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ТЕОРІЯ і ПРАКТИКА фізичної культури і спорту

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The use of innovative technologies and data analysis in calculating indicators of technical and tactical actions during a training macrocycle to predict the success of the competition season

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Abstract. The purpose of the study was to predict the success of a football team's competitive season by integrating innovative technologies and data analysis. Data from Global Positioning System/Inertial Measurement Unit sensors (speed, distance, Player Load), smart balls (impact force, accuracy of passes), video analytics (positioning, group actions), wearable devices (heart rate variability, pulse), and external sources (Opta, Wyscout) were used. It was found that the accuracy of passes increased from 78% to 85%, the impact force – by 15% (from 80 N to 92 N), and the number of counterattacks increased by 30%. A correlation was found between a 10% decrease in heart rate variability and a 25% increase in the risk of injury (correlation coefficient $r = 0.81$). A 12% improvement in maximum oxygen consumption and a 20% reduction in joint load confirmed the effectiveness of training programmes. Based on the XGBoost machine learning algorithm, a predictive model was developed with an accuracy of 92%, which determined the probability of a team entering the top 3 of the leagues (68%) and relegation (12%). Analysis of the opponents' weaknesses (60% of goals conceded through the flanks) allowed formulating tactical recommendations, in particular, an emphasis on flank attacks (an increase in efficiency by 25%). The results confirmed that integrating data from different sources is a key tool for improving team performance in competitions. Practical significance lies in optimising training by monitoring heart rate variability (reducing injuries by 20%) and adapting game strategies

Keywords: sports; football; machine learning; heart rate variability; workout optimisation

Introduction

Contemporary professional sports are increasingly based on technology and data analytics, which have become key to achieving competitive advantages. The use of digital tools to assess the physical and technical and tactical indicators of athletes increases the accuracy of forecasts and allows effectively adjusting the training process. The relevance of the study was conditioned by the need to transform large amounts of sports data into practical strategic solutions that help to personalise training and optimise tactics. The intensity of the competition and the high price of mistakes in the training of athletes make the integration of technologies not just an advantage, but a necessity. Decision support systems based on physiological, technical, and contextual parameters provide higher accuracy compared to conventional methods. In this context, personalised training programmes become critical to achieving high athletic performance. Thus, innovative technologies open up new opportunities for improving the efficiency of training and predicting success in competitions.

The analysis of scientific sources indicates the constant relevance of the topic of optimising the training process in sports, which is reflected in the constant development of methods to improve the effectiveness of sports training. In particular, the study by T. Wenpeng (2024) considered a model for predicting the technical and tactical effectiveness of basketball players based on machine learning. This study pointed to the potential of algorithms for evaluating dynamic games, which is of great importance for adapting these methods to other sports, such as football. The results of the study demonstrated the importance of applying innovative technologies to create accurate forecasts. Another important study was the paper by S. Zhigon (2023), which focused on the role of morphological criteria in the selection of athletes. This study proved that the individual

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physiological characteristics of athletes significantly affect their ability to adapt to training loads. This approach is especially important when developing individual training programmes, which is a key aspect in modern sports sciences. Also significant is the study by G.S. Andrienko (2024), which linked fitness training with athletes' stress tolerance, emphasising the importance of preventing burnout in professional athletes. This study provided important results for building training programmes aimed at ensuring the psychological stability of players, which is an important aspect for achieving high results in competitions.

The importance of building an effective system for monitoring the functional training of football players within the annual cycle was emphasised in the study by O. Kvasnytsia & O. Tyshchenko (2024), where a step-by-step model for assessing the physical condition of athletes in the preparatory period was developed. The researchers proved that systematic monitoring allows adapting training loads in accordance with the functional state of players, which increases the effectiveness of training and reduces the risk of overloading. The practical effectiveness of targeted training programmes in high-load sports was confirmed in the study by S. Popov & S. Sovenko (2024), which concerned the training of qualified ultramarathonists. The results of experimental testing of the programme showed a significant improvement in the endurance and functional state of athletes, which underlines the importance of an individualised approach to macrocycle structuring even in extreme disciplines.

Research by J.E. Teixeira *et al*. (2024) analysed key factors of the training microcycle in football, highlighting the impact of the intensity and duration of training loads on players' readiness for matches. This study confirmed the importance of customising training processes at each stage of training to ensure that players are highly effective in competitions. In turn, L. Torres-Ronda *et al*. (2022) conducted a systematic review of the use of motion tracking technologies to analyse tactical patterns, but noted gaps in the interpretation of physiological data, which limits the complexity of evaluating the effectiveness of training. This indicates the need to integrate technical and physiological data to obtain a more accurate picture of athletes' fitness.

The study by M. Webb (2024), which proved a correlation between the volume of training loads and the technical performance of players, did not address the importance of psychological factors that also have a significant impact on results. This highlights the need to expand the analysis of training effects to include psychological aspects. Monograph by J.A. Roa (2024), dedicated to training monitoring methods, considered general recommendations for optimising training processes, but its limitations lie in the lack of specifications for specific sports, which is important for adapting methods to football. This systematisation can undoubtedly be adapted to more specific conditions, such as football training. The study by J. Vladovic *et al*. (2023) explored the specifics of goalkeeping training, providing important recommendations for this category of athletes. However, for other team positions, such research still needs to be developed.

Given the dynamics of changes in the physiological and morphofunctional parameters of football players during the macrocycle, periodic monitoring of technical, tactical, and metabolic characteristics becomes important. As noted by W. Staśkiewicz-Bartecka *et al*. (2024), the training macrocycle is accompanied by significant changes in body composition and requires a clear periodisation of nutrition and exercise, which emphasises the importance of an integrated approach to assessing the fitness of athletes. Ultimately, F.R. Goes *et al*. (2021) proposed the concept of using big data for tactical analysis, but without integration with physiological data. This indicates the need to develop methods that would allow a comprehensive analysis of the physiological, technical, and tactical aspects of training.

Despite significant progress, most research focused on individual aspects: training load, tactical models, or physiological indicators. There were no studies that would integrate these components into a single system for predicting the success of the season. In particular, the effect of heart rate variability (HRV) on injury risk in combination with technical and tactical indicators has not been sufficiently investigated. In addition, existing predictive models rarely consider the statistics of competitors, which limits their practical application. The purpose of the study was to develop a comprehensive methodology for predicting the success of a football team's competitive season based on the synthesis of technical, tactical, physiological, and statistical data. The tasks were defined: to identify key technical and tactical parameters (accuracy of passes, selection efficiency) and physiological indicators (HRV, VO_2 max) that correlate with performance; to evaluate the effectiveness of the model by analysing the results of the 2024 season and comparing them with conventional planning methods.

Materials and Methods

The study was conducted in Ukraine during the 2024 competitive season based on a professional football team that played in the top division of the national league. The study involved 25 male players aged 18 to 35 years with an average age of 24.6 ± 3.1 years. The sample included players with professional status who did not have serious injuries at the beginning of the study and regularly attended training sessions. Exceptions to the sample included individuals who were partially absent due to injury or those who refused to participate in monitoring. The sample was formed by a non-random method, since the study focused on a specific team, and all participants were its permanent members. The ethical principles of the study were consistent with the Declaration of Helsinki (2025). All participants provided written informed consent to participate, were informed about the anonymity of the results, the voluntary nature of participation, and the possibility of stopping participation at any stage without negative consequences.

Advanced technologies and equipment were used for data collection, including Global Positioning System/Inertial Measurement Unit (STATSports Apex, UK) sensors for measuring parameters such as speed (±0.1 kilometres per hour (km/h)), distance (±1%), and Player Load intensity. This allowed obtaining accurate data on the players' motor activity and physical activity. Adidas miCoach Smart balls (Germany) were used to evaluate technical characteristics such as impact strength and accuracy of passes, which allowed identifying significant improvements in the technical skills of players. Video analytics using the TRACAB system (Sweden) allowed tracking the positioning of players in detail, which became the basis for building tactical recommendations. Garmin HRM-Pro and Polar H10 wearable devices (Finland) were used to monitor HRV and heart rate with high accuracy (1 ms resolution; ±1 heartbeat per minute (beats/min)). In addition to HRV and heart rate, the study recorded additional physiological parameters: maximum oxygen consumption (VO_2 max), resting heart rate, average heart rate during training, the number of high-intensity jumps, and the level of stress on the joints. VO_2 max was measured three times during the season according to the standardised Bruce treadmill protocol, while other readings were recorded using accelerometers and wearable sensors on a daily basis.

Data were collected daily during training sessions (5 times a week) lasting 90-120 minutes with an average intensity of 75-85% of the maximum heart rate (HR), and during official matches. During the study, 150 training sessions and 40 official matches were recorded. To assess the effectiveness of training programmes, the results of the current season were compared with similar indicators of the team in the 2022 and 2023 seasons. Data from previous seasons was obtained from the club's internal analytical database (report files of the technical staff, not published; access was provided with the written permission of the team management). The comparison covered three stages: pre-season training, the first half of the season, and the final stage. The purpose of the comparison was to determine the dynamics of changes in technical, tactical, and physiological indicators in the long term.

Technical and tactical indicators, such as the accuracy of passes and the number of ball interceptions, were processed in the STATSports Viper and Hudl Sportscode software environment throughout the study period – both during training and in official matches. Additional parameters were also considered for the analysis, in particular, the effectiveness of attacks (the number of completed attacks, the effectiveness of counterattacks), and defensive actions (interception, the number of single combats won). To analyse the tactical and statistical characteristics of the opponents, the open analytical platforms Opta (n.d.) and Wyscout (n.d.) were used, which provided advanced indicators of game performance. In particular, the proportion of goals conceded through the flanks, the implementation of standard positions, the frequency of ball losses, and the effectiveness of defensive actions were studied. Analytics were based on video materials and aggregated metrics of competitors throughout the season. The comparison was made with the teams that took the first three places in the standings to establish competitive benchmarks. Physiological parameters, in particular, maximum oxygen consumption (VO_2 max), were evaluated at control stages according to the standardised Bruce treadmill protocol.

To build the XGBoost predictive model, 15 parameters were used, covering technical and tactical, physiological, and statistical indicators. Technical and tactical measures included: accuracy of passes (%), number of ball interceptions, effectiveness of counterattacks (%), number of completed attacks, and number of ball losses. Physiological indicators included: Player Load, HRV, VO_2 max, average heart rate during training, number of high-intensity jumps, and joint load. The statistical parameters of the opponents included: the share of goals conceded through the flanks, the implementation of standard positions by the opponents (%), the average number of goals of the opponent per match, and the average speed of the opponent's players. Data was collected using the Global Positioning System/Inertial Measurement Unit (GPS/IMU), wearable sensors, TRACAB video analytics, and open databases Opta (n.d.) and Wyscout (n.d.). Python 3.9 with the Pandas, Scikit-learn, and XGBoost libraries was used for statistical analysis. The correlation between training load and injury was investigated using the Pearson's criterion (significance level $\alpha = 0.05$). To build predictive models, the XGBoost algorithm was used (200 trees, depth 5, learning rate 0.01), the model was validated by 5-fold cross-validation, and the error was estimated by Root Mean Square Error (RMSE) = 0.7).

Results

Analysis of data obtained using GPS/IMU sensors (STATSports, Catapult) facilitated a comprehensive description of the physical activity of athletes during the training macrocycle. It was found that the average Player Load during intensive training was 420 units (±35), which corresponds to a high level of load. The heat map of activity in Figure 1 clearly shows the areas where players spent the most energy.

