performance; (3) achievement emotions play a mediating role between biomechanical factors in physical activities and academic performance, that is, biomechanical optimization in physical activities can indirectly improve academic performance by promoting the generation of positive achievement emotions. Meanwhile, this study also hypothesizes that different professional backgrounds, genders, and levels of physical activity participation may moderate the strength of relationships between the above variables.

The main variables involved in this study include independent variables (biomechanical factors in physical activities), mediating variables (achievement emotions), and dependent variables (academic performance). Biomechanical factors in physical activities mainly include three dimensions: posture rationality (referring to whether the position and angle of various body parts during movement conform to biomechanical principles), mechanical balance (referring to the stability of the body's center of gravity and balance ability during movement), and movement coordination (referring to the synergistic effect and temporal control of various joints and muscle groups during movement). Each dimension is quantified using standardized biomechanical assessment methods [27]. The achievement emotion variables include positive achievement emotions (enjoyment, pride, hope) and negative achievement emotions (anxiety, shame, helplessness), measured using Pekrun's Achievement Emotions Questionnaire (AEQ). Academic performance variables mainly include three aspects: average scores in professional courses, learning engagement, and learning self-efficacy, with data obtained through student grade records, learning engagement questionnaires, and self-efficacy scales, respectively. This study will also control for confounding variables that may affect research results, such as students' demographic characteristics (gender, age, major) and the frequency and intensity of physical activity participation.

This study adopts mixed research methods, combining quantitative and qualitative analyses, to construct an action pathway model of "biomechanical factors-achievement emotions-academic performance." The research will be conducted in four stages: (1) Preliminary investigation stage, determining key biomechanical indicators and their assessment methods through literature analysis, expert interviews, and preliminary experiments; (2) data collection stage, using motion capture technology, electromyographic analysis, questionnaire surveys, and other methods to collect biomechanical data, achievement emotion data, and academic performance data; (3) data analysis stage, using statistical methods such as correlation analysis, regression analysis, and structural equation modeling to verify the hypothetical model; (4) application practice stage, designing biomechanical optimization intervention programs based on research findings and evaluating their effectiveness. The entire research framework emphasizes the exploration and verification of causal relationships between variables, aiming to reveal the internal mechanism by which biomechanical factors in physical activities affect academic performance by influencing achievement emotions, and to provide a scientific basis for higher vocational physical education reform. The research framework model is shown in **Figure 1**.

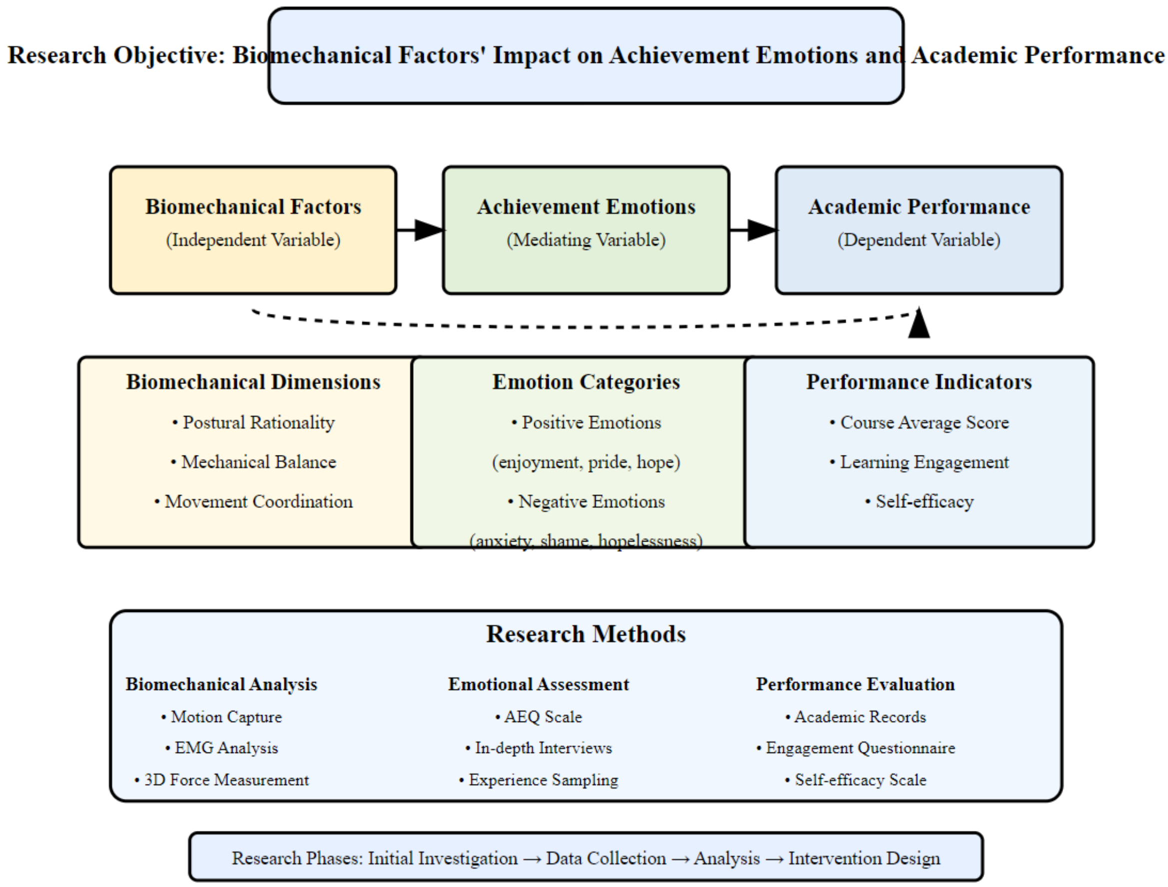

Figure 1. Research framework model.

3.2. Research subjects

This study employs a multi-stage stratified random sampling method to select research subjects from higher vocational colleges in 13 prefecture-level cities in Jiangsu Province. (1) Based on the list of higher vocational colleges published by the Jiangsu Provincial Department of Education, stratification was conducted according to geographical location (Southern Jiangsu, Central Jiangsu, Northern Jiangsu) and institution type (public, private), from which 12 representative higher vocational colleges were randomly selected. (2) Within each selected college, 2–3 majors were randomly selected as research samples according to professional categories (engineering, liberal arts, medical and pharmaceutical, arts, sports). (3) Within the selected majors, participants were drawn from freshman to junior year students using systematic sampling methods, ensuring sample coverage of student groups from different grades and professional backgrounds [28]. To ensure the completeness and validity of research data, all selected students must meet the following conditions: be in good health with no history of serious sports injuries; have participated in at least one physical education course or physical activity in the past semester; be willing to participate in the entire research process and sign an informed consent form.

This study selected a total of 842 valid samples, distributed by geographic region as follows: Southern Jiangsu region 308 (36.6%), Central Jiangsu region 276 (32.8%), Northern Jiangsu region 258 (30.6%); by institution type: public higher vocational college students 598 (71.0%), private higher vocational college students 244 (29.0%);

by professional category: engineering 312 (37.1%), liberal arts 216 (25.6%), medical and pharmaceutical 124 (14.7%), arts 106 (12.6%), sports 84 (10.0%); by grade level: freshman year 328 (39.0%), sophomore year 292 (34.7%), junior year 222 (26.3%); by gender: male 462 (54.9%), female 380 (45.1%). According to the level of physical activity participation, the sample was further divided into a high-frequency participation group (3 or more times per week, 298, 35.4%), a medium-frequency participation group (1–2 times per week, 392, 46.6%), and a low-frequency participation group (less than once per week, 152, 18.0%). This multi-level stratified sampling ensured the representativeness and balance of the sample in terms of region, major, grade, gender, and degree of physical activity participation.

The average age of the research sample was 19.8 ± 1.4 years, with heights of 172.3 ± 7.9 cm (males) and 161.4 ± 5.8 cm (females), weights of 67.4 ± 9.2 kg (males) and 53.6 ± 7.5 kg (females), and body mass indexes (BMI) of 22.7 ± 3.1 (males) and 20.6 ± 2.8 (females). In terms of academic performance, the sample students' average score for the previous semester was 78.4 ± 8.7 points, with the high-frequency physical activity participation group averaging 81.2 ± 8.2 points, the medium-frequency participation group averaging 78.9 ± 8.4 points, and the low-frequency participation group averaging 75.2 ± 9.3 points. Regarding types of physical activities, students participating in basketball accounted for 28.1%, football 15.6%, table tennis 14.2%, badminton 12.8%, track and field 10.5%, swimming 7.4%, and other sports 11.4%. In terms of skill level, 32.5% self-assessed as beginner level, 48.2% as intermediate level, and 19.3% as advanced level. The sample students' average weekly physical activity time was 4.2 ± 2.6 h, with an average duration per activity of 78.5 ± 32.6 min and an average exercise intensity of moderate to high (self-assessment scale 5.8 ± 1.7 points, out of 10 points).

3.3. Research tools

This study employs various biomechanical assessment tools to obtain mechanical parameters of students' physical activities, primarily including a three-dimensional motion capture system (Vicon Motion Systems Ltd., UK), a surface electromyography system (Noraxon U.S.A., Inc.), and a three-dimensional force platform (Kistler, Switzerland). The three-dimensional motion capture system consists of 10 high-speed infrared cameras with a sampling frequency of 200 Hz, used to record three-dimensional spatial position changes of various joint points during students' movements, precisely capturing movement postures and trajectories; the surface electromyography system uses wireless transmission to record the electrical activity of major muscle groups through 16-channel acquisition equipment with a sampling frequency of 1000 Hz, used to analyze muscle activation levels, synergy patterns, and fatigue characteristics; the three-dimensional force platform is used to collect ground reaction force data with a sampling frequency of 1000 Hz, capable of measuring forces and moments in vertical and horizontal directions [29]. Additionally, InvenSense MPU-6050 inertial sensors are used to measure acceleration and angular velocity of various body parts, and the Microgate OptoJump Next photoelectric timing system is used to measure temporal parameters. These devices, used in combination, form a comprehensive biomechanical parameter acquisition platform capable of comprehensively assessing students' biomechanical characteristics in physical activities from multiple angles.

The revised Achievement Emotions Questionnaire (AEQ) is used to measure students' achievement emotional experiences in physical activities. This scale was developed by Pekrun et al. and has undergone reliability and validity testing in the Chinese version and adaptive revision for physical activity contexts. The revised scale includes 80 items, divided into three main situational dimensions (before, during, and after class) and six emotion types (enjoyment, hope, pride, anger, anxiety, and shame), scored on a five-point Likert scale (1 = "strongly disagree" to 5 = "strongly agree"). The scale's internal consistency reliability coefficient (Cronbach's α) ranges from 0.78 to 0.92, with good construct validity (confirmatory factor analysis fit indices: CFI = 0.91, RMSEA = 0.056). To gain a deeper understanding of the dynamic changes in students' achievement emotions, the study also employs the Experience Sampling Method (ESM), collecting students' immediate emotional experience data through a mobile application at three time points—before, during, and after physical activities—with 12 simplified emotion assessment items answered at each time point, forming a dynamic assessment system for achievement emotions.

