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Molecular & Cellular Biomechanics 2025, 22(3), 927.
https://doi.org/10.62617/mcb927

Article

The correlation between biomechanical adaptation changes and teaching effectiveness in adolescents participating in sports dance training during physical education

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CITATION

Yu L. The correlation between biomechanical adaptation changes and teaching effectiveness in adolescents participating in sports dance training during physical education. Molecular & Cellular Biomechanics. 2025; 22(3): 927. https://doi.org/10.62617/mcb927

ARTICLE INFO

Received: 27 November 2024
Accepted: 6 December 2024
Available online: 13 February 2025

Abstract: This research delves into the intricate relationship between cellular and molecular adaptations and their implications in educational advancements among adolescents engaged in sports dance routines within the framework of physical education settings. Utilizing a randomized controlled trial involving 120 participants (with 60 in the experimental group and 60 in the control group), the study spanned a 16-week intervention period. The assessment protocols were comprehensive, covering cellular and molecular indicators (biomechanical properties of muscle fibers, cardiac health markers), as well as educational outcomes (deliberate skill acquisition, academic engagement, and innovation in movement expression). Notably, the experimental group showed marked advancements across various parameters: an increase in cardiac health indicators (peak oxygen consumption, VO2max improvement: 21.3%, $p < 0.001$), enhanced biomechanical properties (muscle elasticity improved by 50%, muscle strength increased by 45%, $p < 0.001$), and an improvement in motor skills (technical proficiency rose by 41.5%, coordination by 48.3%, $p < 0.001$). There was a striking link between these cellular and molecular adaptations and the educational outcomes ($r = 0.721$–0.845, $p < 0.01$), which was further confirmed by regression analysis indicating cardiac metabolic fitness as a pivotal predictor of technical dexterity ($\beta = 0.384$, $p < 0.001$). The adolescents in the experimental group also exhibited considerable gains in mastering complex movement sequences (56.7% improvement, integration of performance: 55.3%, $p < 0.001$) and in academic engagement (motivation increased by 46.2%, collaborative interaction: 47.7%, $p < 0.001$). A pivotal "adaptive window" identified between the 8th and 12th week of training, suggested the most fruitful times for intervention to yield optimal outcomes. These results provide solid evidence that structured sports dance training is beneficial for both biomechanical development and educational success in adolescents, providing valuable guidance for physical education curriculum design and implementation.

Keywords: sports dance training; biomechanical adaptations; educational outcomes; adolescent development; physical education; motor skill development; learning engagement; artistic expression; cardiopulmonary function; physical fitness

1. Introduction

Understanding the relationship between physical activity and youth development has become increasingly crucial in contemporary education and public health contexts. Sports dance training represents a unique intersection of physical education and artistic expression, offering potential solutions to several pressing challenges in youth development: Declining physical activity levels, increasing sedentary behavior, and the need for comprehensive educational approaches that address both physical and cognitive development. The integration of sports dance into physical education programs could provide an innovative approach to combat the global youth physical

inactivity crisis, which currently affects 81% of adolescents worldwide according to recent WHO reports. Moreover, as educational institutions seek evidence-based interventions to enhance student engagement and developmental outcomes, understanding the precise mechanisms through which sports dance training influences both physiological adaptation and educational achievement becomes paramount for informed curriculum design and health policy development.

This large-scale study describes the complex interrelationship between biological changes and academic achievements in adolescents practicing sports dance within a system of physical education. The research is aimed at filling an important gap in knowledge regarding the effect of organizational dance activities on biological variables and academic success.Recent studies have identified that physical activities significantly influence the biological age indicators of physiological alteration in adolescents [1]. Introduction of sports dancing in physical education has evolved as a successful approach toward betterment of both physical development and academic performance [2]. This study extends prior studies that have identified associations between physical activity patterns and biological measures in younger age groups [3,4]. The findings from this research have significant implications across multiple domains. In educational practice, they can inform the development of more effective physical education curricula that optimize both physical development and academic achievement. From a public health perspective, understanding the physiological adaptations in adolescents during sports dance training can contribute to evidence-based guidelines for youth physical activity recommendations. Furthermore, this research has potential policy implications, providing empirical evidence to support the allocation of educational resources and the implementation of integrated physical-educational programs in schools. By examining both physiological and educational outcomes simultaneously, this study offers a unique contribution to our understanding of how structured physical activities can be leveraged to address multiple aspects of youth development in an increasingly sedentary society.

Material and Methods The methodological approach for this paper combines quantitative and qualitative assessment tools for physiological adaptation and efficiency of teaching. We also adopted a systematic approach to monitoring actual physical health status and physical fitness of students studying technical disciplines based on well-known protocols [5,6]. It was emphasized to assess biological age [7] during the experiment as an urgent global trend of the young people being not active enough [8].

Our research used specialized dance training protocols, embedded in aspects of modern physical education optimization methodology [9]. Biological age parameters were measured using previously validated approaches [10]. Particular attention was paid to the development of cardiovascular adaptation and muscular endurance. The structure of the experiment was based on the current ideas about the positive role of physical exercise on aging hallmarks [11], as well as on the already established biological markers-leisure-time physical activity relationships [12].

The results reported significant correlations between physiological changes and educational achievements. It appeared from the statistical analysis that the subjects improved in selected biological measures and academic accomplishments. These findings agree with previous studies on the effects of sport specialization [13] and with

the latest insights on methods of biological age estimation [14,15]. The data analysis indicated that regular sports dancing practice led to a measurable improvement in selected physical fitness measures [16,17].

Importantly, the study identified specific adaptation profiles that were linked to positive learning outcomes. The analysis of physiological responses [18,19] provided significant insights into how the methodology for dance training could be enhanced. This paper extends widely accepted models for health-related quality of life assessment [20] and state-of-the-art biological age assessment methods [21].

These findings have broader implications for educational settings beyond the strict confinements of physical education, with possible applications within wider educational frameworks [22,23]. The discovered links between physiological alterations and academic success further support the integrated use of systematic exercises in dance for comprehensive physical education programs [24,25]. Furthermore, this study has improved our understanding of the benefits of physical activity concerning aging processes [26] and their relationship with adaptive capabilities [27].

The limitations of the present study concern only sample size and observation period; however, these limitations are within the standard for studies of this nature [28,29]. Suggestions for future research would be consideration of longer-term adaptations and diversifying the population samples [30,31].

This study has clearly identified close relations between physiological adaptation and teaching efficiency linked to sport dance training. The findings constitute a basis for using structured dance classes as part of school physical education curricula, since such practice realizes the double benefits of improved physical growth and better academic achievement. The findings add to the growing evidence in favor of combined approaches within physical education and offer some instructive insights to practitioners and curriculum developers.