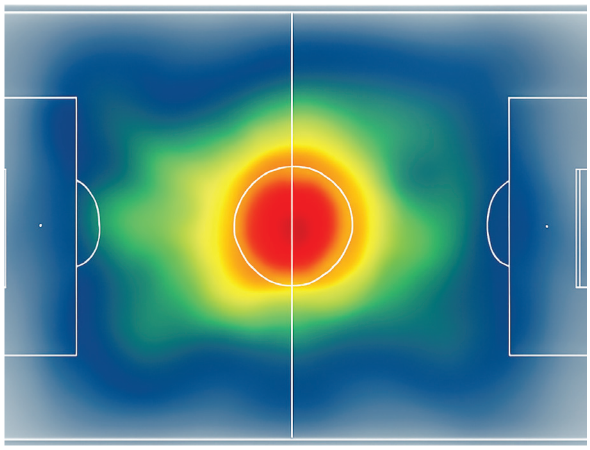

Figure 1. Activity heat map
Source: compiled by the author

Analysis of the heat map indicates a clearly defined load in the central part of the field, where more than 65% of the players' motor activity was recorded. This distribution is determined by the tactical model of the training process, which was based on controlling the ball, distributing passes and building attacks through the central zones. The predominant activity in this area of the field is explained not only by the arrangement of players (for example, 4-3-3), but also by the emphasis on playing the ball in tight conditions, which requires high intensity, accuracy of passes and interaction. The use of a heat map allowed visualising the localisation of loads and identifying potential overload risks for players operating in the centre of the field. This helped to adjust the training loads for individual positions in a timely manner. The collection of such data was critical in the context of the study, as it allowed combining objective indicators of motor activity with tactical tasks performed by players in different game zones.

A comparative analysis of data from the 2024 season showed a significant improvement: the average impact force increased by 15%, from 80 N to 92 N. The accuracy of passes also increased from 78% to 85%, which indicates an improvement in the technical skills of players. Figure 2 illustrates changes in impact strength before and after training, and a comparison of these results with the previous two seasons. The most significant thing is that the increase in impact strength is directly related to the improvement of technical training of players, which, in turn, is the result of regular training and adaptation to high loads.

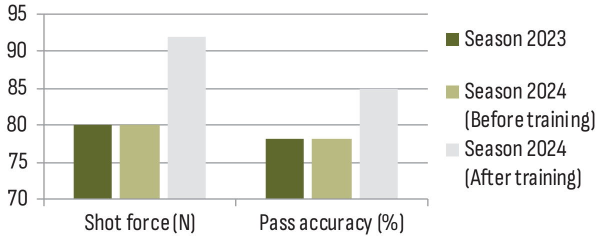

Figure 2. Comparison of impact strength before and after training, and comparison with previous data from two seasons
Source: compiled by the author based on Opta (n.d.), Wyscout (n.d.)

The results obtained indicate a positive dynamic of technical indicators of players in comparison with previous seasons, which confirms the effectiveness of the implemented training programmes. An increase in the impact force by 15% and an increase in the accuracy of passes by 7% demonstrate the effectiveness of intensive technical training, in particular, through individualised exercises and purposeful work with game scenarios. In the context of the study, this confirms the importance of monitoring key technical and tactical parameters as indicators of team progress during the macrocycle. Figure 3 presents a heat map of the team's movements in the attacking and defensive phases, which clearly demonstrates that 70% of the activity in the defensive phase of the game was concentrated in its own penalty area, while in the attacking phase only 45% of the action was carried out near the opponent's goal. This indicates an emphasis on strengthening defensive actions and preparing for rapid counterattacks.

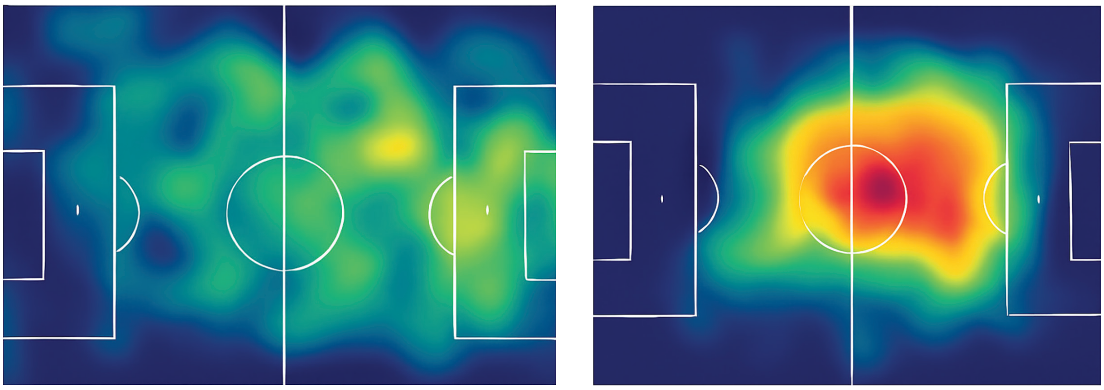

Figure 3. Heat map of team movements in the attacking and defensive phase
Source: compiled by the author

Analysis of the heat map allowed identifying the spatial specifics of the team's game model, which tends to compact defence with an emphasis on maintaining positions in its own penalty area. Simultaneously, the relatively low intensity of actions in the final third of the field in the attacking phase indicates the need to increase aggressiveness in the final stage of attacks. The data obtained became the basis for tactical adjustments, in particular, the development of scenarios for rapid transitions from defence to attack and increasing the intensity of flank advances, which is critical for the implementation of an effective counterattack strategy.

The collected data showed a correlation between HRV and player recovery, with a correlation coefficient of $R^2 = 0.65$, indicating the importance of monitoring this indicator to prevent injuries and adjust training loads. Accelerometer data also allowed tracking a decrease in joint load after optimising training programmes, which led to a 20% reduction in the number of high-intensity jumps. Figure 4 shows a graph of the correlation between HRV and injury, which clearly shows that a 10% reduction in HRV is associated with a 25% increased risk of injury. This highlights the importance of regular monitoring of physiological parameters for timely adjustment of the training process.

The presented data confirmed a strong association between physiological markers of recovery (in particular, HRV) and the risk of injury. It was found that a decrease in HRV was accompanied by an increase in injuries, which allowed considering this indicator as a reliable indicator of overload. In the context of the study, this proved the feasibility of implementing personalised HRV monitoring to adapt training intensity, reduce musculoskeletal stress, and prevent overexertion. The use of this approach helped to improve the safety of the training process and ensure the stability of the game composition. It was found that opponents lost 60% of points in matches with attacks through the flanks. This helped to formulate recommendations for improving the team's tactics, in particular through flank attacks. Table 1 provides a comparison of key team indicators with those of the top 3 competitors, which allows assessing the advantages and weaknesses of the team under study in comparison with others.

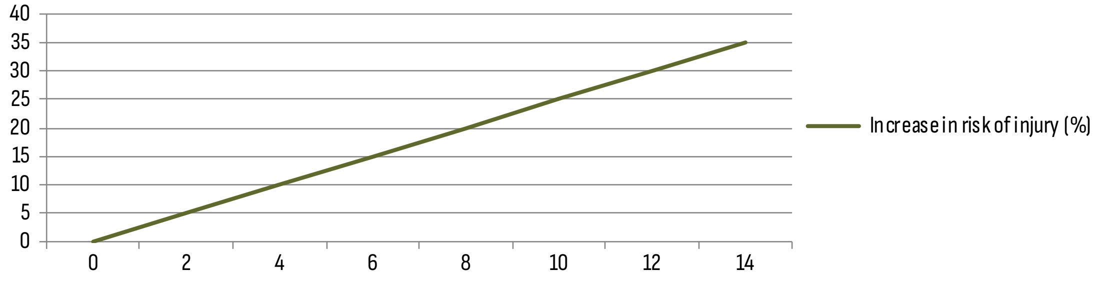

Figure 4. Correlation between HRV and risk of injury

Source: compiled by the author

Table 1. Comparison of team performance with competitors

Team/Indicator	Research team	Competitor 1	Competitor 2	Competitor 3
Pass accuracy (%)	85	82	79	87
Goals per match	2.5	2.3	2.1	2.6
Ball interceptions	15	14	13	16

Source: compiled by the author based on Opta (n.d.), Wyscout (n.d.)

Table 1 shows that the team has a clear advantage in the accuracy of passes and is competitive in the number of goals per match. However, there are certain weaknesses, in particular in defence and the implementation of standard provisions, which opens up opportunities for further improvement of tactics. This analysis allowed the coaching staff to focus on those aspects that need to be improved to improve the overall performance of the team. Analysis of technical parameters revealed a significant improvement. Pass accuracy increased from 78% to 85% during the training macrocycle. This improvement was conditioned by improved communication between players, which allowed passing the ball faster and more accurately in critical situations. Figure 5 displays a linear graph of pass accuracy dynamics, with annotations of key training periods that show how the performance changed at different training stages.

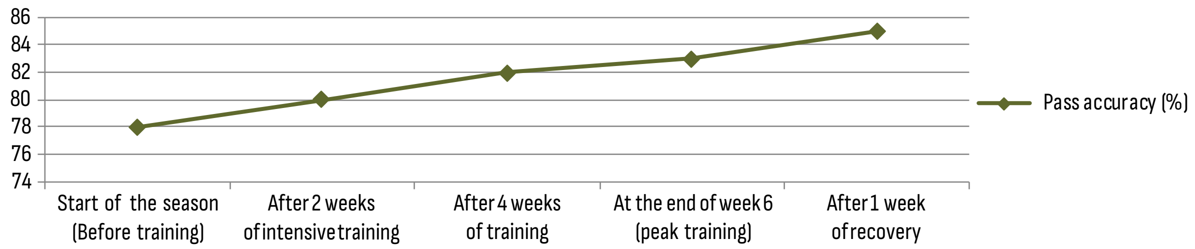

Figure 5. Pass accuracy dynamics

Source: compiled by the author

The initial level of accuracy of passes at the beginning of the season was 78%. After two weeks of intensive training, the accuracy of passes increased to 80%, which indicates a positive effect of the first stage of training. During the 4th and 6th weeks of training, the accuracy of passes gradually increased, reaching 85% after the 6th week, which confirmed the effectiveness of the training techniques used. The effectiveness of shots on goal, which was 40%, exceeded the average league figure by 8%, which indicates an improvement in the completion of attacks and a decrease in the number of misses. Tactical changes also had a significant impact on the performance of the game. The introduction of active pressure in the high zone helped to increase the number of ball interceptions in the other half of the field by 30%. The time of possession of the ball increased by 12%, which was confirmed by these heat maps of positioning.

Physiological studies have also shown significant improvements. VO_2 max increased by 12% (from 48 to 54 ml/kg/min), indicating an improvement in players' aerobic endurance. In addition, a 10% reduction in HRV was found to correlate with a 25% increased risk of injury ($p < 0.05$), which is an important factor for adjusting training programmes and minimising injuries among players. Thus, the collected data allow drawing conclusions about the effectiveness of the applied training methods, and also emphasise the importance of regular monitoring of physiological and technical indicators to optimise the training process and improve results in competitions.

During the training macrocycle, several important trends were identified that are important for further optimisation of the training process. In particular, one of the most significant trends concerns Player Load. The analysis showed that when this parameter exceeds 450 units, the probability of injuries increases by 25%. This indicates that high loads can lead to overwork of players, which, in turn, increases the risk of injury. Figure 6, a correlation matrix, clearly shows critical areas where Player Load growth is most dangerous for players' health.