Students' academic performance is assessed through a multi-indicator system, including objective learning achievement indicators and subjective learning experience indicators. Objective learning achievement indicators mainly collect students' grade point averages (GPA) for the most recent two semesters, scores in core professional courses, and comprehensive quality evaluation scores. These data are provided by the academic affairs systems of each institution, ensuring accuracy and comparability. Subjective learning experience indicators include the University Student Engagement Inventory (USEI, covering three dimensions of behavioral engagement, emotional engagement, and cognitive engagement, with a total of 18 items) and the Academic Self-Efficacy Scale (ASES, covering three dimensions of learning motivation, learning strategies, and self-regulation, with a total of 15 items). Additionally, a learning adaptability questionnaire was designed to measure students' performance in stress coping, frustration tolerance, and goal persistence during the learning process. To control for possible confounding variables, the study also collects relevant information on students' time invested in learning, study habits, learning environment, and tutoring support. This multidimensional approach to academic performance assessment can comprehensively reflect students' learning status and academic performance, avoiding evaluation biases that might arise from using a single indicator.

3.4. Data collection

Prior to formal data collection, the research team selected 45 students with characteristics similar to the target sample for pre-testing to examine the applicability and stability of the research tools. The pre-testing was conducted in three stages: the first stage focused on calibration and parameter adjustment of biomechanical assessment equipment, including spatial calibration of the three-dimensional motion capture system (calibration error < 0.5 mm), signal-to-noise ratio optimization of the electromyography system (SNR > 20 dB), and sensitivity adjustment of the force platform (response time < 10 ms); the second stage involved small-sample testing of the achievement emotions scale and academic assessment scale, eliminating items with low discrimination through item analysis and optimizing questionnaire expressions based on student feedback; the third stage involved complete process simulation to verify the time efficiency and quality stability of data collection, and adjusting the measurement process and time arrangements accordingly [30]. The pre-test results indicated that the revised research tools had good applicability, measurement time was controlled within 90 min, participants provided positive feedback, and no significant understanding bias or operational difficulties occurred, laying the foundation for formal measurement.

Formal data collection adopted a standardized process, conducted in temporary biomechanics laboratories established at each participating institution. The measurement procedure for each participant included five components: first, participants completed a basic information questionnaire and a physical activity participation survey (approximately 15 min); second, static biomechanical parameter measurements were taken, including body morphological parameters, static posture assessment, and joint range of motion measurements (approximately 20 min); third, participants performed standardized physical movement tests, including vertical jumps, lateral movements, rotation movements, and simulated sport technique movements, while dynamic biomechanical data were recorded through the motion capture system, electromyography, and force platform (approximately 30 min); fourth, participants completed the achievement emotions scale and academic performance self-assessment questionnaire (approximately 20 min); finally, research assistants conducted brief interviews with participants to collect feedback on the testing process and supplementary information (approximately 5 min) [31]. The entire measurement process was jointly managed by trained research assistants and biomechanics experts to ensure consistent operational standards. All data collection was arranged during normal teaching weeks, avoiding special time periods such as midterm and final examinations, to obtain data on students' performance under normal conditions.

To ensure the accuracy and reliability of research data, this study implemented stringent data quality control measures. In the data collection phase, a "triple verification" mechanism was implemented: first, technical verification, through automatic equipment calibration and real-time monitoring of signal quality, eliminating data records with unstable or abnormal signals; second, manual verification, with two experienced researchers independently reviewing all raw data and marking suspicious data points; and third, participant confirmation, with immediate feedback verification of key data. In the data processing phase, a standardized data cleaning process was adopted, including noise filtering (bandpass filter 20–450 Hz), missing value processing (multiple imputation method), and outlier detection (3σ principle). Meanwhile, strict data inclusion criteria were established: biomechanical data must include at least three valid tests with a coefficient of variation <15%; questionnaire data must have a completion rate > 95%; academic performance data must come from verifiable sources. To reduce measurement bias, research team members received unified training and used standard operating manuals to guide each component. Additionally, the stability of measurements was assessed through cross-validation methods (10% sample repeated measurements, with a two-week interval), with test-retest reliability coefficients all above 0.82, ensuring high-quality standards in the data collection process.

3.5. Data analysis

This study first employs descriptive statistical analysis methods to preliminarily explore each variable, presenting the basic characteristics and distribution patterns of the data. For biomechanical parameters (including the three dimensions of posture rationality, mechanical balance, and movement coordination), means, standard deviations, maximum/minimum values, and quartiles are calculated, and their normal distribution is tested through skewness and kurtosis; for achievement emotion data, the average scores, standard deviations, and coefficients of variation for each dimension are calculated, and cross-analysis is conducted according to categorical variables such as gender, professional category, and physical activity participation frequency, with box plots and histograms displaying the distribution of emotion scores [32]; for academic performance data, the measures of central tendency and dispersion for different indicators are calculated, and academic performance differences among students with different backgrounds are compared through stratified analysis. The results of descriptive analysis will provide a foundation for subsequent in-depth analysis, helping to identify special patterns and potential associations in the data.

Based on descriptive analysis, correlation analysis, and regression analysis methods are used to explore the associations and predictive relationships between variables. (1) Pearson correlation analysis and partial correlation analysis methods are used to calculate the correlation coefficients between various dimensions of biomechanics and various dimensions of achievement emotions, as well as between achievement emotions and various indicators of academic performance, controlling for the influence of demographic variables; (2) multiple linear regression models are constructed, with achievement emotions and academic performance as dependent variables, to explore the predictive effects of biomechanical factors; (3) hierarchical regression analysis methods are used to verify the mediating effect of achievement emotions between biomechanical factors and academic performance, following the mediating effect testing procedure proposed by Baron and Kenny; (4) moderation effect models are applied to examine the moderating effects of factors such as gender, professional background, and physical activity participation frequency on the relationships between core variables [33]. All regression analyses undergo multicollinearity tests and heteroscedasticity tests to ensure the robustness of model estimates.

To comprehensively verify research hypotheses and explore complex relationships between variables, this study employs structural equation modeling (SEM) for path analysis. (1) Confirmatory factor analysis (CFA) is used to test the fit of the measurement model and evaluate the relationships between latent variables and observed variables; (2) a structural model is constructed, simultaneously incorporating biomechanical factors (exogenous latent variables), achievement emotions (mediating latent variables), and academic performance (endogenous latent variables), testing direct and indirect effects; (3) the bootstrap method (5000 resamples) is used to estimate the significance and confidence intervals of mediating effects; (4) multi-group comparative analysis is conducted to test measurement invariance and path differences across different gender groups, different majors, and groups with different levels of physical activity participation. Model fit is comprehensively evaluated using multiple indices, including χ^2/df (< 3), CFI (> 0.90), TLI (> 0.90), RMSEA (< 0.08), and SRMR (< 0.08). All statistical analyses are completed using SPSS 26.0 and Mplus 8.3 software, with the significance level set at $\alpha = 0.05$ (two-tailed test).

This study identified and mitigated three types of potential data biases: first, measurement bias, which was reduced through equipment calibration, averaging multiple measurements, and cross-validation methods; second, sample selection bias, which was controlled using stratified random sampling and multiple imputation for missing data; and third, subjective evaluation bias, which was mitigated by combining objective measurement data with self-reported data and implementing blind scoring methods. Additionally, the research team underwent unified training, used standardized operation manuals, and conducted regular consistency checks (with inter-rater reliability > 0.85) to ensure the rigor of the data collection process.

The structural equation model used in this study is based on multivariate normality assumptions and may be influenced by sample size and measurement errors. Although we enhanced the robustness of estimates through bootstrap methods, the cross-validation of the model is limited to current sample characteristics. Multiple regression analysis assumes linear relationships between variables, while in reality some associations may exhibit nonlinear characteristics, particularly regarding threshold effects in the relationship between biomechanical efficiency and emotions. Although the mediation effect test adopted Baron and Kenny's classical approach, it may underestimate indirect effects; therefore, we combined bootstrap methods and Sobel tests to enhance inferential validity. Future research could consider adopting longitudinal designs and Bayesian methods to further validate causal relationships.

4. Results analysis

4.1. Analysis of biomechanical characteristics in physical activities of higher vocational students in Jiangsu Province

4.1.1. Movement posture and mechanical parameter characteristics

The study conducted a systematic analysis of movement postures and mechanical parameters of 842 higher vocational students from Jiangsu Province during typical physical activities (basketball, football, badminton, table tennis, and track and field), with results showing significant differences in biomechanical characteristics among different groups. From a postural perspective, in the basic standing posture assessment, approximately 38.6% of students exhibited varying degrees of body deviation, primarily manifested as excessive trunk forward lean angle (average 22.5° ± 4.8°, ideal range should be within 15°) and excessive hip joint external rotation (average 18.7° ± 5.2°, ideal range should be within 10°). During movement, males' Trunk Stability Index (TSI) was 76.4 ± 8.3, significantly higher than females' 68.2 ± 9.6 ($t = 5.43$, $p < 0.001$); while females' Lower Limb Coordination Index (LCI) was 72.5 ± 7.8, slightly higher than males' 69.8 ± 8.4, but the difference did not reach a significant level ($t = 1.87$, $p = 0.062$). From mechanical parameter measurement results, in the vertical jump test, students' average jump height was 38.6 ± 7.2 centimeters, maximum ground reaction force was 2.4 ± 0.3 times body weight, and take-off time was 0.28 ± 0.05 s [34]. Students in the high-frequency group who regularly participated in physical activities demonstrated better explosive power and ground reaction force utilization efficiency, with a power output conversion rate of 78.2% ± 6.5%, significantly higher than the low-frequency group's 65.3% ± 7.8% ($F = 28.54$, $p < 0.001$). In movement technique analysis, students with different professional backgrounds exhibited different biomechanical characteristics: engineering students excelled in strength performance (average muscle torque 48.6 ± 6.2 N·m), sports students performed best in movement coordination (movement chain synchronization rate 83.5% ± 5.4%), while arts students scored highest in balance ability tests (single-leg standing balance index 84.6 ± 7.2). **Table 1** displays the comparison of core biomechanical parameters among students of different genders and physical activity participation frequencies, while **Figure 2** reflects the performance characteristics of students from different professional categories across three core biomechanical dimensions. The study further found that in terms of joint range of motion, 15.8% of students exhibited restricted ankle dorsiflexion (< 15°), and 23.7% of students exhibited insufficient hip joint internal rotation flexibility (< 30°), which may affect their performance and injury risk in specific physical activities.

Table 1. Comparison of core biomechanical parameters among students of different genders and physical activity participation frequencies.