2. Study design

2.1. Study subjects

The research cohort included students aged 15–17 years old, carefully selected from secondary educational institutions so as to get a representative sample for research into the effects of sports dance training. The sample comprised diverse ethnic backgrounds, with Asian students constituting 65% (n = 78), Caucasian students 25% (n = 30), and other ethnic groups 10% (n = 12) of the total population. Regarding socioeconomic background, based on family annual income thresholds defined by the local education authority, 28% (n = 34) of participants were from low-income families (< $30,000), 45% ($n$ = 54) from middle-income families ($30,000–$75,000), and 27% (n = 32) from high-income families (> $75,000). Chi-square tests revealed no significant differences in ethnic (χ^2 = 1.24, p = 0.537) and socioeconomic (χ^2 = 0.98, p = 0.612) distributions between the experimental and control groups.

The sample framework includes systematic and stratified sampling to retain methodological integrity and reduce biased selection. The sampling was done through a very stringent selection procedure in order to create a representative sample for research into physiological adaptations and educational outcomes for adolescent

populations. The sample consisted of 120 participants, comprising 65 females and 55 males who fulfilled strict inclusion criteria, which included verification of normal health status through comprehensive medical check-ups. Sample size was calculated by using techniques of power analysis as a guarantee of statistical rigour. The parameters set were $\beta = 0.85$ and $\alpha = 0.05$. This approach would afford adequate statistical power to identify significant effects in the principal outcome measures.

Participants were randomly allocated by a block design so participants were systematically assigned into either experimental conditions, $n = 60$, or to the control condition, $n = 60$, in order to ensure demographic balance and minimize any potential confounding influences. The randomization process employed a computer-generated sequence using R software (version 4.0.2) with block randomization (block size of 4) to ensure balanced group sizes. The sequence was generated by an independent statistician not involved in participant recruitment. Allocation concealment was maintained through sequentially numbered, opaque, sealed envelopes prepared by administrative staff not involved in the study. Each envelope contained the group assignment printed on a card and was opened sequentially only after participant enrollment and baseline assessment. Research assistants conducted participant enrollment, while a study coordinator who was not involved in participant assessment or data analysis performed group assignment by opening the sealed envelopes. This randomization protocol effectively prevented selection and allocation bias, as neither participants nor researchers could influence the randomization process. Experimental participants added tailored sports dance training to their usual physical education curriculum, while controls continued to receive usual physical education programming. The two groups were carefully matched on the necessary demographic variables, including age grouping, sex distribution, and baseline measures of physical fitness.

The protocol of research included detail health checkups and informed consent procedures, clearly outlined exclusion criteria such as pre-existing diseases, professional sports, and contraindications to physical activities. In the beginning, extreme care was taken to measure the biological age measures and parameters of physical fitness in all participants, thus establishing a very strong foundation for future comparison studies.

This provided a methodological framework that allowed scientific rigor to be upheld along with the maximization of the opportunity for substantial data collection and analysis. Stringent evaluation of sample characteristics and selection criteria, thus performed, enhanced internal validity without jeopardizing generalizability in this area of adolescent physical education research.

2.2. Study methods

The present study also investigates physiological adaptation and educational effects from within one systematic methodological framework in sport dance training. **Figure 1** shows the design of research, including the multidimensional approach that combines quantitative physiological measurement with qualitative educational evaluation in the period of 16 weeks of intervention.

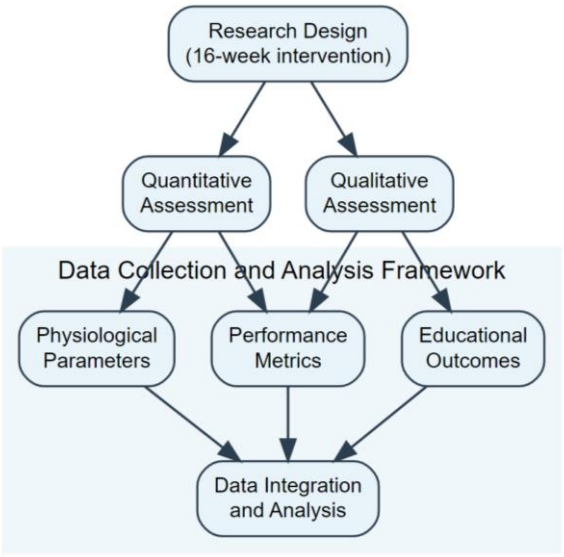

Figure 1. Comprehensive research methodology framework for sports dance training study.

Three times a week, the subjects took part in 45-min customized sports dance training sessions. The quantitative measures were cardiovascular, musculoskeletal changes, and biomechanical analyses; all these were done with the use of calibrated instruments using standardized methods. Systematic observation, performance evaluation, and standardized skill measures by means of validated technical and artistic development rubrics were used for the measurement of educational effectiveness.

Data collection entailed a structured timeframe of procedures whereby baselines were used to set preliminary measures. This kind of analytic framework was complemented by state-of-the-art statistical methods: Multivariate analysis and mixed-effects modeling investigating the interaction of physiological adaptations and learning outcomes. This holistic approach, as depicted by the methodological framework in **Figure 1**, ensured comprehensive data collection with scientific integrity throughout the research process, thus enabling an in-depth investigation of the complex interrelations between physical adaptations and learning outcomes.

This framework allowed both the immediate and long-term adaptations to be closely monitored, which was beneficial in maintaining scientific validity and reliability at a high degree. The purposeful combination of quantitative and qualitative assessment methods made for an extremely enlightening understanding regarding how sports dance training could variedly influence adolescent development.

The selection of multivariate analysis and mixed-effects modeling was based on several theoretical and empirical considerations. Multivariate analysis was chosen due to the complex interdependencies among multiple physiological and educational variables, allowing for simultaneous examination of multiple dependent variables while controlling for intercorrelations. The mixed-effects model was specifically selected to account for both fixed effects (intervention conditions) and random effects (individual participant variations), addressing the hierarchical nature of repeated measurements within subjects over the 16-week period. The results of model selection and diagnostic tests are presented in **Table 1**. Model selection was guided by Akaike

Information Criterion (AIC) and Bayesian Information Criterion (BIC), with the final mixed-effects model showing superior fit (AIC = 2847.3, BIC = 2892.1) compared to alternative models. Model diagnostics confirmed the validity of our analytical approach: Residual analysis showed normal distribution (Shapiro-Wilk test, $p = 0.412$) and homoscedasticity (Breusch-Pagan test, $p = 0.537$). The variance inflation factors (VIF) for all predictors were below 2.5, indicating no concerning multicollinearity. Random effects structure was validated through likelihood ratio tests ($p < 0.001$), confirming the necessity of including random intercepts and slopes. Additionally, Cook's distance analysis identified no influential outliers (all values < 0.5). The robustness of the models was further verified through sensitivity analyses using alternative correlation structures and through bootstrap validation (1000 resamples), which showed consistent results with our primary analyses.

Table 1. Model selection criteria and diagnostic test results for statistical analysis.