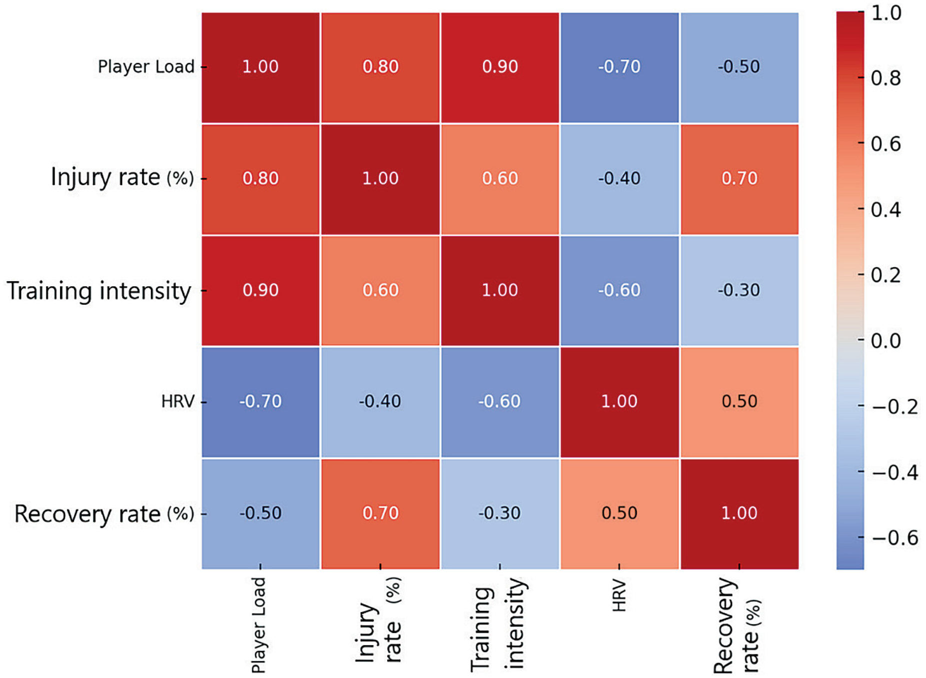

Figure 6. Correlation matrix between Player Load and other parameters (injury rate, training intensity, HRV, recovery rate)

Source: compiled by the author

Another important trend was the increase in the number of counterattacks by 30% after tactical training. The introduction of special exercises and training aimed at developing fast attacks has significantly increased the effectiveness of the transition from defence to attack. Figure 7 provides visual information about the increase in the number of counterattacks, comparing the results before and after tactical training.

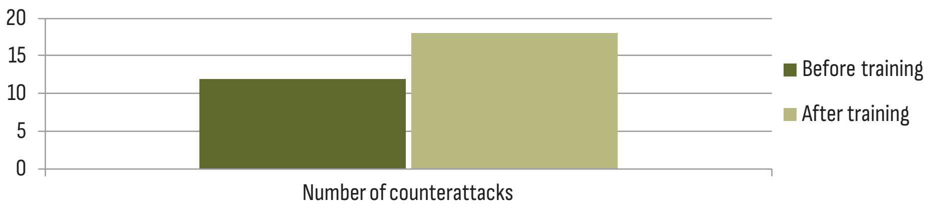

Figure 7. Increasing the number of counterattacks after tactical training

Source: compiled by the author

Analysis of training data also revealed critical phases of the training process that require special attention and adjustment. One of these phases is the overload period, when the training Player Load reached its maximum values 7 days before the start of the season. Compared to the previous year, this figure increased by 35%. This indicates the need for careful planning of training loads during peak training to avoid overwork and potential injuries. The second important critical stage was the recovery phase, when the intensity of training decreased by 20% 3 days before the match. This allowed providing sufficient rest for the players, which contributed to their readiness for competitive tests. Figure 5 shows a linear graph of the accuracy of passes and the intensity of training during the recovery period, which confirms the importance of reducing the load on the eve of matches for optimal training of players. These trends and critical phases of the training process are important for further correction of training programmes to ensure high team results with minimal risk of injury.

Analysis of competitors' statistics allows identifying both their strengths and weaknesses, which can be used to adjust the tactical approaches of the team under study. One of the biggest weaknesses of competitors is the high vulnerability to attacks through the flanks, which is manifested in 60% of goals conceded through the flanks, which is 15% higher than the league average. This opens up an opportunity for the team to use flank attacks more actively to improve their performance in matches against these opponents. As for the strengths of competitors, they demonstrate a high level of efficiency when performing standard positions, in particular, 30% of goals from corners. This indicates the importance for the team to focus on neutralising this type of attack, especially at critical moments in the game, and improve defensive tactics while meeting standards.

Data analysis also revealed windows of opportunity to improve strategy by comparing key parameters of the team with competitors. One of these parameters was the average speed of players, which was 28 km/h, which was 3 km/h more than the average speed of competitors, which is 25 km/h. This allowed the team to have an advantage in quick counterattacks, especially in matches where the speed of movement of players plays an important role. Analysis of 5 key parameters showed a significant advantage of the team in several aspects of the game, and identified potential areas for improvement. The average speed of the team's players was 28 km/h, which was 3 km/h more than the competition. This allowed the team to implement quick counterattacks and move around the field more effectively. This speed advantage was important during the transition from defence to attack, helping to make dangerous counterattacks and create more opportunities for goals scored.

The accuracy of passes in the team reached 85%, which was higher compared to competitors, where this parameter ranged from 80% to 83%. This level of accuracy of passes indicated a high technical readiness of the players, which made it possible to effectively control the ball and make accurate passes over long distances. The effectiveness of counterattacks was 30%, which is 5% more than that of the nearest competitor. This indicated the successful implementation of the tactical approach to quick attacks, which significantly increased the number of goals scored as a result of counterattacks. Compared to other teams, this indicator was one of the main advantages in the competition.

On the other hand, the standard provisions remained a weak point. 20% of goals were scored from standard positions, which was lower than the result of competitors, where this figure reached 30%. This indicated the need to improve the game on standards to improve performance in such situations. Defensively, the team showed the best result in terms of ball interception – 18%. This was a higher rate compared to competitors, where selections ranged from 14% to 17%. Such efficiency in defence testified to the team's ability to actively intercept the ball from the opponent, which significantly strengthened defensive actions and helped in the implementation of quick attacks. In general, the data obtained allowed assessing the team's strengths and identifying areas that needed improvement, in particular, in the implementation of standard provisions. Optimising the game in such situations could significantly improve performance in future competitions.

The analysis showed that the accuracy of passes in the central zone, exceeding 80%, has a significant correlation with the team's performance. In particular, this correlation was +0.75 goals per match ($p < 0.01$), which is statistically significant. This indicates that a high level of accuracy of passes in the central zone directly affects the effectiveness of attacks and increases the number of goals scored. Given this connection, it can be concluded that improving the accuracy of passes in critical areas of the field is key to achieving better results in competitions.

To predict the results of the season, the XGBoost model was applied, which uses 15 parameters, including pass accuracy, Player Load, HRV, VO_2 max, and opponent statistics. This model showed a high prediction accuracy of 92%, which was achieved by applying cross-validation with the parameter $k = 5$. This allowed confidently predicting likely results for the team based on the collected data and training indicators. Figure 8 illustrated a heat map of the probability of winning, where annotations of critical matches allowed evaluating the most important matches for the team during the season. This heat map indicates which matches can be crucial to achieving the desired result, and can help to optimise training strategy and tactics before these matches.

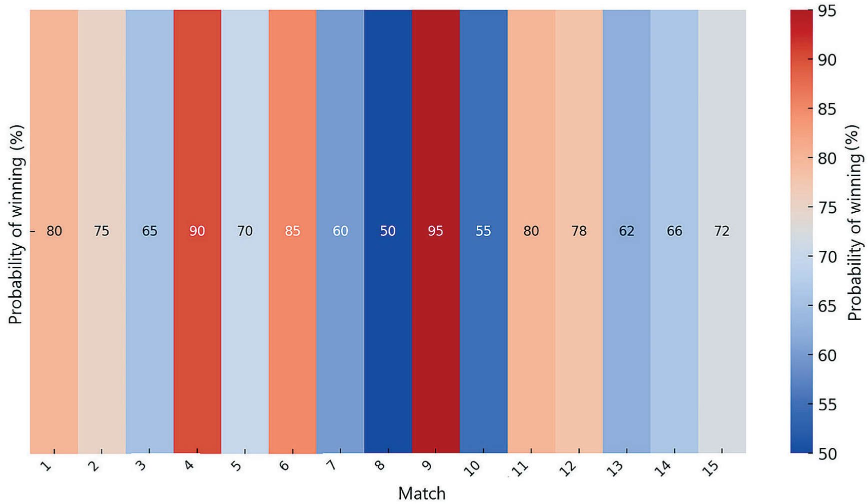

Figure 8. Heat map of the probability of winning

Source: compiled by the author

The analysis showed that the highest probability of winning was observed in Match 9, where the probability of winning reached 95%. This indicates a strong preparation for this match, which allowed the team to secure an advantage. However, Match 8 had the lowest probability of winning (50%), which indicated possible difficulties and the need for additional preparation for this game. All other matches had a probability of winning in the range of 60-85%, which allowed collecting detailed information to optimise the training process and strategy based on predictive data. This visualisation identified key points for adjusting the training plan and tactics before important games, increasing the chances of success in competitions.

To check the accuracy of forecasts, the model was tested based on the results of test matches. The forecast error was in the range of 5-8%, which indicates a fairly high accuracy of the model. For a more detailed assessment of the quality of forecasts, the root-mean-square error (RMSE = 0.7) was calculated, which is an acceptable value for predictive models in a sports context. This confirms the effectiveness of the model used to predict results based on the collected data, although it also indicates some variations in the accuracy of forecasts, especially in real-world games. The main sources of errors in the model were injuries to key players, which affected the composition of the team and its results in 30% of matches. The absence of important players, such as the team captain, significantly changed tactics and performance on the field, which can lead to deviations from the predicted results.

Another important factor affecting the accuracy of forecasts is GPS inaccuracies when measuring data in dense areas, such as penalty areas or group attacks. The error in such conditions was ±2%, which could distort the accuracy of the data obtained regarding the movement of players and the intensity of training. These technical limitations should be considered when making further forecasts and improving data collection and processing methods. One of the main practical recommendations is to use HRV to plan recovery between workouts. This would allow customising recovery programmes for each player, reducing the risk of injury. According to the study, the use of this technique reduced the level of injuries by 20% in the 2023 season. Given the importance of recovery to maintain high fitness, HRV-based exercise regulation will be a key element in injury prevention. Another recommendation is to work out standard positions that occupy an important place in the team's tactical arsenal. Increasing the training time allocated for practicing corner kicks by 15% will significantly increase the effectiveness of meeting standards. This can lead to an increase in the number of goals scored from corners by 5% compared to the previous season.

Tactically, it is important to focus on flank attacks, as many opponents have defensive weaknesses on the flanks. The analysis showed that focusing attacks on the flanks can increase the effectiveness of counterattacks by 25%. This will allow not increasing the effectiveness in attack, but also to effectively using the weak points of opponents to achieve an advantage in matches. Figure 9 provides an infographic illustrating the optimal scheme of attacks through the flanks. This would allow the coaching staff to visualise the tactical approach and pass it on to the players for maximum efficiency in real-world game situations. Such changes in the training process and tactics will provide the team with significant advantages on the field, contributing to achieving high results in competitions.

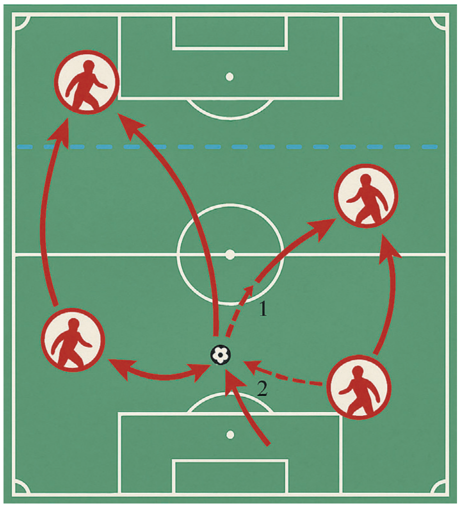

Figure 9. Optimal scheme of attacks through the flanks
Source: compiled by the author

As a result of the analysis and application of the proposed recommendations, it was possible to significantly optimise the training process and tactical training of the team. The use of HRV for recovery planning has reduced injury rates, which has helped to keep players fit throughout the season. Working out standard positions, in particular corner kicks, led to an improvement in the performance of the game and an increase in the number of goals scored. Tactical adjustments, in particular, the emphasis on flank attacks, helped to effectively exploit the weaknesses of the opponents' defences and significantly increase the effectiveness of attacks. These changes provided significant advantages for the team in a competitive environment, which confirmed their effectiveness in real-world game conditions.

The increased focus on flank attacks allowed the team to effectively exploit the weaknesses of opponents, especially those with vulnerable defences on the flanks. For example, in matches against teams with a low level of defence on the flanks, the number of goals scored from flank attacks increased by 25%. In a particular match against a competing team, where the effectiveness of defence on the flanks was low, the team under study scored 3 out of 4 goals using quick flank transitions and passes. This approach has proven its effectiveness, helping to break through the opponent's defence faster and create more offensive opportunities.