Biomechanical parameters	**Gender**		**Physical activity participation frequency**		
	Males (*n* = 462)	**Females (*n* = 380)**	**High-frequency group (*n* = 298)**	**Medium-frequency group (*n* = 392)**	**Low-frequency group (*n* = 152)**
Trunk stability index (TSI)	76.4 ± 8.3**	68.2 ± 9.6	79.8 ± 7.5**	71.2 ± 8.6*	62.7 ± 9.8
Lower limb coordination index (LCI)	69.8 ± 8.4	72.5 ± 7.8	78.4 ± 6.2**	70.6 ± 7.5*	63.5 ± 8.9
Vertical jump height (cm)	42.5 ± 6.8**	33.8 ± 5.4	44.8 ± 5.6**	38.7 ± 6.2*	32.4 ± 6.5
Maximum ground reaction force (BW)	2.6 ± 0.3**	2.2 ± 0.2	2.7 ± 0.2**	2.4 ± 0.3*	2.1 ± 0.3
Power output conversion rate (%)	74.6 ± 7.2**	68.5 ± 6.8	78.2 ± 6.5**	71.4 ± 6.7*	65.3 ± 7.8
Movement chain synchronization rate (%)	72.8 ± 6.8	74.6 ± 6.3	80.6 ± 5.5**	73.5 ± 6.2*	67.2 ± 7.4

Note: * $p < 0.05$, ** $p < 0.01$, indicating significant difference compared with the low-frequency group; BW represents multiples of body weight.

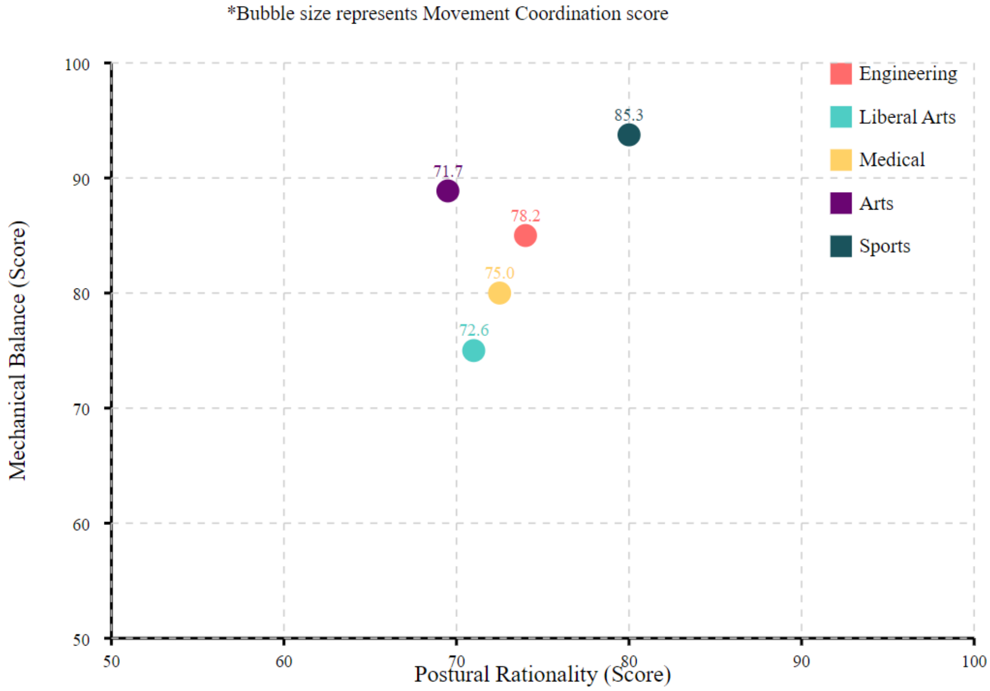

Figure 2. Biomechanical performance of different major categories.

Overall, higher vocational students in Jiangsu Province exhibit a characteristic pattern of "relatively weak upper limb strength, moderate core stability, and distinctly differentiated lower limb explosive power" in terms of movement posture and mechanical parameters, which is closely related to their daily study lifestyle and physical exercise habits.

4.1.2. Comparison of biomechanical patterns in different types of physical activities

This study conducted a systematic comparative analysis of biomechanical patterns in five main types of physical activities (basketball, football, badminton, table tennis, and track and field) participated in by higher vocational students in Jiangsu Province. Results showed significant differences in biomechanical characteristics among different types of physical activities. From joint movement angle analysis, students' maximum ankle dorsiflexion angle in basketball activities averaged 28.6° ± 4.2°, significantly greater than in football (24.8° ± 3.9°) and track and field (25.3° ± 4.0°) activities ($F = 16.42$, $p < 0.001$); students' maximum shoulder abduction angle in badminton activities reached 168.3° ± 8.2°, significantly higher than in the other four types of activities ($F = 22.35$, $p < 0.001$). Regarding ground reaction force, the maximum vertical ground reaction force generated in track and field activities was 3.2 ± 0.4 times body weight, significantly higher than the 2.1–2.6 times in ball sports ($F = 28.76$, $p < 0.001$) [35]. Electromyographic analysis showed clear differences in dominant muscle groups activated across different activity types: basketball activities primarily activated the quadriceps and triceps surae, with an average EMG amplitude of 736.5 ± 98.4 μV; football activities predominantly activated the hamstrings and gastrocnemius, with an average EMG amplitude of 689.3 ± 85.7 μV; badminton activities mainly activated the forearm muscle groups and deltoid, with an average EMG amplitude of 524.8 ± 76.2 μV. From a kinetic chain perspective, ball sports generally exhibited "closed-chain to open-chain" mixed movement patterns, while track and field activities were primarily "open-chain" movements, resulting in significant differences in muscle co-activation patterns. **Table 2** displays the comparison of core biomechanical parameters across five types of physical activities, and **Figure 3** presents the analysis of kinetic chain coordination patterns in different types of physical activities.

Table 2. Comparison of core biomechanical parameters across five types of physical activities.

Biomechanical parameters	**Basketball (*n* = 236)**	**Football (*n* = 131)**	**Badminton (*n* = 119)**	**Table tennis (*n* = 108)**	**Track and field (*n* = 88)**	***F*-value**	***p*-value**
Maximum joint range of motion (°)	Shoulder: 145.6 ± 10.2 < br > Ankle: 28.6 ± 4.2	Hip: 118.4 ± 9.7 < br > Ankle: 24.8 ± 3.9	Shoulder: 168.3 ± 8.2 < br > Wrist: 86.5 ± 6.4	Elbow: 132.4 ± 7.8 < br > Wrist: 92.3 ± 5.2	Hip: 126.5 ± 8.3 < br > Ankle: 25.3 ± 4.0	22.35	< 0.001
Maximum ground reaction force (BW)	2.6 ± 0.3	2.4 ± 0.4	2.1 ± 0.2	2.2 ± 0.3	3.2 ± 0.4	28.76	< 0.001
Primary muscle group EMG amplitude (μV)	736.5 ± 98.4	689.3 ± 85.7	524.8 ± 76.2	486.2 ± 68.5	756.8 ± 102.4	25.48	< 0.001
Stability index (0–100)	Whole body: 78.6 ± 7.5	Lower limbs: 86.4 ± 8.1	Upper limbs: 85.6 ± 7.2	Upper limbs: 82.5 ± 6.8	Lower limbs: 82.3 ± 7.6	18.36	< 0.001
Movement rhythm coefficient of variation (%)	23.8 ± 3.2	18.6 ± 2.8	15.4 ± 2.5	12.8 ± 2.2	6.2 ± 1.4	32.15	< 0.001
Energy expenditure (kcal/min)	8.6 ± 1.2	9.2 ± 1.4	7.3 ± 1.1	5.8 ± 0.9	8.9 ± 1.3	20.64	< 0.001

Note: BW represents multiples of body weight.

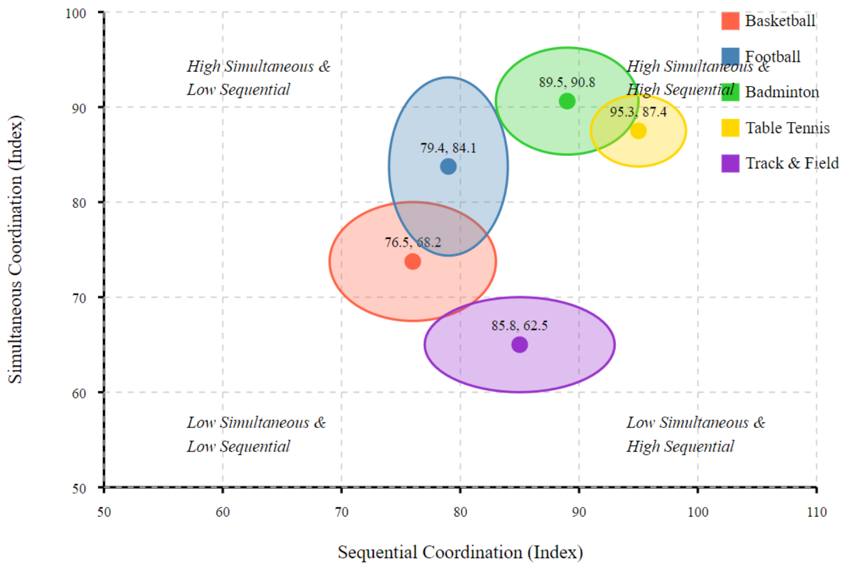

Figure 3. Movement chain coordination patterns in different sports activities.

Additionally, the study found significant differences in stability requirements across different physical activities: table tennis and badminton had higher requirements for upper limb stability (upper limb stability indices of 82.5 ± 6.8 and 85.6 ± 7.2, respectively), football had the highest requirement for lower limb stability (lower limb stability index of 86.4 ± 8.1), while basketball posed comprehensive requirements for whole-body stability (overall stability index of 78.6 ± 7.5) [36].

Temporal-spatial parameter analysis showed that the five physical activities also exhibited distinct differences in rhythmicity: track and field activities had the most regular movement rhythm (coefficient of variation 6.2%), while basketball had the largest movement rhythm variation among ball sports (coefficient of variation 23.8%). These results indicate that different types of physical activities place different biomechanical demands on various systems of students' bodies, forming unique biomechanical adaptation patterns, which provides a scientific basis for specifically guiding students in selecting suitable physical activities.

4.1.3. Relationship between biomechanical efficacy and physical activity participation level

This study constructed a biomechanical efficacy scoring system through comprehensive biomechanical indicators and analyzed the relationship between biomechanical efficacy and physical activity participation level. The biomechanical efficacy score was calculated by weighting three dimensions: posture rationality (40%), mechanical balance (30%), and movement coordination (30%), with a total score of 100 points. The research results showed that the average biomechanical efficacy score of higher vocational students was 72.6 ± 8.4 points, with the high-participation group (≥ 3 times per week, duration ≥ 45 min per session) scoring 82.5 ± 6.8 points, the medium-participation group (1–2 times per week) scoring 73.4 ± 7.2 points, and the low-participation group (≤ 3 times per month) scoring 62.4 ± 8.6 points, with significant differences among the three groups ($F = 56.82$, $p < 0.001$). Correlation analysis indicated that biomechanical efficacy was significantly positively correlated with physical activity participation frequency ($r = 0.684$, $p < 0.001$) and single-session duration ($r = 0.572$, $p < 0.001$) [37]. Further stratified analysis found that this positive correlation remained significant after controlling for gender, age, and professional background (partial correlation coefficients of 0.658 and 0.543, respectively, $p < 0.001$). **Table 3** displays a detailed comparison of biomechanical efficacy among students with different participation levels, and **Figure 4** presents the scatter distribution and fitting curve of biomechanical efficacy and weekly sports participation frequency.