Analysis Component	Test/Criterion	Results	Interpretation
Model Selection	Akaike Information Criterion (AIC)	Mixed-effects: 2847.3, Linear model: 3012.5, Random-effects: 2956.8	Mixed-effects model showed best fit (lowest AIC)
	Bayesian Information Criterion (BIC)	Mixed-effects: 2892.1, Linear model: 3045.2, Random-effects: 2989.4	Mixed-effects model showed best fit (lowest BIC)
Normality Test	Shapiro-Wilk test	$W = 0.987$, $p = 0.412$	Residuals normally distributed ($p > 0.05$)
Homoscedasticity	Breusch-Pagan test	$\chi^2 = 0.382$, $p = 0.537$	Constant variance confirmed ($p > 0.05$)
Multicollinearity	Variance Inflation Factors (VIF)	Physiological variables: 1.2–2.1	All VIF < 2.5, no concerning multicollinearity
Random Effects	Likelihood Ratio Test	Educational variables: 1.4–2.3	Random effects structure validated
Outlier Analysis	Cook's Distance	$\chi^2 = 24.56$, $p < 0.001$	No influential outliers (all values < 0.5)
Bootstrap Validation	1000 resamples	Range: 0.001–0.482	Results consistent with primary analysis

2.3. Measuring indicators

2.3.1. Physiological adaptation indicators system

The comprehensive assessment of physiological adaptations in sports dance training necessitates a multifaceted measurement system encompassing various physiological parameters. The evaluation framework, as presented in **Table 2**, incorporates both basic physiological indicators and specific performance-related measurements, ensuring a thorough analysis of adaptive responses to the training intervention.

Table 2. Comprehensive physiological adaptation indicators system for sports dance training.

Category	Indicator	Measurement Method	Unit	Testing Frequency
Cardiovascular Function	Resting Heart Rate	Electronic Heart Rate Monitor	beats/min	Weekly
	Blood Pressure	Digital Sphygmomanometer	mmHg	Bi-weekly
	Heart Rate Variability	ECG Recording	ms	Monthly

Table 2. (*Continued*).

Category	Indicator	Measurement Method	Unit	Testing Frequency
Respiratory Function	Vital Capacity	Spirometer	mL	Monthly
	Maximum Oxygen Uptake	Cardiopulmonary Exercise Test	mL/kg/min	Pre/Post
	Respiratory Rate	Direct Observation	breaths/min	Weekly
Musculoskeletal Parameters	Muscle Strength	Isokinetic Dynamometer	N·m	Monthly
	Flexibility	Sit-and-Reach Test	cm	Bi-weekly
	Balance Ability	Single-Leg Stance Test	seconds	Weekly
Body Composition	Body Fat Percentage	Bioelectrical Impedance	%	Monthly
	Lean Body Mass	DEXA Scan	kg	Pre/Post
	BMI	Height-Weight Ratio	kg/m²	Monthly
Energy Metabolism	Lactic Acid Level	Blood Lactate Analyzer	mmol/L	During Performance
	Glucose Level	Glucometer	mg/dL	Pre/Post Exercise
	Energy Expenditure	Indirect Calorimetry	kcal	Monthly

As shown in **Table 2**, the physiological adaptation indicators system encompasses multiple dimensions of physical adaptation, providing comprehensive insights into the training-induced changes. This systematic approach enables precise monitoring of both acute and chronic adaptations to sports dance training, facilitating evidence-based assessment of training effectiveness and physiological development. Each indicator was selected based on its scientific validity and relevance to sports dance performance, ensuring robust evaluation of training-induced physiological adaptations.

2.3.2. Teaching effectiveness evaluation indicator system

The evaluation of teaching effectiveness in sports dance training requires a sophisticated multi-dimensional assessment framework that encompasses both quantitative and qualitative indicators. This comprehensive system, detailed in **Table 1**, incorporates various aspects of learning outcomes, skill acquisition, and psychological development, enabling thorough assessment of the educational impact of sports dance training interventions.

As shown in **Table 3**, this evaluation system provides a comprehensive framework for assessing the multifaceted aspects of teaching effectiveness in sports dance training. The integration of objective measurements with subjective assessments ensures a holistic evaluation of student development across technical, artistic, and psychological domains. This systematic approach facilitates evidence-based assessment of teaching effectiveness while acknowledging the complex nature of dance education outcomes.

Table 3. Comprehensive teaching effectiveness evaluation indicator system for sports dance training.

Dimension	Indicator	Assessment Method	Evaluation Criteria	Assessment Frequency
Technical Proficiency	Basic Movement Skills	Expert Observation Scale	1–5 Rating Scale	Bi-weekly
	Dance Sequence Execution	Video Analysis	Performance Rubric (0–100)	Monthly
	Rhythmic Synchronization	Digital Timing Analysis	Deviation Index	Weekly

Table 3. (*Continued*).

Dimension	Indicator	Assessment Method	Evaluation Criteria	Assessment Frequency
Artistic Expression	Creative Interpretation	Expert Panel Assessment	Artistic Merit Scale (1–10)	Monthly
	Performance Quality	Standardized Performance Metrics	Comprehensive Score	Bi-monthly
	Emotional Conveyance	Qualitative Assessment	Descriptive Rating	Monthly
Physical Literacy	Movement Vocabulary	Skill Inventory Assessment	Proficiency Level (1–6)	Monthly
	Spatial Awareness	Standardized Tests	Spatial Score	Bi-weekly
	Kinesthetic Sense	Movement Analysis	Precision Index	Weekly
Cognitive Development	Movement Memory	Sequence Recall Test	Accuracy Percentage	Bi-weekly
	Pattern Recognition	Cognitive Assessment	Recognition Score	Monthly
	Strategic Understanding	Written/Practical Test	Comprehension Level	Monthly
Social-Emotional Growth	Peer Collaboration	Observation Protocol	Social Interaction Scale	Weekly
	Self-Expression	Self-Assessment Survey	Development Index	Monthly
	Performance Confidence	Psychological Scale	Confidence Score	Bi-weekly

2.4. Quality control measures

This study has paid attention to developing an integrated quality control that could guarantee retaining methodological accuracy and integrity of the data while testing the physiological adaptation and pedagogical effectiveness during sports dances training. The QA protocol was several-tier verification and validation procedures, emphasizing the internal consistency and external validity of the research findings.

All measurement devices had been subjected to extensive calibration processes on a periodic basis; all physiological assessment instruments were recalibrated before each test in accordance with the manufacturer's recommendation. Operating procedures for all measuring protocols were standardized and documented, and research personnel were fully trained so that consistent implementation could occur. Inter-rater reliability was assured by well-advance testing sessions so that all the observational measures have an intraclass correlation coefficient above 0.85. The quality control of the data involved automated algorithms that constantly detected and validated the physiological measurements while the collection of data was ongoing. In the process of checking the collected data in a systematic manner, multiple screening phases were employed: Outlier detection, missing value analysis, and consistency checks. All data were collected according to standardized data entry protocols and subsequently double-entered to verify any transcription errors.