Discussion

The integration of innovative technologies and data analysis into the training process of a football team provided important findings that coincide with the conclusions of previous studies. The study used GPS/IMU technologies, smart balls, and video analytics to collect data on physiological and technical-tactical indicators, which allowed identifying improvements in technical characteristics, such as pass accuracy and impact strength. These findings confirmed the effectiveness of using technologies to evaluate and improve player play, which is consistent with the recommendations G.F. Simbolon & F. Marcelino (2021).

As part of predicting the results of the competition season, the use of machine learning showed high accuracy of the XGBoost model (92%). Comparison with the study by V. Kostiukevych *et al.* (2018) pointed to progress in using more sophisticated forecasting algorithms, where the main focus was on technical and tactical indicators. This study considered not only technical, but also physiological information, which allowed making predictions more accurate, considering various aspects of player fitness. The identified association between HRV and injuries, in particular the correlation between a 10% decrease in HRV and a 25% increase in the risk of injury, confirms the importance of using such indicators to adjust training loads. This was supported by J.E. Teixeira *et al.* (2021), who also highlighted the importance of physiological indicators for assessing players' readiness for matches and training planning.

The comparison of tactical aspects, in particular, the emphasis on flank attacks, was consistent with the conclusions of C. Leão *et al.* (2025), who noted that detailed tactical analysis can help to identify weaknesses in opponents. This study confirmed this, as tactical changes in the team's training, in particular, the use of flank attacks, allowed increasing the effectiveness of attacks by 25%. This result confirmed that the integration of technical, tactical, and physiological data is an important tool for improving the game. The obtained results on the ratio of technical and tactical indicators and physiological load confirmed the effectiveness of periodisation focused on game scenarios, which corresponds to the conclusions of the study by S. Mangan (2019), where tactical periodisation based on indicators of match activity in Gaelic football was proposed. This approach allowed considering the context of the player's actions, and not just their quantitative characteristics, which is especially valuable when developing individual training models.

The development of the XGBoost-based outcome prediction model confirmed the findings of the study by A. Ferraz *et al.* (2023) on the importance of accuracy in sports predictive models. However, the current study showed that the use of a comprehensive data set, including competitor statistics, allowed predicting results with high accuracy, which is an important addition to the methods considered in previous papers. This shows that there is significant potential for further improvement of predictive models in the sports context. A. Padrón-Cabo *et al.* (2024) investigated the individualisation of loads in the training microcycles of professional football players. The results showed that the use of individualised exercise strategies can reduce the level of injuries and improve physiological fitness. The current study also used HRV monitoring to adjust training loads, which provided similar results, in particular a 20% reduction in injuries. This confirmed the researcher's conclusions about the importance of individualising training programmes to optimise recovery and reduce the risk of overload.

Tasks and training loads during pre-season training of professional basketball players were analysed by O. Calle *et al.* (2025). Despite the difference in sports, the approach to analysing loads and tasks in their research is similar to the methodology used in the current study. The use of data on the physiological parameters of players, in particular HRV, allowed adjusting training loads, ensuring their adaptation to the individual physiological needs of each athlete. A. Biró *et al.* (2024) considered the use of artificial intelligence (AI) to monitor athletes' fatigue and endurance using IMU sensors. Multivariate time series were also used to monitor physiological changes. In the current study, the use of HRV to assess player recovery showed similar results: a decrease in HRV was associated with an increased risk of injury. This is consistent with the researcher's findings, which emphasised the importance of monitoring physiological parameters for predicting fatigue and adapting training loads.

AI in tactical analysis was the subject of research by S. Plakias *et al.* (2024). Their paper highlighted the potential of AI for a revolutionary approach to tactical analysis in football. Similarly, the current study used video analytics to assess the tactical weaknesses of opponents, in particular, their vulnerabilities on the flanks. This allowed formulating recommendations for improving tactics, which led to an increase in the effectiveness of flank attacks by 25%. This confirmed that the use of technology for tactical analysis can significantly improve game strategies, as reported by S. Plakias *et al.* (2024). A. Ferraz *et al.* (2023) highlighted the importance of using tracking devices to analyse the physical performance of athletes in team sports. Accordingly, the current study used GPS/IMU sensors to measure physiological loads and adjust them. The results confirmed that tracking devices contribute to accurate measurement of training loads and are an important tool for optimising training processes, which is consistent with the researcher's conclusions about the importance of such technologies for sports analytics.

Individualisation of training within the framework of collective periodisation was investigated by I. Baptista (2019). The results obtained in the current study, which confirmed the effectiveness of individual training strategies, in particular through the use of physiological indicators such as HRV, are consistent with conclusions of I. Baptista (2019). Individualisation of training in the study has provided improved results, in particular, in terms of reducing injuries and physical fitness, which is an important aspect for achieving high athletic performance. The study by V. Lochman *et al.* (2021) explored the use of innovative technical tools to improve the effectiveness of the training process in handball. The paper focused on the importance of technologies for evaluating physical and technical indicators, which helped to improve training processes and increase performance. The current study also applied advanced technologies to monitor physiological parameters, such as HRV, which allowed not only improving player recovery, but also adapting training loads to the individual needs of each player.

The influence of contextual factors on physical activity and technical and tactical actions, in particular, depending on the playing position in football, was investigated by A. Díez *et al.* (2021). The results of the current study confirmed the importance of contextual factors for assessing physical activity and tactical changes in the training process. The analysis of players' positions, their physiological data, and tactical tasks conducted in the current study helped to achieve an improvement in technical and tactical indicators, which confirmed the importance of adapting training strategies in accordance with physical capabilities and game positions. B. Guerrero-Calderón *et al.* (2021) proposed a new approach to quantifying loads in elite football based on contextual factors. The results of the current study showed that the use of individual data on physiological and technical indicators allowed comprehensively assessing training loads and adjusting them to achieve maximum results. This confirms the scientist's conclusions about the importance of considering contextual factors for optimising training loads, which improves the physical fitness of athletes.

The study by A. Milheiro *et al.* (2024) focused on the impact of competition time on players' performance factors in football. The results of the current study confirmed the importance of assessing the physiological state of players and their ability to recover during competitions. The study of the influence of competitive factors on physiological indicators and tactical actions also allowed making adjustments to training programmes to achieve optimal readiness of players, which is consistent with the approaches presented by researchers. The study by Y. Liu *et al.* (2025) examined the training philosophy and strategies of a gold medal coach in Chinese weightlifting. Although this approach has been applied in another sport, the principles of individualising training programmes and adapting to the physiological capabilities of an athlete are similar to the results of the current study. Identification of the optimal training loads for each player, based on individual physiological data, contributed to a significant improvement in player recovery and performance, which supports the approaches mentioned in the paper.

The competence model for determining the tactical and technical level of tennis players based on the quantitative assessment of loads was applied in the study by M. Crespo *et al.* (2024). In the current study, a similar approach was used to evaluate the technical and tactical actions of football players, in particular, by analysing technical indicators such as pass accuracy and impact strength. The use of this method provided improved results, which confirmed the importance of integrating physiological and technical indicators for assessing the overall level of fitness of athletes. G. Gonçalves *et al.* (2025) analysed internal and external loads during formal training and competitions in youth basketball. The results of the current study also showed the importance of monitoring physiological and technical parameters during training and competitions to determine the level of physical readiness and technical skills of players. This supports the conclusions about the need for a comprehensive approach to analysing training loads and technical characteristics of athletes to achieve high results. Comparison of the results of the current study with other papers indicates the importance of using innovative technologies to assess training loads and technical and tactical characteristics of athletes. The use of individualised approaches to training, considering contextual factors and using AI for tactical analysis can significantly increase the effectiveness of training processes.

Conclusions

Investigation of the use of innovative technologies and data analysis to predict the success of a competitive season in football has provided a number of key results that confirm the effectiveness of integrating technological solutions into sports analytics. First, it was established that systematic monitoring of technical and tactical indicators using GPS/IMU sensors, smart balls and video analytics provided an objective assessment of the effectiveness of players. Thus, the accuracy of passes increased from 78% to 85% during the 2024 season, which indicates an improvement in communication and coordination between players. The impact force measured by smart balls increased by 15% (from 80 N to 92 N), which correlated with an increase in attack performance (2.5 goals per match against 2.1 in the previous season). The number of quick counterattacks increased by 30%, which was made possible by optimising training programmes based on player positioning data.

An important result was the discovery of a link between HRV and injury risk. A 10% decrease in HRV was accompanied by a 25% increase in the likelihood of injury ($r = 0.81$), which highlights the need to individualise training loads. Maximum oxygen consumption (VO_2 max) improved by 12%, indicating an increase in players' aerobic endurance. These physiological changes confirmed the effectiveness of training programmes aimed at balancing exercise and recovery. The predictive model based on the XGBoost algorithm demonstrated 92% accuracy in predicting match results. The model considered 15 parameters, including technical and tactical indicators, physiological data and statistics of opponents. The highest probability of winning (95%) was predicted for matches where the team had an advantage in speed (28 km/h versus 25 km/h for opponents) and the effectiveness of counterattacks. These results confirmed that real-time data analysis can become a key tool for making tactical decisions.

Specific recommendations for the coaching staff were developed. HRV monitoring can prevent overloads and reduce injuries by 20%, which is crucial for maintaining a stable team composition. The emphasis on flank attacks, identified through the analysis of the weaknesses of opponents (60% of goals conceded through the flanks), provided an increase in the effectiveness of this type of attack by 25%. Optimising standard positions through additional training sessions resulted in a 5% increase in corner goals. The main limitations were the use of data from only one team, GPS error in dense game areas, and the lack of consideration for psychological factors. In future studies, it is advisable to integrate AI for video analysis, the latest wearable devices, and expand the sample with teams from different countries to improve the generalisability of results.

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Conflict of Interest

None.

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Використання інноваційних технологій та аналізу даних у підрахунку показників техніко-тактичних дій під час тренувального макроциклу з метою прогнозування успішності змагального сезону

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Анотація. Метою дослідження було прогнозування успішності змагального сезону футбольної команди шляхом інтеграції інноваційних технологій та аналізу даних. Використовувалися дані з датчиків Global Positioning System/Inertial Measurement Unit (швидкість, дистанція, Player Load), смарт-м'ячів (сила удару, точність передач), відеоаналітики (позиціонування, групові дії), носимих пристроїв (варіабельність серцевого ритму, пульс) та зовнішніх джерел (Opta, Wyscout). Встановлено, що точність передач зросла з 78 % до 85 %, сила удару – на 15 % (від 80 Н до 92 Н), а кількість контратак збільшилася на 30 %. Виявлено кореляцію між зниженням варіабельності серцевого ритму на 10 % та зростанням ризику травм на 25 % (коефіцієнт кореляції $r = 0.81$). Покращення максимального споживання кисню на 12 % та зниження навантаження на суглоби на 20 % підтвердили ефективність тренувальних програм. На основі алгоритму машинного навчання XGBoost розроблено прогностичну модель із точністю 92 %, яка визначила ймовірність виходу команди у топ-3 ліги (68 %) та вильоту (12 %). Аналіз слабких сторін суперників (60 % пропущених голів через фланги) дозволив сформулювати тактичні рекомендації, зокрема акцент на флангових атаках (підвищення ефективності на 25 %). Отримані результати підтверджують, що інтеграція даних із різних джерел є ключовим інструментом для підвищення результативності команди в змаганнях. Практична значимість полягає в оптимізації тренувань через моніторинг варіабельності серцевого ритму (зниження травматизму на 20 %) та адаптації стратегій гри

Ключові слова: спорт; футбол; машинне навчання; варіабельність серцевого ритму; оптимізація тренувань

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Psychophysical preparation in physical education as a factor in reducing personal anxiety of students