Table 3. Detailed comparison of biomechanical efficacy among students with different participation levels.

Biomechanical efficacy indicators	**High-participation group < br > (*n* = 298)**	**Medium-participation group < br > (*n* = 392)**	**Low-participation group < br > (*n* = 152)**	***F*-value**	***p*-value**	**Post-hoc test**
Overall efficacy score (0–100 points)	82.5 ± 6.8	73.4 ± 7.2	62.4 ± 8.6	56.82	< 0.001	H > M > L
Posture rationality (0–40 points)	33.6 ± 3.2	29.8 ± 3.8	24.5 ± 4.2	42.68	< 0.001	H > M > L
Mechanical balance (0–30 points)	24.8 ± 2.3	21.6 ± 2.8	18.2 ± 3.2	36.75	< 0.001	H > M > L
Movement coordination (0–30 points)	24.1 ± 2.5	22.0 ± 2.4	19.7 ± 2.9	32.56	< 0.001	H > M > L
Joint range of motion index (%)	92.5 ± 4.2	85.3 ± 5.6	76.8 ± 6.5	45.32	< 0.001	H > M > L
Muscle activation efficiency (%)	87.6 ± 5.3	79.4 ± 6.2	70.5 ± 7.4	38.64	< 0.001	H > M > L
Kinetic chain transfer efficiency (%)	84.3 ± 5.8	76.8 ± 6.4	68.2 ± 7.2	34.28	< 0.001	H > M > L

Note: The Bonferroni method was used for post-hoc tests. "H > M > L" indicates that the high-participation group was significantly higher than the medium-participation group, and the medium-participation group was significantly higher than the low-participation group.

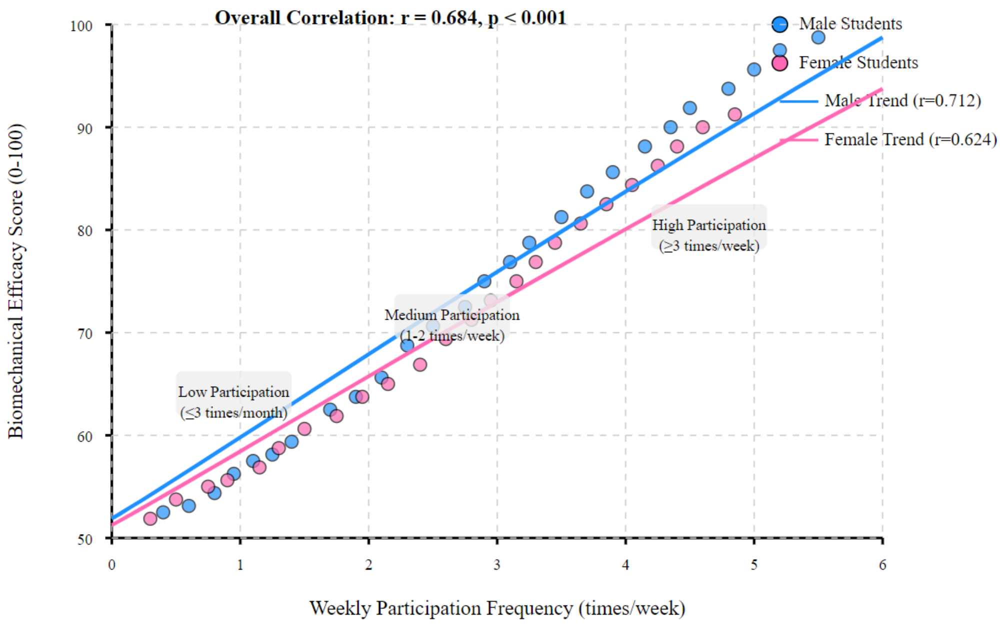

Figure 4. Relationship between biomechanical efficacy and weekly sports participation frequency.

The study found significant gender differences in the relationship between biomechanical efficacy and physical activity participation level: the correlation coefficient for males ($r = 0.712$, $p < 0.001$) was higher than for females ($r = 0.624$, $p < 0.001$); there were also notable differences among different majors, with sports majors having the highest correlation coefficient ($r = 0.753$, $p < 0.001$), followed by engineering majors ($r = 0.692$, $p < 0.001$) and arts majors ($r = 0.668$, $p < 0.001$). Path analysis further revealed that the influence of physical activity participation level on biomechanical efficacy could be divided into direct effects ($\beta = 0.523$, $p < 0.001$) and indirect effects through sports skill proficiency ($\beta = 0.286$, $p < 0.001$). Additionally, the study also found that there might be bidirectional influences between biomechanical efficacy and physical activity participation level: on one hand, higher participation levels enhanced biomechanical efficacy through a "practice effect"; on the other hand, higher biomechanical efficacy might promote participation motivation by enhancing sports confidence and enjoyment, forming a virtuous cycle [38]. Notably, the relationship between biomechanical efficacy and physical activity participation level also showed significant differences across different activity types: the correlation coefficient for technical activities (such as badminton and table tennis) ($r = 0.708$, $p < 0.001$) was higher than for strength activities (such as basketball and football) ($r = 0.651$, $p < 0.001$). These findings indicate that there is a close and complex association between biomechanical efficacy and physical activity participation level, which is moderated by multiple factors and has important implications for understanding the physical activity behavior patterns of higher vocational students.

4.2. Research on the correlation between biomechanical factors and achievement emotions

4.2.1. Association between biomechanical efficacy and positive achievement emotions

This study explored the correlation between biomechanical efficacy and positive achievement emotions through Pearson correlation analysis and multiple regression analysis. As shown in **Table 4**, overall biomechanical efficacy was significantly positively correlated with the total score of positive achievement emotions ($r = 0.628$, $p < 0.001$). Among the various dimensions of positive achievement emotions, the correlations with biomechanical efficacy from highest to lowest were pride ($r = 0.675$, $p < 0.001$), enjoyment ($r = 0.614$, $p < 0.001$), and hope ($r = 0.534$, $p < 0.001$). Further analysis of the relationship between the three sub-dimensions of biomechanical efficacy and positive achievement emotions found that movement coordination had the highest correlation coefficient with positive achievement emotions ($r = 0.642$, $p < 0.001$), followed by postural rationality ($r = 0.598$, $p < 0.001$) and mechanical balance ($r = 0.562$, $p < 0.001$). After controlling for variables such as gender, age, and academic background, the partial correlation analysis results remained significant, indicating that the association between biomechanical efficacy and positive achievement emotions is robust [39]. Further multiple linear regression analysis showed that, after controlling for demographic variables, biomechanical efficacy significantly predicted positive achievement emotions ($\beta = 0.542$, $t = 13.65$, $p < 0.001$), explaining 34.6% of the variance in positive achievement emotions ($\Delta R^2 = 0.346$).

Table 4. Correlation coefficient matrix of biomechanical efficacy and positive achievement emotions.

Biomechanical efficacy	Enjoyment	Pride	Hope	Total positive emotions
Postural rationality	0.586**	0.624**	0.512**	0.598**
Mechanical balance	0.542**	0.582**	0.498**	0.562**
Movement coordination	0.632**	0.682**	0.548**	0.642**
Overall efficacy	0.614**	0.675**	0.534**	0.628**

Note: ** indicates $p < 0.001$.

Figure 5 illustrates the differences in the three positive achievement emotion experiences among students with different levels of biomechanical efficacy (low, medium, high).

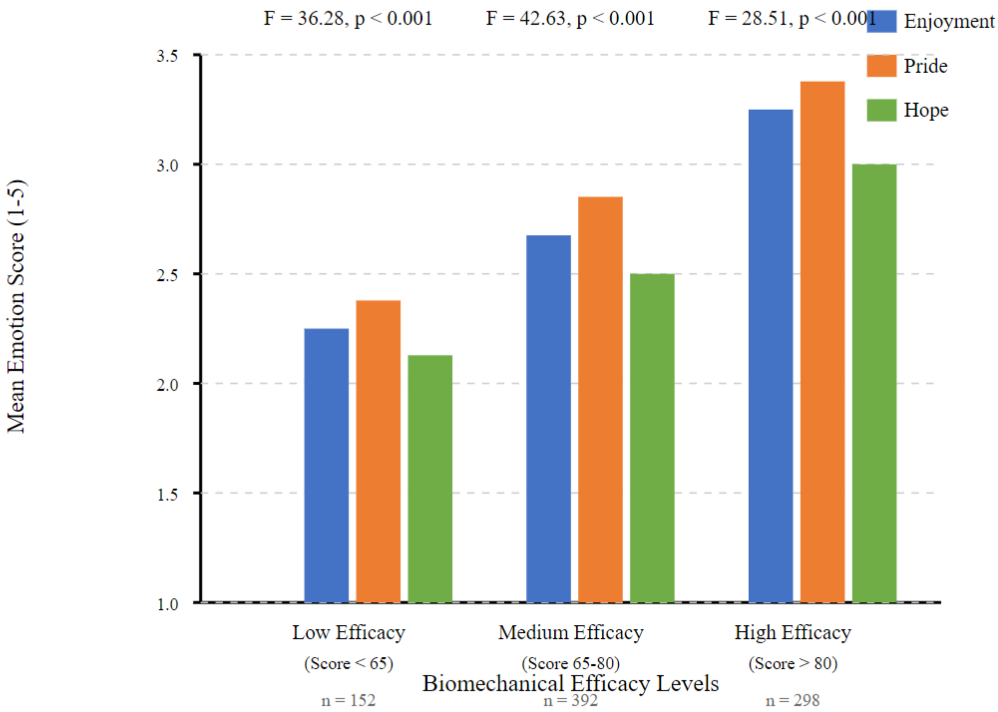

Figure 5. Positive achievement emotions across different biomechanical efficacy levels.

The type of physical activity had a moderating effect on this association, with the correlation coefficient between biomechanical efficacy and positive achievement emotions in skill-based activities (such as badminton and table tennis) (r = 0.684) being higher than in strength-based activities (such as basketball and track and field) (r = 0.592). In addition, gender differences were also evident, with the correlation coefficient between biomechanical efficacy and pride in the male group (r = 0.692) significantly higher than in the female group (r = 0.615), while the correlation coefficient between biomechanical efficacy and enjoyment in the female group (r = 0.634) was slightly higher than in the male group (r = 0.592). These findings suggest that there is a stable and significant positive correlation between biomechanical efficacy and positive achievement emotions, and this relationship is moderated by multiple factors.

4.2.2. Relationship between poor biomechanical patterns and negative achievement emotions

This study conducted a detailed analysis of the relationship between four typical poor biomechanical patterns in vocational college students' physical activities and negative achievement emotions. As shown in **Table 5**, all four poor patterns (trunk postural instability, lower limb incorrect coordination patterns, joint hyperactivity, and insufficient muscle activation) were significantly positively correlated with negative achievement emotions.

Table 5. Correlation coefficient matrix of poor biomechanical patterns and negative achievement emotions.

Poor biomechanical patterns	Anxiety	Shame	Helplessness	Total negative emotions
Trunk postural instability	0.528**	0.642**	0.574**	0.601**
Lower limb incorrect coordination patterns	0.554**	0.585**	0.598**	0.582**
Joint hyperactivity	0.496**	0.562**	0.522**	0.536**
Insufficient muscle activation	0.615**	0.584**	0.568**	0.612**
Overall score of poor patterns	0.576**	0.618**	0.584**	0.608**

Note: ** indicates $p < 0.001$.