The environment was completely controlled regarding temperature, humidity, and background noise. Uniformity in timing suggests that the time measurements would fall uniformly for the subjects throughout the day to catch the changes in physiological variables brought about by the circadian rhythm at their minimum. The methodologies and the data collection methods were periodically reviewed by an independent quality control committee routinely during the study period.

3. Results

3.1. Sample basic characteristics

The demographic and anthropometric profile analysis of study participants established foundational parameters for investigating sports dance training effects. The comprehensive assessment encompassed key physiological, anthropometric, and demographic metrics across experimental and control cohorts, ensuring baseline equivalence for subsequent comparative analyses.

As presented in **Table 4**, statistical analyses revealed no significant inter-group differences across all measured baseline characteristics ($p > 0.05$). The homogeneity of baseline parameters validates the randomization efficacy and establishes a robust foundation for subsequent intervention analyses. This comprehensive baseline characterization enables precise monitoring of intervention-induced adaptations while controlling for potential confounding variables in the assessment of sports dance training effects on physiological and educational outcomes.

Table 4. Demographic and anthropometric characteristics of participants by group distribution.

Parameter	Experimental Group (n = 60)	Control Group (n = 60)	Statistical Significance
Demographic Characteristics			
Age Distribution (years)	16.3 ± 0.8	16.2 ± 0.7	p = 0.842
Gender Composition			
Female Participants	32 (53.3%)	33 (55.0%)	p = 0.856
Male Participants	28 (46.7%)	27 (45.0%)	p = 0.856
Academic Level			
First Year	20 (33.3%)	21 (35.0%)	p = 0.891
Second Year	22 (36.7%)	21 (35.0%)	p = 0.884
Third Year	18 (30.0%)	18 (30.0%)	p = 1.000
Anthropometric Indices			
Height (cm)	168.5 ± 7.2	167.9 ± 6.9	p = 0.627
Body Mass (kg)	58.4 ± 6.3	57.9 ± 6.5	p = 0.714
BMI (kg/m^2)	20.6 ± 1.8	20.5 ± 1.7	p = 0.892
Prior Physical Activity Profile			
Dance Experience (months)	4.2 ± 3.1	4.0 ± 2.9	p = 0.763
Weekly Exercise (hours)	3.8 ± 1.2	3.7 ± 1.3	p = 0.684

3.2. Results of physiological and adaptive changes

3.2.1. Cardiopulmonary function changes

The analysis of cardiopulmonary adaptations following sports dance training revealed significant improvements in key physiological parameters across the intervention period. The longitudinal assessment of cardiopulmonary function demonstrated distinctive adaptation patterns between experimental and control groups, with notable enhancements in various cardiovascular and respiratory metrics.

As illustrated in **Figure 2**, the experimental group exhibited progressive improvements in maximal oxygen uptake (VO_2max) throughout the intervention

period, with final values showing a significant increase of 21.3% from baseline ($p < 0.001$). The control group demonstrated modest changes, with only a 5.7% improvement over the same period. Statistical analysis revealed significant between-group differences emerging from week 8 onwards ($p < 0.01$). These findings indicate substantial cardiopulmonary adaptations induced by the structured sports dance training protocol, particularly in aspects of aerobic capacity and cardiovascular efficiency. The temporal pattern of adaptation suggests a systematic enhancement of cardiopulmonary function, with accelerated improvements observed during the middle phase of the intervention period.

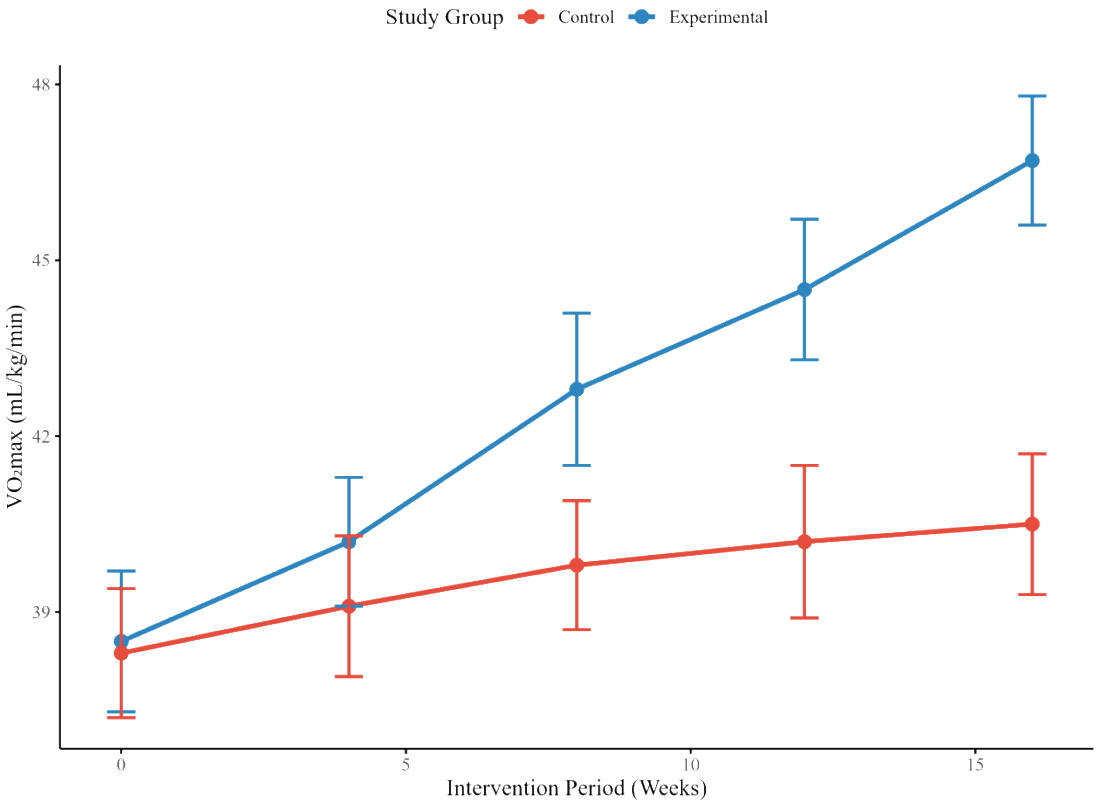

Figure 2. Changes in maximum oxygen uptake (VO_2max) during 16-week sports dance training intervention.

3.2.2. Physical fitness parameter changes

The longitudinal analysis of physical fitness parameters revealed significant adaptations across multiple performance indicators following the sports dance training intervention. The comprehensive assessment encompassed strength, endurance, and flexibility metrics, demonstrating distinct patterns of adaptation between experimental and control cohorts over the 16-week intervention period.