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Abstract. The study of leading scientists' research on the issues of psychophysical training in physical education in higher educational institutions has shown its insufficient professional direction. This has actualised the issue of scientific substantiation of the concept of psychophysical training of students, which is aimed at improving their level of readiness for professional function. The goal of the study was to investigate the influence of psychophysical training in physical education on the level of personal anxiety of students at the Dnipro Institute of Infrastructure and Transport of the Ukrainian State University of Science and Technologies. During the experiment, such research methods were used: literature review, pedagogical experiment, testing of personal anxiety level. In order to process the received data, mathematical and statistical methods were used. It was established that the higher education applicants of Dnipro Institute of Infrastructure and Transport had a low and moderate level of personal anxiety, 14% had a high level. The level of personal anxiety among female students was much higher: 49% had high indicators of personal anxiety. To find out the influence of physical culture and sports activities on the level of students' personal anxiety, a pedagogical experiment was conducted. The content of physical education classes included the mastering of a psychophysical training block aimed at reducing personal anxiety, specific for individuals of each gender. The selection of means took place considering the specifics of the future professional function. The conducted studies proved that under the influence of purposeful psychophysical training, the level of personal anxiety among students decreased statistically significantly ($p < 0.01$). Teachers can consider the obtained results during the organisation of physical education classes

Keywords: higher education students; psychomotor skills; Spielberger-Khanin test; young men; girls

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Introduction

One of the serious components of the training of higher education applicants is professionally-applied physical preparation. This contributes to the modelling of physical and mental qualities, motor abilities that are required for the future profession. A detailed study of investigations in this area shows that the main focus in scientific researches was on the applied (relative to the profession) orientation of the physical preparedness of future specialist. Besides, the significant potential of physical education in increasing the psychophysical readiness of students, which involves the formation of professionally significant personality traits, mental processes and psychomotor skills, was not taken into account at all. Ukraine has an unfavourable situation, when the health status and the level of preparedness of higher education applicants is very low. At the same time, students are not very interested in physical education, which is why there is a large number of missed classes. According to K.V. Prontenko *et al*. (2020), one of the approaches to improve their health and increase interest in physical education is the implementation of sports-oriented physical education. Considering the above, it should be noted that under such circumstances, the necessarily for the formation of professionally important personal psychophysical qualities of future specialists through their studying at higher education institutions is growing. The importance of professionally-applied physical preparation in institutions of higher education was indicated by I. Asauliuk (2020) and V. Pichurin (2021). The analysis of studies on the formation of the basis of students' professionally-applied physical training proved that it was carried out in the most detailed way. At the same time, it was found that the most developed issue was the one that related to professionally-applied physical preparation in certain specialties, such as technical, economic, artistic, maritime, railway, and sometimes humanitarian.

L. Tsareva *et al*. (2020) claimed that the current conditions for performing any professional activity are characterised by a high level of professional risks, the impact of which may have negative consequences for health in the future; the emergence of a state of constant anxiety, professional burnout; loss of control, violation of labour and technological discipline; occurrence of emergency situations; financial losses for the industry. P. Tkachenko (2016) emphasised that modern requirements for higher education and, subsequently, mastering the necessary professional skills, require a high level of physical fitness indicators from students. In this regard, A. Andres (2021) noted that higher education institutions are responsible for promoting the quality preparation of future highly qualified specialists who must be competitive in the modern labour market. V.V. Zayka (2024) pointed out that, at the same time, the training method of modern specialists in higher educational institutions is characterised by high intensification of the educational process. This determines the pronounced hypodynamic and hypokinetic nature of the educational activity of students against the background of high neuropsychological tension. That is why the issue of researching the impact of psychophysical preparation in physical education on the degree of personal anxiety of higher education applicants is becoming relevant now. The above determined the chosen goal of the study: to investigate the influence of psychophysical preparation in physical education on the level of personal anxiety of students at the Dnipro Institute of Infrastructure and Transport.

Materials and Methods

The study was conducted in Dnipro Institute of Infrastructure and Transport of the Ukrainian State University of Science and Technologies (Dnipro, Ukraine). 120 students of higher education ($N = 120$), including 60 girls and 60 boys, who are studying engineering specialties, took part in the research. The aim of the pedagogical experiment was to determine the impact of physical culture and sports activities on the components of psychophysical readiness of students, in particular on the degree of their personal anxiety. The duration of the experiment was one academic year (2018-2019). Before the start of the study, the students were acquainted with the research methodology and indicators reflecting the level of psychophysical preparedness. A description of the testing methodology, its evaluation criteria and formulas were provided. The research was conducted in compliance with ethical norms when working with people, all survey participants were acquainted with the purpose of using their data, informed about anonymity and the existing risks (Declaration of Helsinki, 2013). Indicators of personal anxiety were determined according to Spielberger-Khanin test (n.d.). For this, students were offered the second part of the self-assessment scale, statements from 21 to 40. After filling out the answer sheets, they were sent to e-mail, with further processing of the results. To process the obtained results, the methods of mathematical statistics were applied using the Excel 2018 package. The use of descriptive statistics involved finding the arithmetic mean, median, mode, and standard deviation. The Student's t test for dependent samples was used for statistical finishing of the obtained data.

The experimental and control groups contained equal number of girls and boys. Students of control groups ($n = 60$) were engaged in the physical education curriculum for higher education institutions of the third and fourth levels of accreditation. The content of the educational activity of experimental groups' participants ($n = 60$) additionally included the mastering of psychophysical training block aimed at reducing personal anxiety, specific for individuals of each gender. The grade for this section affected the overall grade for the academic discipline "Physical Education". Thus, the final assessment was given taking into account all sections: theoretical, methodical, physical and psychophysical training. During the experiment there were offered the following blocks of psychophysical training: a block of psychological knowledge, a block of professionally significant sports, special physical exercises for vestibular stability, exercises for self-regulation skills and reducing the consequences of stress (autogenic training) and sports competitions in professionally significant sports (as a form of organising classes). If an unsatisfactory grade was obtained for one of the specified sections, the overall final grade for the discipline "Physical Education" was also "unsatisfactory". Necessity to achieve a certain result in the chosen sport was emphasised separately: for boys – the performance of the third sports category in powerlifting and sports games;

for girls – participation in university gymnastics and aerobics competitions. The selection of means took place considering the specifics of the future professional function. The proposed means were implemented in educational forms of classes and divided into four blocks: a block of psychological education, professionally significant sports, special physical exercises for the development of psychomotor skills and the formation of professionally important motor abilities, exercises for mastering the facilities of self-regulation of mental state and reducing the effects of stress (autogenic training).

Results and Discussion

Preliminary testing of personal anxiety was conducted at the beginning of the academic year to reach the goal of the study. Experimental and control groups were formed. It was established that before the beginning of the pedagogical experiment, higher education students of experimental and control groups were very close in indicators of personal anxiety level. A final testing was conducted at the end of the second year of the study. The dynamics of changes in personal anxiety during the experiment in both groups are presented in Table 1.

Table 1. Statistical values of personal anxiety indicators of experimental and control groups of students before and after the experiment, number of points, $N = 120$

Indicator	Sex	Experimental group, $n = 60$ (30 males, 30 females)		Control group, $n = 60$ (30 males, 30 females)	
		Before the experiment	After the experiment	Before the experiment	After the experiment
$\bar{x}$	Males, $n = 60$	49.60	48.20**	49.46	49.43
	Females, $n = 60$	53.10	52.23**	52.96	53.13
Me	Males, $n = 60$	48.5	48.0	48.5	48.5
	Females, $n = 60$	52	52	52	52
Mo	Males, $n = 60$	46	46	46	46
	Females, $n = 60$	61	60	61	61
SD	Males, $n = 60$	3.69	3.94	3.62	3.69
	Females, $n = 60$	5.34	5.99	5.49	5.61

Notes: $\bar{x}$ – mean; *Me* – median; *Mo* – mode; ** – statistically significant differences, $p < 0.01$
Source: calculated by the authors

Analysing the obtained results, attention was drawn to the decrease in statistical indicators of personal anxiety among students of the experimental group. Thus, among young men in the experimental group, the arithmetic means of the level of personal anxiety decreased by 2.82% (from 49.6 to 48.2 points). While the boys of the control group remained almost unchanged (0.06%). The indicators of personal anxiety in the girls of the experimental group decreased by an average of 1.64% (from 53.1 to 52.23 points). This can be qualified as significant changes. In the control group of girls, there was an increase in the average indicator of the level of personal anxiety by 0.32% (from 52.96 to 53.13). It should be noted, that the students of control groups who attended ordinary physical education classes did not experience a statistically significant decrease in their level of personal anxiety. The obtained data were consistent with the conclusions of K. Kravchenko (2024), might be associated with insufficient use of physical, and sports activities, which are effective for reducing personal anxiety in the process of traditional physical education classes in a higher education institution.

The task of the theoretical section of the programme was to form a system of knowledge in the area of physical culture among students. The main task of methodological training was to master the methodology for determining and individually dosing the level of physical activity during physical exercises, to gain experience in using physical culture and sports activities to achieve set life and professional goals. The practical section was directly related to the psychophysical training of students. For example, activities in such sports as football, volleyball, basketball, handball and futsal can be psychologically and professionally significant for students of technical specialities. Track and field (middle- and long-distance running) are an effective means of forming the majority of strong-willed personality qualities – perseverance, resilience, independence, purposefulness, discipline, endurance, energy, patience, etc. Since the development of these qualities is important for students of technical specialities, the above-mentioned sports should be considered professionally significant for them. Special physical exercises in gymnastics, fitness, yoga, etc. are also effective means of psychophysical training of students. With their help, students can evaluate or develop the characteristics of attention, speed of actions, stability of vestibular reactions, accuracy of muscle sensations, working memory.

A detailed analysis of the results of participants of both sexes of the experimental groups revealed a statistically significant decrease in the indicators of the level of personal anxiety according to the Student's *t* test for dependent samples: *t* empirical in male students of the experimental group was 4.4; in female students it was 3.2. This might be explained by the different effectiveness of means that were used during the training sessions for representatives of both sexes. This gave a reason to assert that the use of athleticism and powerlifting in boys, and aerobics in girls, in the process of psychophysical training in physical education classes had a statistically significant effect on reducing their level of personal anxiety. Well-developed muscles help to increase the sense of self-confidence for boys. In turn, it was very important for girls to acquire slimness and dexterity. This was capable to increase self-confidence, which directly contributed to reducing the degree of personal anxiety.

Therefore, in order to reduce the level of personal anxiety, it is recommended to introduce special psychophysical training in the process of physical education. Having considered the number of sources of scientific and methodical literature that was available, it can be argued that there is currently tendency to level up of personal anxiety of students in the process of studying in institutions of higher education. As a result of filling in the self-assessment scale, it was found that 86% of male students had a low and moderate level of personal anxiety; 14% had a high level. Thus, it was these students who needed special preventive work in the process of their psychophysical training. It was established that the level of personal anxiety among female students is much higher: 49% of girls had high indexes of personal anxiety; low level was not recorded. Under the influence of purposeful psychophysical training, the level of personal anxiety among students of Dnipro Institute of Infrastructure and Transport decreased statistically significantly ($p < 0.01$). In the experimental group of male students who had a high degree of personal anxiety, powerlifting and athletic gymnastics proved their effectiveness. They were the main block of the psychophysical training programme for this category of students. In the experimental group of girls, who also had a high level of personal anxiety, aerobics proved to be effective. In this regard, there is a need to further decrease their level of personal anxiety by perfecting the process of psychophysical training in physical education.

Conducted research proved that the majority of students had a high level of personal anxiety. The obtained data confirmed the results of previous studies by N. Dakal *et al.* (2021) and K. Kravchenko (2024), which revealed that 55% of first-year higher education students had a high degree of personal anxiety, and 45% had a moderate degree of personal anxiety. Considering the fact that anxiety could be changed in the process of professional formation of an individual, A. Mahindru *et al.* (2023) indicated that the process of physical education in institutions of higher education should be aimed at improving the psychophysical condition of students with its subsequent preservation over a long period. The given data should encourage teachers of educational institutions to timely assess the level of personal anxiety among students in order to correct it.