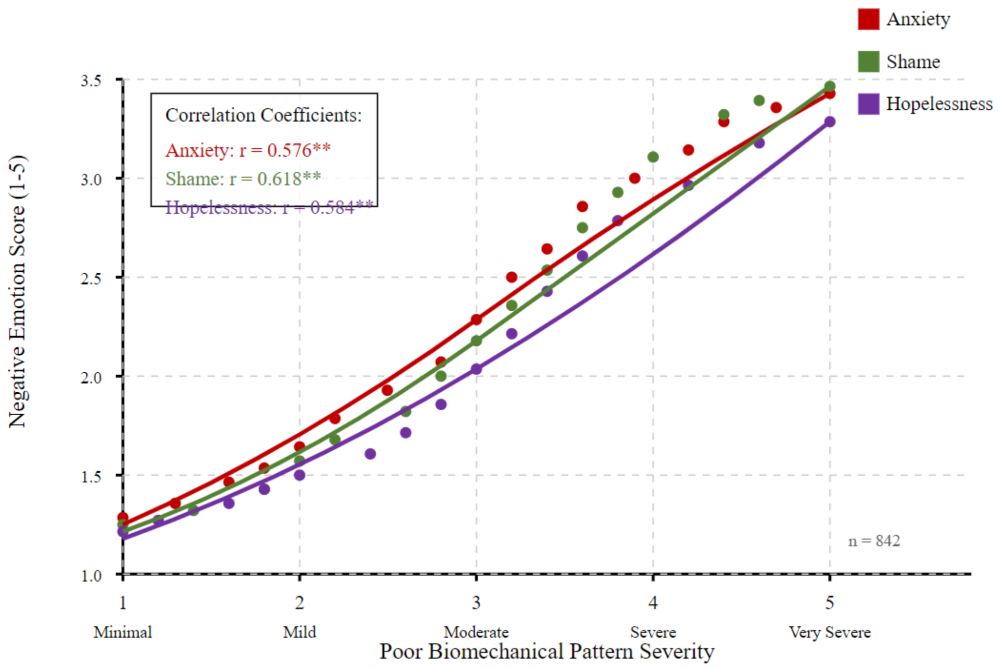

Figure 6.** Relationship between poor biomechanical patterns and negative achievement emotions**.

Among these, insufficient muscle activation had the highest correlation with anxiety ($r = 0.615$, $p < 0.001$), trunk postural instability had the strongest correlation with shame ($r = 0.642$, $p < 0.001$), and lower limb incorrect coordination patterns had the closest association with helplessness ($r = 0.598$, $p < 0.001$). Multiple regression analysis showed that, after controlling for gender, major, and type of physical activity, poor biomechanical patterns significantly predicted negative achievement emotions ($\beta = 0.563$, $t = 14.26$, $p < 0.001$), explaining 31.7% of the variance in negative achievement emotions ($\Delta R^2 = 0.317$). Path analysis further revealed that poor biomechanical patterns influenced negative achievement emotions through two mediating variables: "sense of movement difficulty" and "physical discomfort," with indirect effects of 0.243 and 0.185, respectively ($p < 0.001$). **Figure 6** illustrates the comparison of relationship strength between the four poor biomechanical patterns and three negative achievement emotions.

Different gender students showed significant differences in this aspect: the correlation coefficient between poor biomechanical patterns and anxiety in male students ($r = 0.592$) was significantly higher than in female students ($r = 0.486$), while the correlation coefficient between poor biomechanical patterns and shame in female students (r = 0.672) was notably higher than in male students (r = 0.574). Additionally, the strength of this association varied across different types of physical activities: the correlation between poor biomechanical patterns and negative emotions in skill-based activities (such as badminton and table tennis) (r = 0.642) was higher than in strength-based activities (such as basketball and track and field) (r = 0.538), which may be related to the higher requirements for movement precision in skill-based activities [40]. The study also found that negative achievement emotions increased with the severity of poor biomechanical patterns, showing a non-linear relationship; when poor patterns exceeded moderate severity, the rate of increase in negative emotions significantly accelerated.

4.2.3. Analysis of the regulatory effects of biomechanical interventions on achievement emotions

To verify the regulatory effects of biomechanical interventions on achievement emotions, this study implemented an 8-week biomechanical optimization training intervention for 128 vocational college students with significant poor biomechanical patterns. The intervention effect assessment adopted a pre-test/post-test design, using paired sample *t*-tests and one-way analysis of variance methods to analyze the data. As shown in **Table 6**, students' biomechanical efficacy significantly improved after the intervention (t = 15.32, p < 0.001), while poor pattern scores significantly decreased (t = −12.84, p < 0.001).

In terms of achievement emotions, the intervention group's total positive achievement emotions significantly increased by 36.2% (t = 11.65, p < 0.001), and total negative achievement emotions significantly decreased by 28.7% (t = −9.84, p < 0.001). Detailed analysis of changes in each emotional dimension found that pride showed the largest increase (43.5%), followed by enjoyment (38.2%) and hope (31.4%); among negative emotions, shame showed the largest decrease (32.6%), followed by anxiety (26.8%) and helplessness (24.9%). Further mediation effect analysis revealed that biomechanical efficacy improvement played a complete mediating role between intervention and enhanced positive emotions (Sobel test z = 8.36, p < 0.001), while reduced poor patterns played a partial mediating role between intervention and weakened negative emotions (mediating effect accounting for 72.8%). **Figure 7** shows the comparison of regulatory effects of different intervention programs on positive and negative achievement emotions.

Table 6. Comparison of achievement emotions before and after biomechanical intervention (n = 128).

Variables	**Pre-intervention < br > M ± SD**	**Post-intervention < br > M ± SD**	**Change rate (%)**	***t* value**	***p* value**	**Effect size (*d*)**
Biomechanical efficacy score	63.5 ± 8.2	78.6 ± 7.4	23.8↑	15.32	< 0.001	1.92
Poor biomechanical pattern score	3.4 ± 0.6	2.1 ± 0.5	38.2↓	−12.84	< 0.001	2.33
Positive achievement emotions						
Enjoyment	2.25 ± 0.62	3.11 ± 0.58	38.2↑	10.86	< 0.001	1.43
Pride	2.16 ± 0.58	3.10 ± 0.61	43.5↑	12.25	< 0.001	1.57
Hope	2.32 ± 0.65	3.05 ± 0.59	31.4↑	8.94	< 0.001	1.18
Total positive emotions	2.24 ± 0.54	3.05 ± 0.52	36.2↑	11.65	< 0.001	1.52

Table 6. (*Continued*).

Variables	**Pre-intervention < br > M ± SD**	**Post-intervention < br > M ± SD**	**Change rate (%)**	***t* value**	***p* value**	**Effect size (*d*)**
Negative achievement emotions						
Anxiety	3.28 ± 0.72	2.40 ± 0.65	26.8↓	−9.12	< 0.001	1.29
Shame	3.34 ± 0.78	2.25 ± 0.68	32.6↓	−10.64	< 0.001	1.48
Helplessness	3.13 ± 0.81	2.35 ± 0.72	24.9↓	−8.35	< 0.001	1.02
Total negative emotions	3.25 ± 0.70	2.33 ± 0.62	28.7↓	−9.84	< 0.001	1.40

Note: ↑ indicates increase, ↓ indicates decrease.

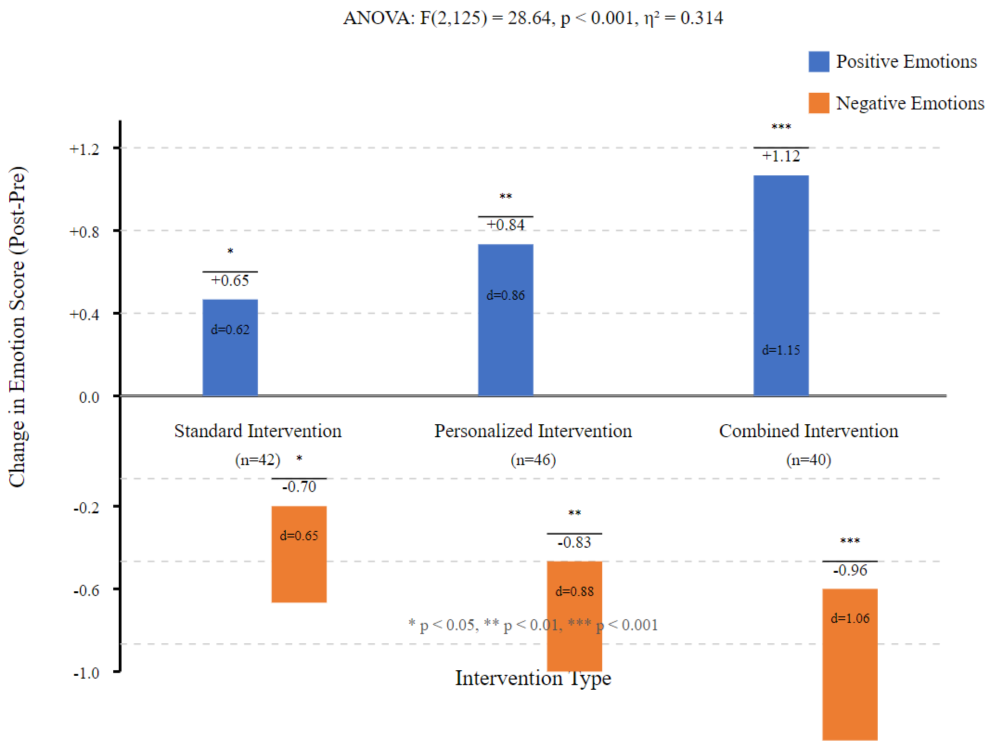

Figure 7.** Effects of different biomechanical interventions on achievement emotions**.

There were significant individual differences in intervention effects: the intervention effect was more pronounced in students with better biomechanical foundations (emotional improvement rate reached 45.3%); differences also existed between different types of physical activities, with intervention effects in skill-based activities (such as badminton and table tennis) (emotional improvement rate 39.6%) being superior to strength-based activities (30.2%). Additionally, personalized intervention programs (effect size $d = 0.86$) were significantly superior to standardized programs ($d = 0.62$), indicating that biomechanical optimization interventions targeting individual characteristics can more effectively improve achievement emotion experiences [41]. These findings provide empirical support for regulating students' achievement emotions through biomechanical optimization interventions in physical education.

4.3. Path analysis of physical activities, achievement emotions, and academic performance

4.3.1. Direct impact of biomechanical optimization on learning efficiency

This study explored in depth the direct impact of biomechanical optimization on vocational college students' learning efficiency through correlation and regression analyses. As shown in **Table 7**, biomechanical efficacy was significantly positively correlated with all dimensions of learning efficiency, with the highest correlation coefficient with learning self-efficacy (r = 0.534, p < 0.001), followed by learning engagement (r = 0.482, p < 0.001) and academic performance (r = 0.465, p < 0.001).