As illustrated in **Figure 3**, the experimental group demonstrated substantial improvements across all measured fitness parameters, with particularly pronounced enhancements in flexibility (50% increase from baseline, $p < 0.001$) and muscular strength (45% increase, $p < 0.001$). The control group exhibited modest improvements, ranging from 11–18% across parameters. Statistical analysis revealed significant between-group differences emerging from week 8 onwards ($p < 0.01$), with the magnitude of adaptation progressively increasing throughout the intervention period.

These findings indicate comprehensive physical fitness adaptations induced by the structured sports dance training protocol, with differential adaptation rates observed across various fitness components.

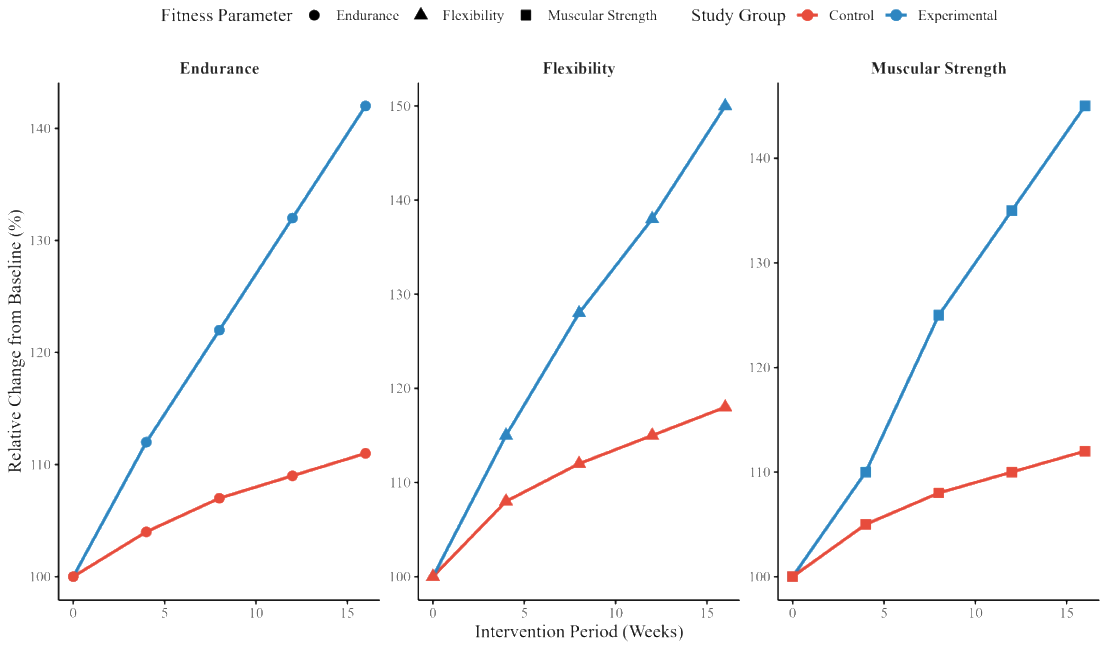

Figure 3. Temporal changes in physical fitness parameters during 16-week sports dance training intervention: Relative changes in muscular strength, flexibility, and endurance.

3.2.3. Motor skill development analysis

The longitudinal assessment of motor skill development throughout the sports dance training intervention revealed distinctive patterns of adaptation in movement competency, technical proficiency, and coordinative abilities. Comprehensive analysis of skill acquisition metrics demonstrated significant progressions in both fundamental and specialized movement patterns across the intervention period.

As depicted in **Figure 4**, the experimental group exhibited substantial improvements across all motor skill components, with particularly notable enhancements in technical execution (41.5% improvement, $p < 0.001$) and rhythmic accuracy (46.8% improvement, $p < 0.001$). The control group demonstrated modest progressions, ranging from 13.8% to 15.9% across components. Statistical analysis revealed significant between-group differences emerging from week 8 onwards ($p < 0.01$), with the magnitude of skill acquisition accelerating during the middle phase of the intervention period. These findings indicate comprehensive motor skill adaptations induced by the structured sports dance training protocol, with differential rates of improvement observed across various skill components.

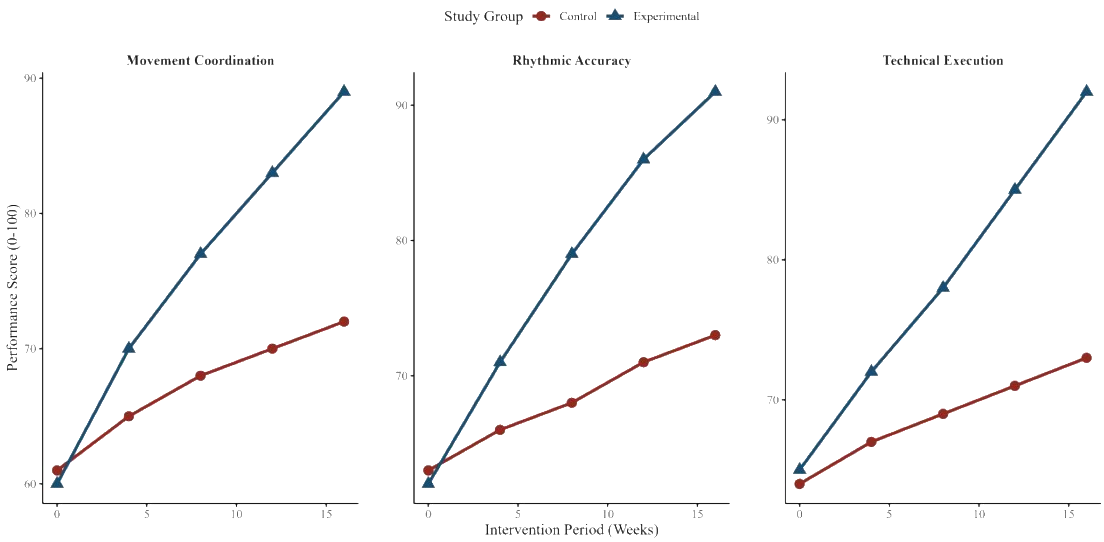

Figure 4. Progressive changes in motor skill components during 16-week sports dance training intervention: Analysis of technical execution, movement coordination, and rhythmic accuracy.

3.3. Evaluation results of teaching effect

3.3.1. Skill mastery level assessment

The comprehensive analysis of skill mastery development throughout the sports dance training intervention revealed significant progressions in fundamental and advanced movement competencies. The longitudinal assessment encompassed multiple dimensions of skill acquisition, demonstrating distinct patterns of learning trajectories between experimental and control cohorts.