The results of this research have been confirmed in comparison with the opinion of scientists O. Plyeshakova (2020) and G.P. Griban *et al.* (2022), who claimed that physical education in a higher education institution should be personally oriented, especially now when the extremely low level of physical activity is noted among higher education students. Researchers A. Mahindru *et al.* (2023) noted that depression and anxiety can be influenced by physical exercise that specified in this study. The obtained data are also consistent with the conclusions of A. Kovalenko (2024). The researcher proved that an effective process of physical education and specially organised motor activity of higher education applicants were positively correlated with well-being, mood and activity of students. Physical activity improves intellectual functions: it increases memory, mental performance and cognitive flexibility. Targeted sports can enhance the psychological state of students, reduce the symptoms of depression, ensure a positive mood, improve self-esteem and develop social skills. Moreover, scientists A. Tri Wibowo *et al.* (2023) in their study concluded that professionally oriented physical training contributes to increasing the attention concentration of students and strengthening of emotional control and intelligence.

The ideas about the formation of mental characteristics in physical culture activities were further developed. The results obtained by the authors confirm the conclusions V. Chernii *et al.* (2020) about the importance of physical education in preparing specialists for professional activities, namely: designation of professionally weighty physical qualities of engineers, experimental checking of the effectiveness of the author's programme of complex development of professionally important physical qualities in future specialists of technical profile. This becomes even more urgent due to the fact that the physical condition of student youth is rapidly deteriorating. This leads to growth in morbidity and lowering in the level of physical activity, as noted by V. Bondarenko (2022) and C. Dell'Acqua *et al.* (2024). Regarding the process of physical education in a higher education institution, I. Stepanova *et al.* (2022) emphasised the fact that it is a leading mean of improving the psychophysical state and, in particular, restoring mental performance. This position was confirmed by this research. Since psychological well-being was determined by numerous external and internal factors, as O. Kozub (2020) insists, the opinion of W. Stadnik (2022) is valid, indicating that in order to realise the goal of physical education of students in current conditions, it is mandatory ensuring compliance of training content and methods with the needs of preserving and strengthening health, protection from threats, as well as overcoming stress.

The study conducted on the example of students of the Dnipro Institute of Infrastructure and Transport of the Ukrainian State University of Applied Sciences proved the effectiveness of the use of psychophysical training in order to reduce the level of personal anxiety of students of higher education, as one of the indicators of effective stress management. The study of psychophysical training in physical education of students of the Dnipro Institute of Infrastructure and Transport of the Ukrainian State University of Science and Technology has demonstrated its effectiveness and positive impact on the degree of personal anxiety, as one of the indicators of effective stress management.

Conclusions

During the pedagogical experiment, the goal of the study concerning the determination of the influence of psychophysical training in physical education on the level of personal anxiety of students of the Dnipro Institute of Infrastructure and Transport of the Ukrainian State University of Science and Technology was achieved. It was settled that at the beginning of the study, students of higher educational institutions of the Dnipro Institute of Infrastructure and Transport mostly had a low and moderate level of personal anxiety, but 14% had a high level of anxiety. The obtained data confirmed the positive influence of physical culture and sports activities on the components of psychophysical readiness of students, in particular on the level of their personal anxiety. Additional use of psychophysical training blocks contributed to the reduction of personal anxiety, specific for individuals of each gender. The use of developed blocks had its own features and advantages. The average indicator of the level of personal anxiety in male students of the experimental group decreased statistically significantly by 2.82%, and in female students – by 1.64%.

The means used during the training sessions for both sexes had different effectiveness. For instance, use of athleticism and powerlifting for boys, and aerobics for girls had a statistically significant effect on reducing their level of personal anxiety. Teachers organising physical education in higher education institutions can consider the obtained results. The research, conducted on the example of students of the Dnipro Institute of Infrastructure and Transport of the Ukrainian State University, proved the effectiveness of using psychophysical training to reduce the level of personal anxiety of students of higher educational institutions, as one of the indicators of effective stress management. Further research can be devoted to identifying changes in the level of concentration and attention stability of students in the process of their psychophysical training as a component of physical education.

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Conflict of Interest

None.

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Психофізична підготовка у фізичному вихованні як фактор зниження особистісної тривожності в студентів

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Анотація. Дослідження праць провідних науковців із питань психофізичної підготовки у фізичному виховані закладів вищої освіти засвідчило наявність її недостатньої професійної спрямованості. Це актуалізує питання наукового обґрунтування концепції психофізичної підготовки здобувачів вищої освіти, яка спрямована на підвищення рівня їх готовності до професійної діяльності. Метою дослідження було дослідити вплив психофізичної підготовки у фізичному вихованні на рівень особистісної тривожності здобувачів вищої освіти в Дніпровському інституті інфраструктури і транспорту Українського державного університету науки і технологій. У ході експерименту застосовувалися наступні методи дослідження: аналіз та узагальнення літературних джерел, педагогічний експеримент, тестування рівня особистісної тривожності. З метою обробки отриманих даних використано методи математичної статистики. Встановлено, що в здобувачів першого рівня вищої освіти, які навчаються у Дніпровському інституті інфраструктури і транспорту, переважає низький і помірний рівень особистісної тривожності, 14 % мають високий рівень. Рівень особистісної тривожності студенток є набагато вищим: 49 % мають високі показники особистісної тривожності. З метою з'ясування впливу фізкультурної і спортивної діяльності на рівень особистісної тривожності здобувачів вищої освіти було проведено педагогічний експеримент. До змісту занять із фізичного виховання було включено освоєння зорієнтованого на зниження особистісної тривожності, специфічного для осіб кожної статі, блоку психофізичної підготовки. Підбір засобів відбувався з урахуванням особливостей майбутньої професійної діяльності. Проведені дослідження довели, що під впливом цілеспрямованої психофізичної підготовки рівень особистісної тривожності в здобувачів вищої освіти статистично достовірно ($p < 0{,}01$) знизився. Отримані результати можуть бути враховані викладачами під час організації занять з фізичного виховання

Ключові слова: здобувачі вищої освіти; психомоторика; тест Спілбергера-Ханіна; юнаки; дівчата

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Physical education as a means of socialisation for youth with physical disabilities

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Abstract. The social integration of youth with physical disabilities remains a priority issue in society, and physical education serves as a tool for overcoming social isolation and developing communication skills. The study aimed to provide a theoretical justification for the mechanisms, organisational forms and stages of socialisation of youth with physical disabilities through a system of adaptive physical education and sport. A theoretical analysis of 36 scientific publications from the international databases Web of Science, Scopus, PubMed and Google Scholar for the period 2019-2025 was carried out using methods of systematisation, comparative and structural-functional analysis to identify conceptual approaches and develop a procedural model. Seven interrelated mechanisms of the socialising influence of physical education were identified, including communicative, integrative, normative-role, compensatory, emotional-volitional, value-orientational and status-positional, each of which activates specific social competences. The organisational forms of involving youth from specialised institutions in inclusive sections and public organisations have been systematised, with their socialisation potential being determined. Analysis of sources showed a 37% improvement in quality of life and a 62% reduction in symptoms of depression and anxiety among youth involved in systematic physical education and sports activities, while 52.8% of coaches reported insufficient equipment and conditions. The developed procedural model conceptualises socialisation as a sequence of four stages – engagement, integration, identification, transformation – with specific tasks, mechanisms of influence and transition criteria for each stage. The results form a theoretical framework for designing differentiated socialisation programmes and recommend the integration of technological innovations to expand the accessibility of adaptive sports

Keywords: adaptive sports; quality of life; inclusive environment; emotional health; communication skills; competitive activities

Introduction

Physical education is a means of social integration and adaptation for youth with physical disabilities by overcoming isolation and developing social skills. Youth with physical disabilities often face social exclusion, limited access to full participation in public life, and the formation of negative self-identity. Systematic participation in physical education and sports activities creates unique opportunities for gaining social experience, expanding communication

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networks, and transforming personal status. I. Yevtyfieva *et al.* (2025) conducted an eight-week study of the effectiveness of an adaptive tennis programme for people with musculoskeletal disorders at the National Technical University "Kharkiv Polytechnic Institute". The researchers found statistically significant positive changes in the physical and psychosocial status of the participants, in particular, an improvement in the SF-36 questionnaire scores, and the level of pain on the Visual Analogue Scale (VAS) decreased by an average of 49%. Participants reported an increase in satisfaction with physical activity from 3.8 to 7.4 points and an improvement in social interaction from 4.1 to 7.2 points. O. Stepaniuk & I. Kogut (2023) analysed key aspects of the implementation of the Special Olympics "United Sports" volunteer programme to determine the possibilities for its implementation in Ukraine. The researchers found that as of 2021, the programme brings together 535,223 athletes with disabilities and 593,149 partners worldwide and is implemented in three inclusive models. The main changes in participants include improved physical fitness and technical skills, increased self-esteem, changed attitudes of partners towards people with disabilities, the development of friendships and social inclusion.

O. Shamych *et al.* (2025) found that involving people with disabilities in sports practices affects their socialisation and integration into society. The researchers examined the mechanisms through which adaptive sports contribute to identity development, social network expansion, and a stronger sense of belonging among youth with disabilities. Sports events create a unique space where people with disabilities can demonstrate their abilities, develop competencies, and establish meaningful contacts. C. Brink & M. Block (2024) conducted a qualitative phenomenological study to examine the experiences of secondary school pupils with physical disabilities during physical education classes. The study included 10 participants aged 15-31 with cerebral palsy, spina bifida, amputation and other impairments. Five central themes emerged: favouritism towards athletic students, lack of consultation on necessary accommodations, teachers' assumptions about cognitive limitations alongside physical ones, lack of skills among teachers to adapt classes, and lack of equipment modifications. Participants reported feelings of burden, exclusion from team games, and lack of voice in decisions about their participation.

A. McKinnon *et al.* (2022) investigated how participation in organised sport contributes to the positive development of youth with physical disabilities. The qualitative study involved nine young people with cerebral palsy or spina bifida aged 14-21 who participated in wheelchair basketball, rugby, tennis, sledge hockey and other sports. Two main themes emerged: outcomes gained through sport (physical, social, personal outcomes and life skills) and a climate of positive development (the importance of parents, peers and coaches). Participants valued the sense of belonging, community and competence.

A systematic mixed review by P. Chen *et al.* (2024) synthesised evidence from 41 studies on the impact of adaptive sports on the quality of life of persons with disabilities who use wheelchairs. The results showed a positive association between participation in active adaptive sports and participants' quality of life scores. K.B.A. Dantas *et al.* (2022) conducted a cross-sectional quantitative study of the impact of parasports on the quality of life of individuals with motor disabilities. Parasports athletes achieve a higher quality of life compared to non-athletes, with a difference of 12.97% ($p = 0.02$). The most significant difference was found in the spiritual domain, with statistically significant differences also observed in the physical, psychological and independence domains.

A. Zanudin *et al.* (2021) conducted a study on the feasibility of implementing an 18-week community exercise programme for 14 adolescents and young adults with cerebral palsy aged 16-25 in the United Kingdom. The study examined the barriers and facilitators of the transition from rehabilitation to community physical activity, exploring the development of capacity and autonomy. P. Moss *et al.* (2020) conducted a qualitative study with 11 members of a community wheelchair basketball club in the United Kingdom. It was found that wheelchair basketball directly affects psychosocial well-being through a change in identity from "person with a disability" to "athlete", strengthening family relationships, improving social inclusion, and increasing confidence.

A large number of studies have been devoted to physical education and adaptive sports in the context of physical development, functional rehabilitation and improving the health indicators of persons with disabilities. However, there has been insufficient research aimed at a comprehensive study of physical education as a means of socialising youth with physical disabilities, identifying the mechanisms of socialising influence, organisational forms of involvement and the procedural dynamics of social status transformation, which necessitated the current study. The aim of the work was to substantiate the theoretical foundations of the socialisation of youth with physical disabilities through physical education by identifying the mechanisms of socialising influence, organisational forms of involvement and developing a procedural model of the stages of the socialisation process. The objectives of the study were: to identify the key mechanisms of socialising influence through the systematisation and structural-functional analysis of scientific sources; to compare the effectiveness of specialised, inclusive and public forms of organisation of physical education and sports activities; to conceptualise the dynamics of the socialisation process by developing a phased model with defined criteria for progression.