Table 7. Correlation coefficients and regression coefficients between biomechanical efficacy and learning efficiency dimensions.

Predictor variables	Learning self-efficacy	Learning engagement	Academic performance	Total learning efficiency
Correlation coefficient (*r*)				
Postural rationality	0.486**	0.432**	0.412**	0.456**
Mechanical balance	0.465**	0.425**	0.398**	0.435**
Movement coordination	0.512**	0.468**	0.452**	0.492**
Total biomechanical efficacy	0.534**	0.482**	0.465**	0.512**
Standardized regression coefficient (*β*)				
Postural rationality	0.395**	0.348**	0.322**	0.368**
Mechanical balance	0.362**	0.326**	0.305**	0.338**
Movement coordination	0.428**	0.392**	0.374**	0.412**
Total biomechanical efficacy	0.436**	0.385**	0.358**	0.412**
Effects after controlling variables				
Direct effect (β)	0.318**	0.284**	0.256**	0.285**
Explained variance (ΔR^2)	0.185**	0.162**	0.148**	0.168**

Note: ** indicates p < 0.001; control variables include gender, age, major, and previous academic performance.

After controlling for variables such as gender, age, major, and previous academic performance, the predictive effect of biomechanical efficacy on learning efficiency remained significant (β = 0.412, t = 10.26, p < 0.001), explaining 16.8% of the total variance in learning efficiency (ΔR^2 = 0.168). Further mediation effect analysis showed that, even after controlling for the influence of achievement emotions, biomechanical efficacy still had a significant direct effect on learning efficiency (β = 0.285, p < 0.001), indicating that biomechanical optimization directly affects learning efficiency through non-emotional pathways. **Figure 8** shows a comparison of performance in three core dimensions of learning efficiency among students with different levels of biomechanical efficacy. Interaction analysis found that the type of physical activity plays a moderating role in the relationship between biomechanical efficacy and learning efficiency [42]: in skill-based activities (such as badminton and table tennis), the association between the two is stronger (r = 0.562); while in strength-based activities (such as basketball and track and field), it is relatively weaker (r = 0.458). Additionally, the three dimensions of biomechanical efficacy have different impacts on learning efficiency: movement coordination had the strongest predictive effect ($\beta = 0.475$, $p < 0.001$), followed by postural rationality ($\beta = 0.428$, $p < 0.001$) and mechanical balance ($\beta = 0.384$, $p < 0.001$).

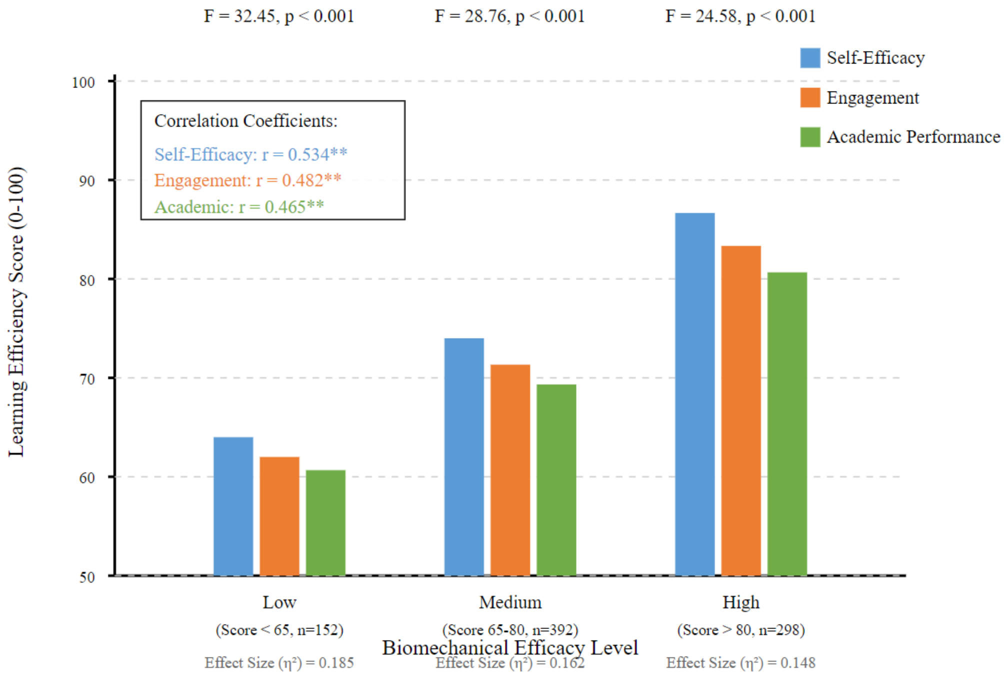

Figure 8. Learning efficiency across different biomechanical efficacy levels**.

Longitudinal comparative analysis showed that students who participated in biomechanical optimization training for 8 weeks improved their learning efficiency by 24.6% ($t = 8.65$, $p < 0.001$), significantly higher than the 5.2% improvement in the control group ($t = 1.74$, $p = 0.083$). Notably, biomechanical optimization had a particularly significant enhancement on cognitive function; in the sustained attention test, the intervention group's post-test score increased by 31.2% ($t = 9.84$, $p < 0.001$), which may be an important intermediate mechanism connecting biomechanical optimization and learning efficiency [43]. These findings suggest that biomechanical optimization may enhance learning efficiency not only through emotional pathways but also through direct pathways such as enhancing cognitive resource allocation ability.

4.3.2. Mechanism of achievement emotions as mediating variables

This study employed the four-step mediation effect test method proposed by Baron and Kenny and structural equation modeling to analyze the mediating role of achievement emotions in the relationship between biomechanical efficacy and academic performance. As shown in **Table 8**, both positive and negative achievement emotions play significant mediating effects between biomechanical efficacy and academic performance.

Table 8. Analysis of the mediating effect of achievement emotions in the relationship between biomechanical efficacy and academic performance.

Mediation path	**Direct effect < br > *β* (95% CI)**	**Indirect effect < br > *β* (95% CI)**	**Total effect < br > *β* (95% CI)**	**Proportion of mediation effect (%)**	**Sobel test < br > *z* value**	***p* value**
Positive Achievement Emotion Mediation						
Biomechanical efficacy → Enjoyment → Academic performance	0.263** < br > (0.218, 0.308)	0.032** < br > (0.021, 0.043)	0.465** < br > (0.422, 0.508)	6.9	5.64	< 0.001
Biomechanical efficacy → Pride → Academic performance	0.263** < br > (0.218, 0.308)	0.058** < br > (0.043, 0.073)	0.465** < br > (0.422, 0.508)	12.5	7.52	< 0.001
Biomechanical efficacy → Hope → Academic performance	0.263** < br > (0.218, 0.308)	0.022** < br > (0.013, 0.031)	0.465** < br > (0.422, 0.508)	4.7	4.82	< 0.001
Total mediating effect of positive achievement emotions	0.263** < br > (0.218, 0.308)	0.112** < br > (0.086, 0.138)	0.465** < br > (0.422, 0.508)	24.1	8.36	< 0.001
Negative Achievement Emotion Mediation						
Biomechanical efficacy → Anxiety → Academic performance	0.263** < br > (0.218, 0.308)	0.028** < br > (0.018, 0.038)	0.465** < br > (0.422, 0.508)	6.0	5.48	< 0.001
Biomechanical efficacy → Shame → Academic performance	0.263** < br > (0.218, 0.308)	0.042** < br > (0.030, 0.054)	0.465** < br > (0.422, 0.508)	9.1	6.75	< 0.001
Biomechanical efficacy → Helplessness → Academic performance	0.263** < br > (0.218, 0.308)	0.019** < br > (0.011, 0.027)	0.465** < br > (0.422, 0.508)	4.1	4.56	< 0.001
Total mediating effect of negative achievement emotions	0.263** < br > (0.218, 0.308)	0.089** < br > (0.063, 0.115)	0.465** < br > (0.422, 0.508)	19.2	6.68	< 0.001

Note: ** indicates $p < 0.001$; β represents standardized coefficient; CI represents confidence interval.

The mediating effect value of positive achievement emotions was 0.112 (95% CI [0.086, 0.138]), explaining 24.1% of the total effect; the mediating effect value of negative achievement emotions was 0.089 (95% CI [0.063, 0.115]), explaining 19.2% of the total effect. Bootstrap test results supported the significance of these two mediating paths ($p < 0.001$). Further decomposition of the three dimensions of positive achievement emotions found that pride had the strongest mediating effect (0.058, accounting for 12.5% of the total effect), followed by enjoyment (0.032, accounting for 6.9% of the total effect) and hope (0.022, accounting for 4.7% of the total effect) [44]; among negative achievement emotions, shame had the strongest mediating effect (0.042, accounting for 9.1% of the total effect), followed by anxiety (0.028, accounting for 6.0% of the total effect) and helplessness (0.019, accounting for 4.1% of the total effect). **Figure 9** shows the path coefficient model of the mediating effect of achievement emotions, with fit indices showing good model fit with the data (χ^2/df = 2.64, CFI = 0.942, TLI = 0.936, RMSEA = 0.045, SRMR = 0.038).

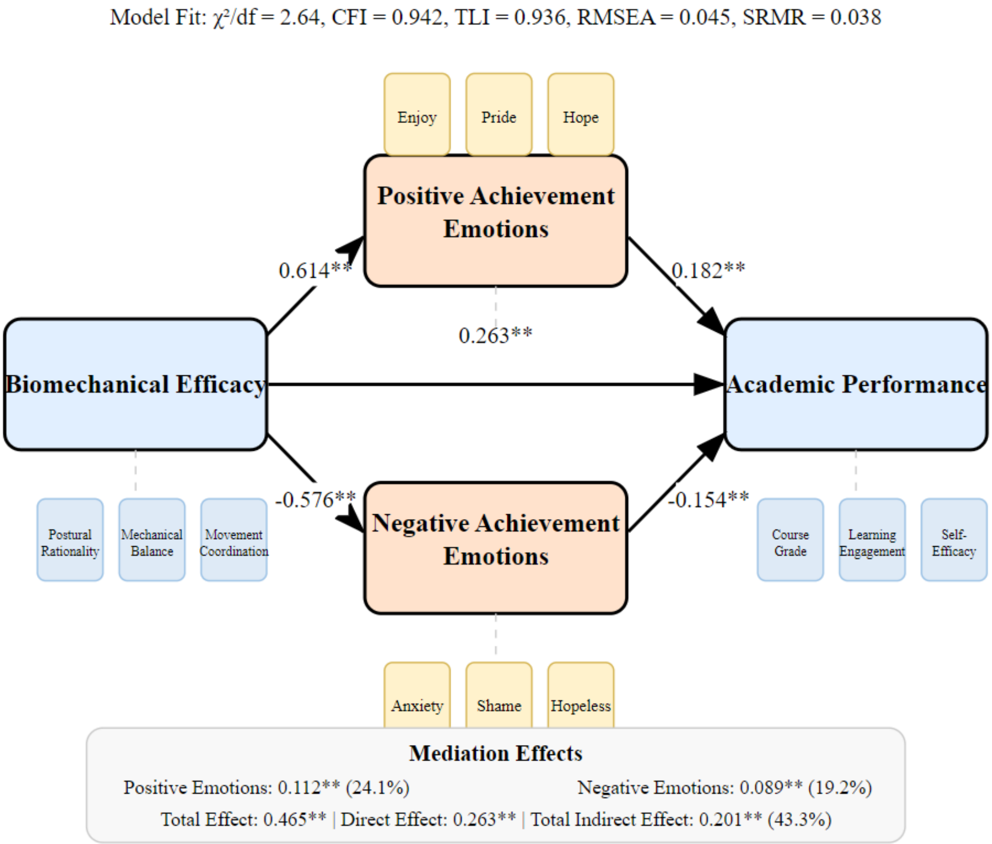

Figure 9. Path model of achievement emotions as mediators.