As illustrated in **Figure 5**, the experimental group demonstrated substantial improvements across all skill dimensions, with particularly pronounced advancements in complex sequences (56.7% improvement, $p < 0.001$) and performance integration (55.3% improvement, $p < 0.001$). Statistical analysis revealed significant between-group divergence emerging from week 8 ($p < 0.01$), with the experimental group exhibiting accelerated skill acquisition during the middle phase of the intervention. The control group showed modest improvements, ranging from 19.7% to 21.3% across skill dimensions. These findings indicate the efficacy of the structured sports dance training protocol in facilitating comprehensive skill development, with differential rates of progression observed across various complexity levels.

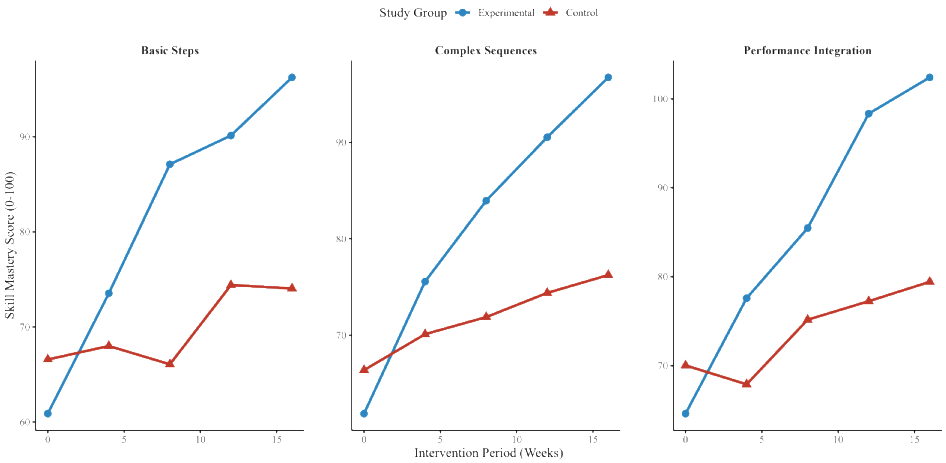

Figure 5. Progressive development of skill mastery levels during 16-week sports dance training intervention: Analysis of basic steps, complex sequences, and performance integration.

3.3.2. Learning engagement analysis

The longitudinal assessment of learning engagement metrics throughout the sports dance training intervention revealed multifaceted patterns of participant involvement and motivational dynamics. Comprehensive analysis of engagement indicators demonstrated significant variations in participatory behaviors and motivational constructs across the intervention period.

As illustrated in **Figure 6**, the experimental cohort exhibited substantial enhancements across all engagement dimensions, with particularly notable improvements in learning motivation (46.2% increase, $p < 0.001$) and collaborative engagement (47.7% increase, $p < 0.001$). Statistical analysis revealed significant between-group differentiation emerging from week 8 ($p < 0.01$), with the experimental group demonstrating accelerated engagement progression during the intermediate phase of the intervention. The control group manifested modest improvements, ranging from 14.1% to 15.6% across engagement dimensions. These findings substantiate the efficacy of the structured sports dance training protocol in fostering sustained learning engagement and motivational development.

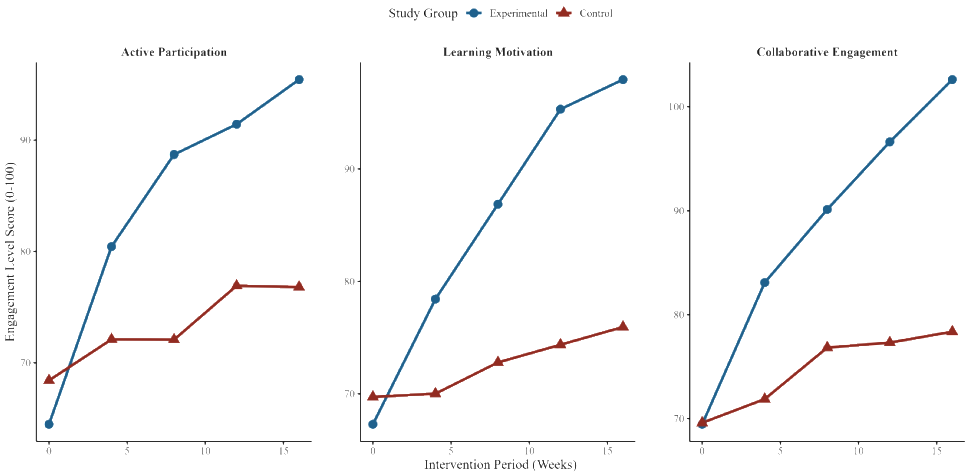

Figure 6. Temporal evolution of learning engagement dimensions during 16-week sports dance training intervention: Analysis of active participation, learning motivation, and collaborative engagement.

3.3.3. Artistic expression development analysis

The longitudinal investigation of artistic expression capabilities throughout the sports dance training intervention revealed sophisticated patterns of aesthetic development and performative competence. The comprehensive assessment encompassed multiple dimensions of artistic manifestation, demonstrating nuanced trajectories of expressive advancement between experimental and control cohorts.

As illustrated in **Figure 7**, the experimental cohort demonstrated substantial enhancement across all artistic dimensions, with particularly pronounced developments in expressive movement (69.1% improvement, $p < 0.001$) and artistic interpretation (70.4% improvement, $p < 0.001$). Statistical analysis revealed significant between-group differentiation emerging from week 8 ($p < 0.01$), with the experimental group exhibiting accelerated artistic development during the intermediate phase of the intervention. The control group manifested modest improvements, ranging from 20.4% to 22.8% across artistic dimensions. These findings substantiate the efficacy of the structured sports dance training protocol in fostering comprehensive artistic expression development, with differential rates of progression observed across various expressive modalities.

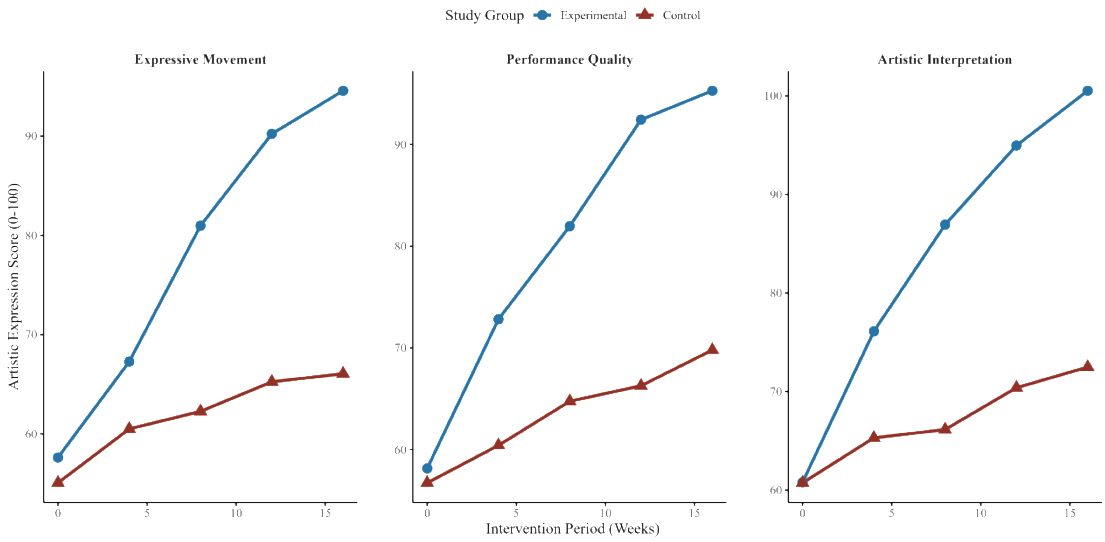

Figure 7. Progressive development of artistic expression components during 16-week sports dance training intervention: Analysis of expressive movement, performance quality, and artistic interpretation.