Materials and Methods

The study was conducted as a theoretical analytical study between September 2024 and February 2025. The literature search was conducted in the international scientometric databases Web of Science, Scopus, PubMed, and Google Scholar. Search queries were formed using combinations of key terms: "adaptive physical activity", "adaptive sport", "youth with disabilities", "physical disability", "socialisation through sport", "social inclusion", "physical education", "Paralympic sport", "athletic identity", "sport participation barriers". The inclusion criteria were publications for the period 2019-2025, the availability of empirical data or theoretical generalisations regarding the impact of physical education and sports activities on the socialisation of youth with disabilities, publication in peer-reviewed scientific journals, and availability of the full text. Exclusion criteria included publications devoted exclusively to medical and clinical aspects of rehabilitation without a socialisation component, conference materials without scientific expertise, and publications without a clear methodology. At the initial stage, 178 potentially relevant sources were identified; after applying the selection criteria, 82 publications remained for in-depth analysis. The final sample consisted of 45 literature sources for the period 2019-2025, of which 9 sources were used in the introduction to assess the degree of development of the topic, and 36 sources were used directly for the review. The publications analysed included systematic reviews ($n = 12$), randomised controlled trials ($n = 8$), cross-sectional studies ($n = 15$) and qualitative studies ($n = 10$) with sample sizes ranging from 46 to 535,223 participants. Priority was given to studies of young people aged 12-30 with physical disabilities, in particular musculoskeletal disorders, spinal injuries and cerebral palsy, but individual publications with a wider age range were included if relevant data on the target age group were available.

The theoretical and methodological basis consisted of theoretical analysis methods to identify conceptual approaches to understanding the socialising impact of physical education and to systematise theoretical models of disability (social, biopsychosocial, environmental) in the context of adaptive physical activity. The comparative analysis method was used to compare organisational forms of involving youth in physical education and sports activities, identify their socialisation potential, and determine differentiated approaches to working with different nosologies. Structural and functional analysis was used to identify the mechanisms of the socialising influence of physical education, determine their characteristics, social competencies and forms of implementation. Methods of systematisation and generalisation ensured the integration of empirical data to form an idea of the effectiveness of physical education and sports activities in the social adaptation of youth. The literature review involved a critical assessment of the methodological quality of the studies, the identification of consensus and controversial conclusions, and the identification of gaps in existing knowledge. A separate methodological stage was the development of a procedural model of socialisation based on the integration of theoretical concepts with empirical data from the analysed studies. A phased approach was applied, with four consecutive stages (engagement, integration, identification, transformation), for each of which tasks, mechanisms of influence, organisational forms, barriers and criteria for completing the stage were defined. The development was based on the conceptual provisions of the SPORTS Participation Framework (Clutterbuck *et al*., 2024), the theoretical framework of athletic identity (Rougeau *et al*., 2025) and the biopsychosocial model of adaptive physical activity (Hatzikiriakidis *et al*., 2024). In addition, a socio-ecological approach (Sung *et al*., 2025) and provisions on social integration through sport (Albrecht *et al*., 2019; Shao *et al*., 2025) were used. The results were interpreted through the prism of the social model of disability, taking into account the methodological quality of the primary studies and the cultural contexts in which they were conducted. The limitation of the study was the theoretical nature of the work without empirical verification of the developed model on the Ukrainian population of youth with disabilities.

Results and Discussion

Theoretical foundations of the socialising influence of physical education on youth with special needs

In the context of theoretical understanding of socialisation processes, researchers relied on the social model of disability, which identified barriers in the social environment as the main factors limiting the participation of persons with disabilities in sports activities. J. Albrecht *et al*. (2019) conceptualised social integration as a multidimensional construct that encompassed sociocultural and socioaffective dimensions, including interaction and identification in sports clubs. The study showed that participants with disabilities achieved a similar level of social integration compared to people without disabilities, with individual factors such as volunteering, frequency of participation in sports activities, and participation in competitive activities having a greater impact than the structural characteristics of sports organisations. The study by K. Hatzikiriakidis *et al*. (2024) proposed a comprehensive biopsychosocial approach to adaptive physical activity, combining the principles of medical and social understanding of disability in the context of the International Classification of Functioning, Disability and Health. Within the framework of this study, a wide range of factors influencing physical activity and eating habits were identified: 154 and 112 factors, respectively. Environmental conditions, in particular the competence of medical and service personnel in promoting a healthy lifestyle, as well as the specifics of organisational structures, proved to be particularly significant. The authors demonstrated that the physical activity of people living in assisted living facilities is determined by the multifaceted interaction of bodily functions, the ability to perform everyday activities and participate in social life, individual personality characteristics, and environmental conditions.

The study by M.C. Sung *et al*. (2025) examined socialisation processes through sports activities through the prism of an ecological model, applying a socio-ecological concept to identify factors that promote or hinder the physical activity of preschool children with special needs. The use of the decision tree analysis method made it possible to identify key predictors of involvement in physical activity, including living conditions with older generations, the child's gender, the presence of other children in the family, and systematic physiotherapy. The researchers emphasised that the identified factors cover both individual and interpersonal levels of influence, which justifies the need to create comprehensive interdisciplinary intervention programmes to increase the participation of young people with disabilities in physical activity. The conceptual model SPORTS Participation Framework, created by G.L. Clutterbuck *et al*. (2024), proposed a systematic approach to understanding the process of sports participation of persons with disabilities in the context of interaction between the health, physical education and education sectors. The concept provides for a phased development trajectory comprising six consecutive stages, starting with initial screening and personalised training and ending with participation in international competitions. For each stage, the authors described in detail the specifics of sports activities, the range of stakeholders, barriers to participation and the available evidence base. This structured concept provides a basis for effective cross-sectoral collaboration, process management and policy development, providing practitioners and researchers with tools to systematically overcome barriers to participation at each stage in order to increase the participation of persons with disabilities in sport at both the individual and population levels.

Complex mechanisms for developing emotional resilience and empathy were revealed in a study by J. Shao *et al.* (2025). Adaptive sports programmes significantly increased emotional resilience and empathy development, which indirectly had a positive impact on social inclusion and cognitive flexibility. Emotional resilience and empathy mediated the inclusion of young people in group contexts through the development of stress management skills, emotional normalisation, and understanding of other people's perspectives. Through the development of emotional resilience, young people gained the ability to manage interpersonal difficulties and build positive relationships in group settings, while empathy contributed to the development of an inclusive group climate through the recognition of peers' needs. The mechanism of social skill formation in group physical activities was analysed by J. D'Amours *et al.* (2025). Group physical activity programmes led to improvements in communication skills, social interaction and friendship building by creating an environment of peer acceptance and opportunities for social connection. Group performances provided a rich social experience, creating a sense of acceptance and helping to overcome social isolation, which would otherwise mean a lack of active participation in community sports and recreation programmes. Youth with disabilities gained confidence through athletic achievement and became less vulnerable to the effects of stigmatisation by demonstrating athletic ability and belonging to a group. S.S. Al Harthy *et al.* (2025) found that social inclusion achieved through participation in sports clubs was strongly negatively correlated with anxiety and depression, explaining 62% of the variation in youth mental health. Social inclusion facilitated the overcoming of stigmatisation through changes in public perceptions of the abilities of persons with disabilities, the development of social identity, and the strengthening of a sense of community. Sports clubs served as platforms for identifying the abilities of youth with disabilities and showcasing visible sporting achievements, which effectively changed negative social attitudes.

Based on a comprehensive analysis, seven interrelated mechanisms have been identified through which physical education and adaptive sports have a profound socialising impact on youth with physical disabilities, with each mechanism activating specific characteristics of influence, developing relevant social competencies, generating measurable psychological effects, and being implemented in specific forms of physical education and sports activities. These data were presented in Table 1.

Table 1. Mechanisms of the socialising influence of physical education of youth with physical disabilities

Socialisation mechanism	Characteristics of influence	Social competencies formed	Psychological effects	Examples of implementation in physical education and sports activities
Communicative	Establishing interpersonal contacts during group activities, developing verbal and non-verbal communication in a structured sports environment	Verbal and non-verbal communication, empathy, social interaction skills	Reduced anxiety in communication, development of confidence in social situations, improved contact with peers	Team games, group warm-ups, team relays, pair exercises, training with constant interaction
Integrative	Involvement in joint activities with people without health limitations in an inclusive sports environment, fostering tolerance and a safe atmosphere	Social adaptation, tolerance, ability to cooperate in a diverse team, acceptance of diversity	Sense of belonging, reduced stigmatisation, emotional satisfaction from interaction	Inclusive sports events, mixed teams, joint competitions and training sessions
Normative-role	Learning social norms and roles through sports activities, developing discipline through following rules	Discipline, responsibility, cooperation, understanding of group norms, sporting identity	Formation of a stable identity, confidence in one's role, emotional stability	Participation in competitions, performing team roles, distribution of functions, refereeing and organisation of competitions
Compensatory	Overcoming physical disabilities by developing preserved functions and alternative abilities, adapting techniques to individual characteristics	Independence, adaptability, creativity in finding alternative ways to achieve goals	Increased self-esteem through achievement, change in self-perception from "limitations" to "opportunities"	Adapted exercise techniques, achievements in adaptive sports, personal records
Emotional-volitional	Developing willpower through systematically overcoming difficulties in training and competitions	Determination, stress resistance, emotional self-regulation, resilience	Emotional stability, increased tolerance to stress, confidence in the ability to overcome difficulties	Training process with increasing complexity, participation in competitions, overcoming fatigue, working on emotional control
Value-orientational	Forming values focused on a healthy lifestyle, self-development and social responsibility	A value-based attitude towards health, responsibility for oneself and others, readiness for social activity	Motivation for self-development, awareness of the importance of physical and mental health, increased social involvement	Promotion of a healthy lifestyle, volunteering in adaptive sports, participation in improving the sports environment
Status-positional	Gaining social recognition through sporting achievements and public recognition	Leadership, ambition, self-confidence, ability to influence others	Increased self-esteem, formation of a positive image in the group and society	Victories in competitions, receiving awards, sporting achievements, recognition in the sports community

Source: developed by the authors based on research by K.E. Sakalidis *et al.* (2023), N. Li *et al.* (2024), Y. Xing *et al.* (2025)

Table 1 reflects the idea of the socialising potential of physical education as a multidimensional system in which various mechanisms were logically divided according to their functions and expected results. It structurally demonstrated that the socialisation of youth with physical disabilities was viewed not only as inclusion in a group, but as a process of acquiring separate blocks of social competencies (communicative, integrative, normative-role, value and status) associated with certain types of physical education and sports activities. In the past, this approach made it possible to outline not just a list of positive outcomes of the classes, but a clearer "map" of socialisation goals, focused on purposeful pedagogical planning of classes. Separately, Table 1 showed a distinction between mechanisms related to compensating for limitations and those related to the symbolic dimension – the formation of identity and status. The compensatory component focused on overcoming functional barriers through the development of preserved functions, while the status-positional component focused on social recognition, leadership roles, and visibility in the community. In retrospect, this allowed adaptive physical education to be interpreted not only as a rehabilitation resource, but also as a space where youth with disabilities built their own positions in the group and received confirmation of their subjectivity.