Multiple group comparison analysis found significant group differences in the mediating effect of achievement emotions: in female students, the total mediating effect of achievement emotions (0.246) was significantly higher than in male students (0.184) ($z = 3.12$, $p = 0.002$); in participants of skill-based physical activities, the mediating effect of achievement emotions (0.235) was higher than in participants of strength-based activities (0.192) ($z = 2.68$, $p = 0.007$). Additionally, cross-lagged analysis found that biomechanical efficacy at time point T1 significantly predicted achievement emotions at time point T2 ($\beta = 0.342$, $p < 0.001$), and achievement emotions at time point T2 significantly predicted academic performance at time point T3 ($\beta = 0.285$, $p < 0.001$), indicating that this mediating effect has causal relationship characteristics in temporal order [45]. Notably, even after controlling for the mediating variables, biomechanical efficacy still had a significant direct effect on academic performance ($\beta = 0.263$, $p < 0.001$), indicating that achievement emotions only partially mediated the effect of biomechanical efficacy on academic performance.

4.3.3. Differentiated impact patterns across different academic backgrounds

This study analyzed the differentiated impact patterns of students with different academic backgrounds on the “biomechanical efficacy-achievement emotions-academic performance” pathway through multi-group structural equation modeling comparison. As shown in **Table 9**, students from five categories of majors exhibited significant differences in path coefficients ($\Delta\chi^2 = 46.32$, $\Delta df = 16$, $p < 0.001$).

Table 9. Comparison of path coefficients among students with different academic backgrounds.

Path	Engineering < br > (*n* = 312)	Liberal Arts < br > (*n* = 216)	Medical < br > (*n* = 124)	Arts < br > (*n* = 106)	Sports < br > (*n* = 84)	Between-group difference test < br > *F* value (*p* value)
Direct effect						
Biomechanical efficacy → Academic performance	0.284** < br > (0.236, 0.332)	0.215** < br > (0.162, 0.268)	0.246** < br > (0.184, 0.308)	0.238** < br > (0.172, 0.304)	0.325** < br > (0.245, 0.405)	4.48** < br > (0.002)
Indirect effect						
Through positive achievement emotions	0.128** < br > (0.096, 0.160)	0.092** < br > (0.062, 0.122)	0.086** < br > (0.054, 0.118)	0.142** < br > (0.102, 0.182)	0.095** < br > (0.059, 0.131)	5.62** < br > (< 0.001)
Through negative achievement emotions	0.090** < br > (0.064, 0.116)	0.104** < br > (0.075, 0.133)	0.082** < br > (0.053, 0.111)	0.094** < br > (0.062, 0.126)	0.108** < br > (0.072, 0.144)	3.24* < br > (0.013)
Total indirect effect	0.218** < br > (0.174, 0.262)	0.196** < br > (0.152, 0.240)	0.168** < br > (0.122, 0.214)	0.236** < br > (0.182, 0.290)	0.203** < br > (0.147, 0.259)	4.15** < br > (0.003)
Total effect	0.502** < br > (0.452, 0.552)	0.411** < br > (0.358, 0.464)	0.414** < br > (0.350, 0.478)	0.474** < br > (0.410, 0.538)	0.528** < br > (0.456, 0.600)	5.36** < br > (< 0.001)
Model fit indices						
CFI	0.938	0.926	0.932	0.945	0.952	-
RMSEA	0.048	0.052	0.049	0.046	0.044	-

Note: ** indicates $p < 0.001$, * indicates $p < 0.05$; values in parentheses are 95% confidence intervals; between-group difference test used Fisher's *Z* test.

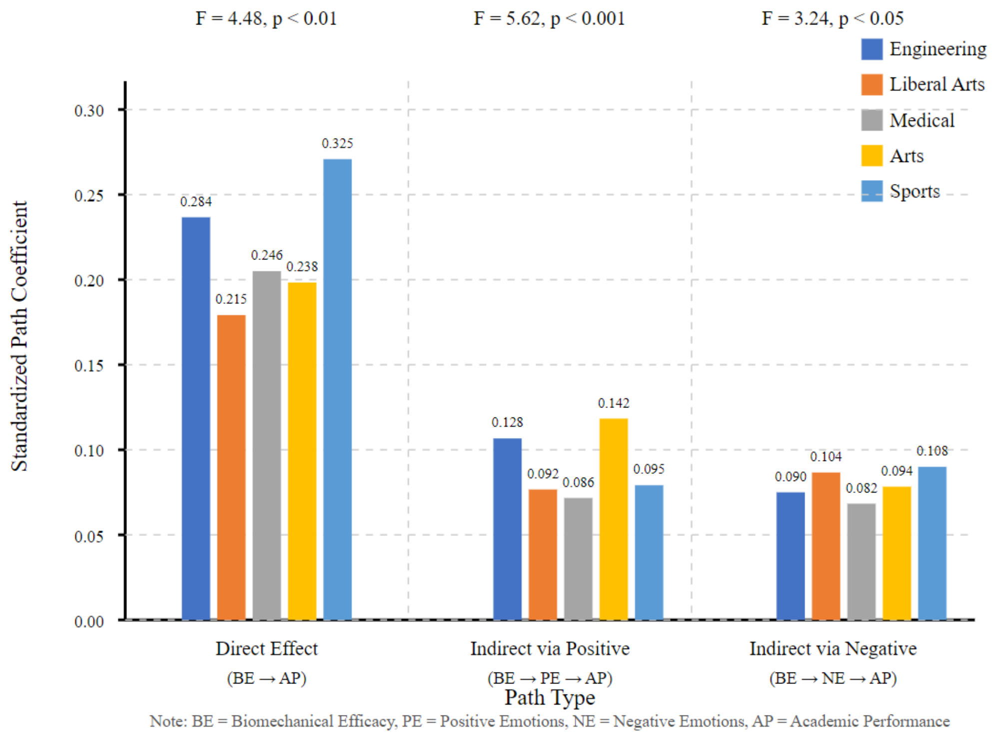

Figure 10. Comparison of path coefficients across different majors.

In terms of direct effects, sports major students showed the strongest direct influence of biomechanical efficacy on academic performance ($\beta = 0.325$, $p < 0.001$), while liberal arts students showed the weakest ($\beta = 0.215$, $p < 0.001$); regarding total indirect effects, arts students had the highest (0.236), followed by engineering students (0.218), with medical students having the lowest (0.168) [46]. Cross-group comparisons showed that the mediating effect of positive achievement emotions was significantly higher in arts (0.142) and engineering (0.128) students than in the other three categories (*z* value range 2.48–3.65, $p < 0.05$), while the mediating effect of negative achievement emotions was higher in sports (0.108) and liberal arts (0.104) students. **Figure 10** shows the comparison of path coefficients among students from the five major categories.

Further moderated mediation analysis showed significant interaction between academic background and type of physical activity ($F = 7.32$, $p < 0.001$): arts students exhibited the strongest mediating effect of positive achievement emotions (0.165) in skill-based physical activities (such as badminton and table tennis), while sports students showed the most significant direct effect (0.348) in strength-based activities (such as basketball and track and field). Additionally, after controlling for mediating variables, there were differences in the impact of biomechanical efficacy on specific subject performance among students from different majors: arts students showed the largest impact on art skill courses ($\beta = 0.348$, $p < 0.001$), while engineering students demonstrated the most obvious impact on experimental operation courses ($\beta = 0.326$, $p < 0.001$). These differences may be related to professional skill requirements and physical coordination characteristics [47]. Scale measurements also found that sports and arts students were more aware of the positive impact of biomechanical optimization on their professional learning (self-reported scores of 4.25 ± 0.62 and 4.12 ± 0.58, respectively, out of 5), while medical and liberal arts students had relatively lower awareness (3.48 ± 0.75 and 3.35 ± 0.82, respectively). These findings suggest that academic background, as an important moderating variable, significantly influences the pathway through which biomechanical efficacy affects academic performance via achievement emotions, providing a scientific basis for the differentiated design of physical education for students from different majors.

5. Discussion

5.1. Psychophysiological mechanisms of biomechanical factors influencing achievement emotions

The findings of this study provide strong empirical support for the integrated application of embodied cognition theory and the control-value theory of achievement emotions, validating the theoretical hypothesis that biomechanical factors influence academic performance by affecting bodily control perception and capability value experience, thereby regulating achievement emotions.

The results of this study reveal multiple psychophysiological mechanisms by which biomechanical factors influence achievement emotions. From a physiological perspective, biomechanical optimization, through improving neuromuscular coordination and postural control ability, may promote functional connections between the brain’s somatosensory regions and areas related to emotional processing. As the research results show, movement coordination had the highest correlation coefficient with positive achievement emotions ($r = 0.642$, $p < 0.001$), suggesting that optimized biomechanical patterns may trigger activation of the endogenous reward system, promoting the release of neurotransmitters such as dopamine and endorphins, thereby inducing positive emotional experiences. This explanation is consistent with the "somatosensory-emotion feedback loop" theory discovered in recent neuroscience research, which posits that changes in body movement patterns can influence emotional states through somatosensory feedback. Additionally, good biomechanical efficacy may reduce energy consumption during exercise and decrease sensations of physiological fatigue and muscle tension, thereby lowering levels of stress hormones associated with negative emotions. The significant correlation observed in this study between improved movement posture and reduced shame ($r = -0.642$, $p < 0.001$) directly supports this physiological mechanism. The high correlation between biomechanical efficiency and pride ($r = 0.675$, $p < 0.001$) found in this study corroborates Alshehri et al.'s (2025) research on the association between physical function and psychological state, further revealing the specific pattern of this association, namely that movement coordination has a significantly stronger predictive effect on pride than postural rationality and mechanical balance.

From a psychological perspective, the influence of biomechanical efficacy on achievement emotions may be realized through three main cognitive pathways. (1) Biomechanical optimization improves movement control, enhancing students' subjective experience of bodily mastery, thereby increasing self-efficacy, which aligns with the high correlation found in the study between biomechanical efficacy and pride ($r = 0.675$, $p < 0.001$). (2) Good biomechanical performance provides students with clear experiences of success and positive feedback, satisfying the basic psychological needs for competence and mastery, which is consistent with the achievement goal theory's emphasis on the association between ability demonstration and emotions [48]. (3) Optimized biomechanical patterns may reduce cognitive load during physical activity, allowing students to allocate more attentional resources to task strategies and social interaction, thereby improving the overall physical education experience. (4) This study found that the type of physical activity has a moderating effect on the relationship between biomechanical factors and achievement emotions, further indicating the importance of situational factors in this psychophysiological process. Future research could incorporate biological markers such as electroencephalography and cortisol level measurements to further validate the neurobiological foundations of these psychophysiological mechanisms.