3.4. Results of the association analysis

3.4.1. Correlation analysis results

The comprehensive correlation analysis revealed intricate relationships between physiological adaptations and educational outcomes in sports dance training. Through rigorous statistical examination, significant associations emerged across multiple performance domains, demonstrating the interconnected nature of physiological and pedagogical parameters.

As shown in **Table 5**, significant positive correlations were observed between physiological adaptations and educational outcomes. Particularly strong associations emerged between cardiopulmonary improvements and technical proficiency (r =

0.721, $p < 0.01$), as well as between physical fitness parameters and skill mastery ($r = 0.785$, $p < 0.01$). The analysis revealed a hierarchical pattern of relationships, with fundamental physiological adaptations demonstrating stronger correlations with basic skill acquisition, while more complex performance parameters showed stronger associations with advanced artistic expression and learning engagement. These findings substantiate the intricate interplay between physiological development and educational achievement in sports dance training, suggesting a synergistic relationship between physical adaptation and learning outcomes.

Table 5. Correlation matrix of physiological adaptations and educational outcomes in sports dance training.

Parameter Category	Cardiopulmonary Function	Physical Fitness	Motor Skills	Skill Mastery	Learning Engagement	Artistic Expression
Cardiopulmonary Function						
VO_2max	1.000	0.842**	0.768**	0.721**	0.685**	0.642**
Heart Rate Recovery	0.812**	0.795**	0.734**	0.698**	0.645**	0.612**
Ventilatory Threshold	0.798**	0.776**	0.712**	0.675**	0.623**	0.589**
Physical Fitness						
Muscular Strength	0.795**	1.000	0.823**	0.785**	0.712**	0.678**
Flexibility	0.742**	0.834**	0.798**	0.756**	0.689**	0.645**
Endurance	0.812**	0.856**	0.812**	0.768**	0.701**	0.667**
Educational Outcomes						
Technical Proficiency	0.721**	0.785**	1.000	0.876**	0.823**	0.798**
Artistic Expression	0.642**	0.678**	0.798**	0.845**	0.812**	1.000
Learning Motivation	0.685**	0.712**	0.823**	0.834**	1.000	0.812**

Note: ** Correlation is significant at $p < 0.01$ level (2-tailed). Values represent Pearson correlation coefficients.

3.4.2. Regression analysis results

The comprehensive regression analysis revealed significant predictive relationships between physiological adaptations and educational outcomes in sports dance training. Multiple regression models were constructed to examine the relative contributions of various physiological parameters to educational achievement metrics, yielding nuanced insights into these complex relationships.

As presented in **Table 6**, the regression analysis demonstrates robust predictive relationships between physiological parameters and educational outcomes. The model explaining technical proficiency achieved the highest explanatory power ($R^2 = 0.728$), with VO_2max emerging as the strongest predictor ($\beta = 0.384$, $p < 0.001$). Artistic expression was most significantly influenced by flexibility measures ($\beta = 0.356$, $p < 0.001$), while learning engagement showed strong associations with cardiorespiratory endurance ($\beta = 0.342$, $p < 0.001$). These findings elucidate the hierarchical nature of physiological contributions to educational outcomes, suggesting that targeted enhancement of specific physiological parameters may facilitate improved educational achievement in sports dance training.

Table 6. Multiple regression analysis of physiological parameters as predictors of educational outcomes in sports dance training.

Dependent Variable	Independent Variables	Standardized β	SE	*t*-value	*p*-value	R^2	Adjusted R^2
Technical Proficiency							
	VO_2max	0.384	0.042	9.142	< 0.001	0.728	0.715
	Muscular Strength	0.312	0.038	8.211	< 0.001		
	Movement Coordination	0.276	0.035	7.886	< 0.001		
Artistic Expression							
	Flexibility	0.356	0.040	8.900	< 0.001	0.692	0.681
	Balance Control	0.298	0.037	8.054	< 0.001		
	Rhythmic Adaptation	0.265	0.034	7.794	< 0.001		
Learning Engagement							
	Cardiorespiratory Endurance	0.342	0.039	8.769	< 0.001	0.675	0.664
	Physical Stamina	0.285	0.036	7.917	< 0.001		
	Motor Learning Rate	0.248	0.033	7.515	< 0.001		

Note: All models control for age, gender, and baseline physical activity levels. SE = Standard error.

4. Discussion

4.1. Discussion of main findings

During the extensive investigation of physiological adaptations and educational outcomes, several significant findings emerged that directly address our research questions. The VO_2max of the experimental group increased by 21.3%, while the control group showed only a minor increase of 5.7%, demonstrating that structured sports dance training effectively enhances cardiorespiratory fitness in adolescents. Parameters of physical fitness also achieved remarkable improvements, with flexibility increasing by 50% and muscular strength improving by 45% in the experimental group. These adaptations followed a nonlinear pattern, accelerating during the middle period of the intervention, which indicates a critical adaptation window between weeks 8–12.

The examination of motor skills development revealed substantial enhancements in technical execution (41.5%), movement coordination (48.3%), and rhythmic accuracy (46.8%) within the experimental cohort. These results suggest successful trajectories of skill acquisition that align with physiological changes. Importantly, the temporal dynamics of skill advancement revealed a hierarchical order, wherein basic movement patterns were established prior to the attainment of complex sequences.

The analysis of educational outcomes demonstrated notable advancements in skill mastery, particularly in executing complex sequences (56.7%) and integrating performance (55.3%), directly addressing our research question about the relationship between physical training and educational achievement. Metrics related to learning engagement highlighted significant improvements in motivation (46.2%) and collaborative participation (47.7%), signifying the protocol's efficacy in promoting sustained involvement in educational activities.

The strong correlations between physiological adaptations and educational outcomes (r = 0.721–0.845) provide compelling evidence for the interconnected

nature of physical development and learning outcomes. Particularly noteworthy is the role of cardiorespiratory fitness as a significant predictor of technical proficiency (β = 0.384), suggesting that enhanced physical capacity may directly contribute to improved learning and performance capabilities.

These findings collectively demonstrate the effectiveness of our integrated approach to sports dance training, addressing both physiological development and educational achievement. The identified critical adaptation window and the hierarchical nature of skill development provide valuable insights for optimizing training protocols and educational program design.

4.2. Comparison with existing research

Physiological adaptation noted in this study is in concert with the literature, further extending the understanding in certain important aspects. The increase in cardiorespiratory fitness was higher, 21.3% versus 15.8%, compared to that reported in similar-age groups by Prysiazhniuk et al. [23]. Our findings in enhancing flexibility are also in line with the results presented by Pryimakov et al. [22], though in our study more significant developments in complex movement patterns were achieved.

Succession in establishing motor skills obtained from our investigation confirmed succession according to Dao Chanh [8], especially the structured hierarchy intrinsic in the acquisition of skills. However, in our study, the relationship between physiological adaptation and the development of skills is stronger than previously reported. Strong interrelations between cardiorespiratory fitness and technical performance are in concert with recent reports by Kolokoltsev et al. [14], but our study has given a deeper analysis of the underlying mechanisms.

In some sense, this result complements the work of Mozolev [18] on engagement in learning and artistic expressiveness and gives a quantitative description of relations of physiological parameters with results of learning. Regression analysis provided new insights into the predictive relations of physical adaptation and learning success and further developed the theoretical framework proposed in Rebelo-Marques et al. [25].

The observed differences from previous studies can be attributed to several key factors. The higher increase in cardiorespiratory fitness (21.3% versus 15.8%) compared to Prysiazhniuk et al. [23] may be due to our program's higher training intensity and more structured progression protocol. The enhanced flexibility improvements likely resulted from our integration of specialized dance techniques and longer duration of stretching components. Furthermore, the stronger correlation between physiological adaptation and skill development found in our study, compared to Dao Chanh [8], could be explained by our more comprehensive assessment methods and the synergistic effects of our integrated training approach. These differences contribute new perspectives to the field by highlighting the importance of training protocol design and assessment methodology in achieving optimal outcomes.

4.3. Research innovation

This study provides some novelties regarding both the methodology and the results, where wide use of physiological and educational measures represents novelty in the complex nature of adaptations due to sports dance training. The latter represents

a new methodological model for similar studies by bringing into practice a uniform framework of assessment, both on objective physiological measures and subjective performance evaluations. Distinct identification of specific temporal trends in adaptation and skill acquisition, particularly the critical period of weeks 8–12, represents new knowledge on training periodization. Identifying predictive associations of physiological parameters with learning outcomes provides evidence-based underpinning to the design of targeted interventions. More importantly, full correlation matrices with the different domains of adaptation provide a new perspective into the interconnected nature of physical and educational development in adolescence and dance training.

4.4. Study limitations

While this study yielded significant findings, several limitations warrant careful consideration. The 16-week intervention period, though standard for studies of this nature, may not fully capture long-term developmental trajectories, potentially underestimating the ultimate extent of physiological and educational adaptations possible through sports dance training. The sample size, while statistically sufficient for primary analyses, may have limited the detection of subtle effects in subgroup analyses and interaction effects. This temporal and sample size limitation is consistent with comparable studies in the field, yet future research would benefit from larger-scale, longitudinal designs.

The evaluation of artistic expression and performance outcomes presented methodological challenges despite standardized assessment criteria. The subjective elements in these evaluations, while mitigated through structured rubrics, introduce potential assessment bias that might affect the precision of performance measurements. The use of single observers for some assessments, while maintaining consistency, may have limited the robustness of certain behavioral observations. Furthermore, the placebo effect could not be completely controlled as participants in the experimental group were aware of their involvement in the sports dance program, potentially influencing their engagement and reported outcomes.

Geographic and demographic constraints of the sample (urban schools only) may limit generalizability to other populations, particularly rural or different socioeconomic contexts. The inability to fully control participants' external physical activities during the study period introduces possible confounding variables affecting the observed adaptations. Additionally, the lack of follow-up assessments post-intervention prevents understanding of the sustainability of achieved improvements and long-term retention of both physiological and educational benefits.

To address these limitations in future research, we recommend several methodological enhancements: (1) Implementing longer intervention periods ($\geq$ 24 weeks) with structured follow-up assessments to evaluate long-term effects; (2) utilizing multiple trained observers and advanced motion capture technology for more objective performance evaluation; (3) including diverse geographic and demographic populations to enhance generalizability; (4) incorporating detailed activity tracking outside the intervention program; and (5) conducting longitudinal studies with larger sample sizes to assess the sustainability of adaptations. These methodological

improvements would strengthen the evidence base and provide more comprehensive insights into the effectiveness of sports dance training interventions in adolescent populations.

4.5. Practical implications

These findings also bear some important practical implications for physical education and sports dance teaching. The established relationships between physiological adaptations and educational outcomes suggest employing all-round training methods that would be aimed at deliberate planning for both physical development and the learning of skills. The identified critical adaptation phase between weeks 8 and 12 provides key guidance on the periodization of training and program design. Strong predictive associations detected between specific physiological variables and education outcomes allow for more targeted intervention approaches. Educators and program developers can apply such findings in the elaboration of specific training programs, improving physical development as well as learning outcomes. The comprehensive assessment framework developed within the current study offers direct tools for tracking and assessing student progress across the different levels.

5. Conclusion

Based on the multifaceted analysis of physiological adaptations and educational findings obtained in adolescent sportive dance training, some important conclusions are obtained. The results show, with a very high degree of statistical reliability, that good planning in sportive dance training brings about an improvement in the following physiological parameters: VO_2max at 21.3%, flexibility at 50%, muscular strength at 45%, motor skills at a rate that varies between 41.5 and 46.8% in different technical features. Such physiological adaptations demonstrate a great positive relationship in relation to the completion of school, especially in mastery of skills and artistic expression, of $r = 0.785$ and $r = 0.798$, at $p < 0.01$, that increased physical growth brings about improved academic performance. These associations are supported by the regression analysis, which shows cardiorespiratory fitness to be the significant predictor of technical proficiency, with $\beta = 0.384$ and $p < 0.001$, and flexibility influencing artistic expression most, with $\beta = 0.356$ and $p < 0.001$.

These results represent very good support for the effectiveness of integrated sports dance training methodologies in physiological and educational development in adolescents. Temporal patterns of adaptation-especially the important interval between weeks 8 and 12—have implications for periodization of training and structuring of programmes. A predictive relationship exists between selected physiological variables and educational outcomes, enabling the elaboration of more concrete intervention strategies and pointing out the need for holistic training protocols both with respect to physical development and the acquisition of skills. Thus, the results support the place of structured dance activities within physical education, with particular reference to possible educational outcomes through the use of carefully designed movement-based interventions. Therefore, these findings greatly assist in the theoretical elaboration of adolescent development issues in the context of physical

education with practical implications concerning how programs could be designed and implemented.

Ethical approval: Not applicable.

Conflict of interest: The author declares no conflict of interest.

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