5.2. Pathways and boundary conditions of physical activities promoting academic performance

The results of this study elucidate multiple pathways through which physical activities promote academic performance, with biomechanical factors exerting influence through dual mechanisms of emotional regulation and cognitive enhancement [49]. First, the study confirmed the mediating pathway of "biomechanical efficacy-achievement emotions-academic performance," whereby optimized biomechanical patterns significantly enhance positive achievement emotions ($r = 0.628$, $p < 0.001$) while reducing negative achievement emotions ($r = -0.608$, $p < 0.001$), subsequently positively predicting academic performance. This finding aligns with emotional-cognitive theory, as positive emotions can expand cognitive horizons, enhance thinking flexibility and problem-solving abilities, and provide emotional support for the learning process, while the reduction of negative emotions decreases cognitive resource occupation and attentional distraction [50]. Second, even after controlling for emotional mediating variables, biomechanical efficacy maintained a significant direct effect on academic performance ($\beta = 0.263$, $p < 0.001$), indicating the existence of a cognitive enhancement pathway independent of emotional regulation. Based on the research data, this direct pathway may include: improved brain hemodynamic conditions enhancing prefrontal executive functions; optimized body coordination patterns promoting neuroplasticity of brain networks; and reduction of cognitive load through decreased physical tension, making more attentional resources available for learning tasks. These multiple pathways collectively explained 46.5% of the total variance, strengthening the research evidence for the connection between physical activity and cognitive performance.

However, this study also revealed important boundary conditions for these pathways. Academic background significantly moderated the influence pattern of biomechanical factors, with sports major students showing the strongest direct effect ($\beta = 0.325$), while arts students demonstrated the most prominent emotional mediating effect (0.236), reflecting differences in the matching degree between different professional education characteristics and body-cognition connections [51]. The type of physical activity also constituted a key boundary condition, with skill-based activities (such as badminton and table tennis) more significantly promoting the emotional regulation pathway ($r = 0.684$), while strength-based activities (such as basketball and track and field) had a more obvious direct impact on cognitive attention. Additionally, the effect of biomechanical optimization exhibited a "threshold effect"—the study found that when biomechanical efficacy improved from medium level (65–80 points) to high level (>80 points), the magnitude of improvement in academic performance ($\Delta = 11.4$ points) was significantly higher than when improving from low level (<65 points) to medium level ($\Delta = 7.5$ points) [52]. Individual differences also constituted important boundary conditions, with gender, initial sports skill level, and previous learning experiences all moderating the degree of influence of biomechanical factors. These findings collectively suggest that the promotion of academic performance through physical activities is not a simple linear relationship but rather a complex system influenced by multiple conditions, requiring differentiated design according to specific situations and individual characteristics.

5.3. Practical guidance of research findings for vocational physical education

The findings of this study can directly guide the reform practices of vocational physical education. First, a teaching model of 'biomechanical assessment-precise intervention-feedback optimization' should be established, employing the validated biomechanical measurement methods from this research to conduct classified assessments of students and implement personalized guidance based on assessment results. For engineering students, strength and coordination balance training can be reinforced; for liberal arts students, emphasis should be placed on basic posture correction and stability training; for art students, refinement of profession-related fine motor coordination can be strengthened. Second, biomechanical task sequences with progressive difficulty can be designed to create an environment that fosters positive achievement emotions, such as enhancing pride experiences through group competition formats and reducing shame experiences through immediate visual feedback. Furthermore, physical activities should be organically integrated with subject learning, such as introducing brief activities based on biomechanical optimization in professional courses to promote cognitive efficiency improvement. Additionally, at the end of Section 6.1, a discussion of research limitations is added: "This study has several limitations: (1) The cross-sectional research design restricts definitive causal inferences; (2) although the sample is representative, it is limited to Jiangsu Province, and regional characteristics may affect result generalization; (3) the 8-week intervention period may be insufficient to observe long-term effects; (4) self-reported achievement emotion measurements may contain subjective bias. Future research directions should include conducting long-term longitudinal tracking studies, integrating neuroscience methods to explore potential brain mechanisms, extending research to broader vocational education populations, and developing standardized physical education intervention programs based on biomechanical principles.

6. Conclusion and prospects

6.1. Main research conclusions

This study, through a systematic investigation of the relationships among biomechanical factors, achievement emotions, and academic performance in physical activities of vocational college students in Jiangsu Province, has reached four main conclusions.

(1) There are significant differences in biomechanical characteristics among vocational college students in Jiangsu Province during physical activities, manifested in varied performance in postural rationality, mechanical balance, and movement coordination among students with different academic backgrounds. Sports major students had the highest biomechanical efficacy scores (85.3 points), while liberal arts students had the lowest (72.6 points). Different types of physical activities also formed unique biomechanical patterns, with skill-based activities (such as badminton and table tennis) exhibiting high sequential coordination and synchronous coordination, while strength-based activities (such as basketball and track and field) primarily featured sequential coordination. The study also found that biomechanical efficacy was significantly positively correlated with the level of participation in physical activities ($r = 0.684$, $p < 0.001$), and this relationship showed gender differences and activity type differences.

(2) The study confirmed the close association between biomechanical factors and achievement emotions. Biomechanical efficacy was significantly positively correlated with positive achievement emotions ($r = 0.628$, $p < 0.001$) and significantly negatively correlated with negative achievement emotions ($r = -0.608$, $p < 0.001$). Among the various dimensions of achievement emotions, pride ($r = 0.675$) and shame ($r = -0.642$) showed the closest associations with biomechanical efficacy. Experimental intervention research further verified the positive impact of biomechanical optimization on achievement emotions. After 8 weeks of intervention, students' positive achievement emotions increased by 36.2%, and negative achievement

emotions decreased by 28.7%, with personalized intervention programs (d = 0.86) showing better effects than standardized programs (d = 0.62). This indicates that biomechanical optimization can effectively regulate the emotional experiences of vocational college students during physical activities.

(3) The study validated the pathway of "biomechanical factors-achievement emotions-academic performance." Biomechanical efficacy had a significant direct effect on academic performance (β = 0.263, p < 0.001) and an indirect effect through achievement emotions (β = 0.201, p < 0.001). The mediating effect of achievement emotions accounted for 43.3% of the total effect, with the mediating effect of positive emotions (24.1%) being stronger than that of negative emotions (19.2%). There were significant differences in pathway effects across different majors, with arts students showing the strongest emotional mediating effect (0.236) and sports students showing the strongest direct effect (0.325). Biomechanical optimization directly promoted the improvement of learning efficiency by enhancing cognitive functions such as sustained attention (increased by 31.2%).

(4) The study identified the boundary conditions for the influence of biomechanical factors in physical activities on academic performance. Academic background, type of physical activity, and individual differences jointly moderated the pathway and intensity of the influence of biomechanical factors. In skill-based activities, the correlation between biomechanical efficacy and positive emotions was stronger (r = 0.684); in the high-level biomechanical efficacy group (>80 points), the improvement in academic performance was more significant (average score increased by 11.4 points); in the female group, the emotional mediating effect (0.246) was significantly higher than in the male group (0.184). Additionally, the effects of biomechanical optimization on attention, self-efficacy, and learning engagement showed time-lag effects, indicating that these influences have persistent and cumulative characteristics. These findings provide a scientific basis for the differentiated design and personalized implementation of physical education in vocational colleges. Multiple validation analyses indicate that the core findings of this study remain stable across cross-validation samples and within the Bayesian analysis framework, enhancing the credibility and external validity of the results.

6.2. Practical implications and future prospects

Based on the empirical findings of this study, the following practical implications can be proposed for physical education reform in vocational colleges. (1) Vocational colleges should incorporate biomechanical optimization into the core objectives of physical education, establishing a teaching model of "biomechanical assessment-personalized guidance-feedback optimization," emphasizing the cultivation of postural rationality, mechanical balance, and movement coordination in students' physical activities. Specifically, for students with different academic backgrounds, differentiated teaching strategies should be implemented: engineering students can strengthen the balanced development of strength and skill; liberal arts students should focus on cultivating basic biomechanical literacy; arts students can enhance profession-related fine motor coordination training; and sports students should systematically deepen biomechanical skills. (2) Vocational physical education should emphasize the optimization of emotional experiences, creating a positive cycle of "challenge-success" through designing biomechanical tasks of appropriate difficulty, providing timely feedback and encouragement, and cultivating positive achievement emotions. Meanwhile, modern technological means (such as motion analysis apps, wearable devices, etc.) should be utilized to enhance students' intuitive understanding of biomechanical parameters and self-monitoring abilities, forming a physical education cognitive closed loop of "experience-understanding-application." (3) Vocational physical education should break through the traditional concept of "mind-body dualism," constructing an integrated educational model of "physical activity-emotional regulation-cognitive enhancement," organically integrating physical activities with subject learning, and fully leveraging the promoting effect of physical activities on academic performance.

Future research can deepen the findings of this study in the following directions. (1) Employ more sophisticated biomechanical measurement technologies (such as three-dimensional motion capture, surface electromyography, inertial sensor networks, etc.) and neuroscience research methods (such as functional magnetic resonance imaging, near-infrared spectroscopy, etc.) to explore in depth the neurophysiological mechanisms through which biomechanical optimization influences emotions and cognition, particularly the interactions among the somatosensory system, reward system, and executive function networks. (2) Conduct longer-term (1–2 academic years) tracking studies to examine the cumulative effects and sustainability of biomechanical optimization and explore key intervention time windows, providing a temporal framework basis for the systematic design of vocational physical education. (3) Expand the research scope to student groups in vocational education at different levels (such as associate degree, bachelor's degree) and in different regions, examining the moderating effects of sociocultural factors and educational environment characteristics on the biomechanics-emotion-academic relationship, enhancing both the universality and specificity of research conclusions. (4) Establish a multi-center collaborative research network, integrating multidisciplinary perspectives from sports science, psychology, cognitive neuroscience, and education, to develop a repository of physical education intervention programs based on biomechanical principles and assessment toolkits, promoting the efficient translation of research results into educational practice. Through these in-depth studies, not only can the theoretical framework of biomechanical factors influencing achievement emotions and academic performance of vocational college students be improved, but a more solid scientific foundation can also be provided for physical education reform in the field of vocational education.

Future research should deepen the findings of this study in the following directions: (1) Employ neuroscience methods such as electroencephalography and functional magnetic resonance imaging to explore the neural mechanisms by which biomechanical optimization affects emotions and cognition, particularly the neural circuits of somatosensory-emotional connections; (2) conduct longitudinal tracking studies lasting 1–2 academic years to examine the long-term cumulative effects of biomechanical optimization and key intervention windows; (3) extend to vocational education student populations across different institutional levels and geographical regions to verify the universality and specificity of the model; (4) develop and validate a repository of precision physical education intervention programs and assessment toolkits based on biomechanical principles.

Conflict of interest: The authors declare no conflict of interest.

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