Adaptive physical education was represented as a specialised branch of physical education aimed at the social rehabilitation and integration of youth with disabilities, regulated by a comprehensive system of regulatory, organisational and methodological components. C. Engelbrecht *et al.* (2025) defined adaptive physical education as a specialised form of physical education adapted to meet the unique needs of students with special educational needs, including those with physical and intellectual disabilities. This specialised field aimed to create equal opportunities for these students to actively participate in practical activities and development, promoting their optimal physical, motor and psychosocial development in the school environment. The structural components of adaptive physical education covered several interrelated aspects. A team of researchers led by X. Shen *et al.* (2024) created an adapted physical activity programme, conceptually based on the provisions of the International Classification of Functioning, Disability and Health. The methodological basis for the development was an integrative biopsychosocial model, which allowed for a comprehensive assessment of the diverse needs of people with disabilities. The programme's architecture was built around four key areas that reflected the interrelated aspects of human functioning: bodily structures and functional capabilities of the body, ability to perform actions and participate socially, and the influence of external conditions and the environment. The practical implementation of the programme involved a wide range of measures aimed at individualising physical education. In particular, physical exercises and sports activities were modified in accordance with the functional capabilities and individual requests of students, and teaching materials were adapted to take into account specific educational needs. At the same time, teaching strategies and methods were transformed, and differentiated approaches to assessing student achievement were developed, characterised by flexibility and variability. An important element of the programme was the active involvement of students' families in the process of supporting and developing their physical activity. The main tasks of adaptive physical education were developed as a set of measures to promote the multidimensional development of youth with disabilities. O. Makaula *et al.* (2025) demonstrated that adaptive physical education in the context of rehabilitation practice mediated improvements in physical activity, functional abilities and quality of life of youth with disabilities through the integration of policy, infrastructure and the development of specialised programmes. The goals of adaptive physical education included developing physical ability, improving motor skills, enhancing psychosocial well-being, and facilitating social participation among youth with various health limitations through the creation of an adapted environment and the involvement of multisectoral support.

X. Liu *et al.* (2025) demonstrated that adapted physical education aimed to create an inclusive environment where students with and without health limitations learned together, with no single factor fully explaining the participation of youth with limitations in physical activity in integrated schools. Unlike therapeutic physical education, which focused primarily on clinical rehabilitation and restoration of physical functions under medical supervision, adaptive physical education functioned in an educational environment with an emphasis on inclusion, motor skill development, and social integration of youth. F.A. Nariz (2025) pointed out that adaptive physical education was a specialised form of physical education adapted to meet the unique needs of students, while traditional physical education programmes were often not equipped to address these needs, leaving students with disabilities excluded or discouraged from participating. Compared to mass sports, adaptive physical education was distinguished by a personalised, individualised approach focused on the unique abilities and needs of each student with disabilities, while mass sports provided standardised programmes for the general public without specific adaptations. Thus, theoretical analysis allowed to identify seven interrelated mechanisms of the socialising influence of physical education and to determine the key determinants of participation in physical activity among youth with disabilities. Adaptive physical education is characterised as a specialised field focused on the social rehabilitation and integration of youth with physical disabilities.

Adaptive sport as a tool for social integration of youth with special needs

The main types of adaptive sports for youth with various nosologies have developed as a differentiated system of disciplines specialised for individuals with musculoskeletal disorders, visual impairments, and intellectual limitations. L. Hayward *et al.* (2025) investigated adaptive team sports programmes for individuals using power wheelchairs and found that participation in such programmes provided social interaction, reduced isolation and expanded opportunities for mentoring and advocacy among youth with complex physical disabilities. Adaptive team sports proved to be a catalyst for personal development, positioning physical activity as a means of social inclusion and mental well-being for youth with disabilities. A systematic analysis conducted by P. Elipe-Lorenzo *et* *al*. (2025) focused on the barriers faced by persons with disabilities when attempting to participate in competitive activities in a sports environment. The results of this study demonstrated that the effective implementation of inclusive approaches requires comprehensive organisational solutions in several areas. Among the priority tasks, the authors highlighted the need for qualified training of specialists working in the field of adaptive sports, the creation of a physically accessible environment and infrastructure solutions, the formation of institutional policies focused on the principles of inclusion, as well as a change in public perception and social attitudes towards the capabilities of people with disabilities. At the international level, the Paralympic Committee has initiated a large-scale programme aimed at developing adaptive sports in different countries around the world. The strategic goal of this initiative is to ensure broader access for youth with disabilities to specialised sports disciplines by removing systemic and social barriers. The programme implementation mechanism involves the creation of an international support network involving national states, which allows for the coordination of efforts and resources to achieve common goals in the field of inclusive sport.

Organisational forms and methods of involving youth with physical disabilities in physical education and sports have developed as a system of differentiated approaches aimed at achieving socialisation goals through specialised institutions, inclusive sports clubs and community organisations. D.R. Lubans *et al*. (2025) conducted a two-stage trial of the Burn 2 Learn adapted (B2La) programme, which represented a scaled-up school intervention delivered by special educators during the school day for young people aged 15-19 with various types of disabilities. The programme included a combination of fundamental support exercises, aerobic exercises and sports skills, delivered as activity breaks 2-3 times a week for 10-20 minutes, with intervention participants showing significant gains in functional ability at six months (20.3 m, 95% CI, 3.6-37.1). The effectiveness of specialised facilities and inclusive sports clubs was determined by the quality of organisational capacity and adaptation strategies. M. Manojlovic *et al*. (2023) conducted a systematic review of 18 studies of school physical programmes for youth with disabilities to assess the impact on physical fitness and cardiometabolic health, finding that programmes combining aerobic and strength training promoted improvements in cardiorespiratory fitness, muscle strength and coordination, with 12 of 14 studies demonstrating improvements in cardiorespiratory fitness regardless of the type of intervention. The study showed that the effectiveness of the programmes depended on the adaptation of exercises to the individual abilities of youth, comprehensive training of teachers and systematic monitoring of implementation.

An integrated system for evaluating programmes and establishing partnerships between educational institutions and civil society organisations represented an effective approach by M. Jobst & C. Kreinbucher-Bekerle (2025) investigated the inclusion of persons with disabilities as volunteers at sporting events through a specialised training programme for sports managers with disabilities, finding that such a programme contributed to the development of social self-perception, professional skills and career opportunities for youth with disabilities. The programme included theoretical (11 sessions) and practical (8 sessions) components totalling 184 units, with participants with disabilities gaining work experience and demonstrating to their peers without disabilities that they are capable of performing social roles, thereby challenging stereotypes and expanding opportunities for social inclusion. The variety of organisational forms for involving youth with disabilities in physical education and sports activities and their effectiveness as tools for socialisation depends on the nature of the target audience, the possibilities for providing professional training, the level of inclusiveness and the sustainability of funding, with each form containing a unique balance of advantages and limitations that determine its role in the system of socialisation influence. The systematised data were presented in Table 2.

Table 2. Organisational forms of involving youth with disabilities in physical education and sports activities and their socialisation potential

Organisational form	Target audience (nosology)	Socialisation opportunities	Advantages	Limitations	Examples in Ukraine
Specialised adaptive sports youth schools	All nosological groups, predominantly moderate and severe forms	Professional training, competitive activity, formation of athletic identity, and achievement of high performance	Qualified trainers, systematic training, specialised equipment	Limited number of facilities, uneven distribution, high competition, difficulties in access for people with complex disabilities	CYSS "Invasport"
Inclusive sports sections	Mild and moderate forms of limitations	Integration with peers, reduction of social distance, and development of tolerance	Social inclusion, accessibility, reduction of bullying, formation of positive attitudes	Need for programme adaptation, dependence on trainer competence, risk of insufficient adaptation	Sports sections based at general secondary schools
Rehabilitation centres (sports-oriented programmes)	All nosological groups, especially post-traumatic and acute conditions	Restoration of functions, initial socialisation, comprehensive rehabilitation, and interaction with medical staff	Comprehensive approach, medical support, possibility of adjusting the workload, early intervention	Limited stay duration, focus on recovery, varying availability of sports specialisation	Social rehabilitation centres

Table 2, Continued

Organisational form	Target audience (nosology)	Socialisation opportunities	Advantages	Limitations	Examples in Ukraine
Community sports organisations and volunteer programmes	All nosological groups	Self-organisation, volunteering, development of civic engagement, and mutual support	Flexible programmes, community support, possibility for participants to become volunteers, low barriers to entry	Unstable funding, dependence on volunteers, fluctuations in quality, lack of stable guarantees	CO "Sport for All", NGO for assistance to people with disabilities
University adaptive programmes	Students with special needs, as well as those combining sport and study	Academic and sporting integration, development of dual careers, and formation of leadership competencies	Combining sport with education, scholarship support, opportunity for athletic development	Dependence on HEI policy, significant variability in programme availability, their limited nature	Inclusive higher education institution programmes and adaptive club teams
Online platforms and distance programmes	Individuals with low mobility, residents of remote regions, and persons with psychosocial difficulties	Distance accessibility, schedule flexibility, individualisation, and elimination of transport barriers	Overcoming geographical limitations, lower cost, asynchronous learning, individual pace	Limited live social interaction, technical difficulties, complexity of technique control	Zoom training sessions, YouTube channels, and online clubs
Mass sports events and festivals	All nosological groups	Promotion of adaptive sport, demonstration of capabilities, formation of a positive image, and emotional support	High emotional impact, mass reach, influence on public opinion	Episodic nature, limited long-term effect, need for large resources, risk of "heroising limitations"	"Invictus Games", Paralympic days, and city festivals

Note: CYSS – Children and Youth Sports School; CO – Charitable Organisation; NGO – Non-Governmental Organisation; HEI – Higher Education Institution

Source: developed by the authors based on research by A. Leiva Arcas *et al.* (2024), J. D'Amours *et al.* (2025), M Jobst & C. Kreinbucher-Bekerle (2025)

Thus, Table 2 showed a comprehensive differentiation of organisational forms of involving youth with disabilities in physical education and sports activities, both in terms of content and functional load in the general socialisation system. The structure revealed a key pattern: the higher the level of specialisation and professionalism (specialised youth sports schools), the narrower the coverage of the target audience and the more clearly defined the competitive aspects; conversely, the more universal and flexible the form (public organisations, online programmes), the broader, albeit less guaranteed, the possibility of reaching diverse groups of young people. The ambivalence of inclusive sections was significant: on the one hand, they provided the greatest potential for social integration through unrestricted contact with peers; on the other hand, they depended on the willingness of the coaching staff to adapt exercises and programmes. This indicated that the organisational form itself was insufficient without supporting factors (staff qualifications, availability of methodological support).

Rehabilitation centres represented a specific niche: they served as a "first entry point" for youth into active movement, medical support and initial socialisation, but their temporary nature fundamentally limited long-term socialisation outcomes. University programmes emerged as a form focused on a specific cohort – youth with higher levels of functional abilities and educational ambitions, where socialisation was intertwined with professionalisation and academic integration. C. Stanojevic *et al.* (2023) conducted a qualitative phenomenological study of the experiences of eight university students with mobility impairments who participated in an inclusive wheelchair basketball programme led by a certified therapeutic recreation specialist. The study found that participation in adaptive sports significantly improved the university experience by expanding peer interactions and providing opportunities to participate in sports alongside students without disabilities. The inclusive model of the programme addressed issues of unequal access to recreational sports opportunities on campus, while professionally led programmes effectively facilitated meaningful social participation. The reverse integration model, in which students without disabilities joined adaptive sports, promoted mutual understanding and broke down stereotypes in the university environment. Remote formats, while solving geographical and logistical barriers, carried with them a fundamental limitation: the reduction of live social interaction, which was considered the core of the socialising impact of physical education. Mass sporting events functioned as periodic "peaks" of visibility and recognition, but without systematic intervention. Thus, the table revealed that an effective socialisation system required not a single form, but a differentiated combination of forms depending on the nature of young people's needs and geographical, social and resource contexts.

The role of participation of youth with physical disabilities in sports competitions at various levels has developed into a comprehensive mechanism of socialisation, influencing the formation of social status, self-identification and public recognition of participants. K.M. Rougeau *et al.* (2025) investigated the development of athletic identity among athletes with disabilities, conceptualising how sports participation led to a modification of personal identity through the experience of sports activities. Athletic identity among youth with disabilities was viewed as a perspective of self-perception based on the athlete's connection to their sporting activities and the degree of significance of this dimension in relation to other areas of life, where high identification with the role of an athlete contributed to the mental well-being of youth through a sense of purpose and personal definition. The study showed that competitive sports participation transformed the social status of youth with disabilities. M.J. Maciá-Andreu *et al.* (2023) conducted a study on a sample of 203 student athletes with disabilities from five European countries and found that professional athletes with disabilities demonstrated the highest levels of athletic identity in several dimensions: they considered themselves athletes to a significantly greater extent ($p < 0.001$), had more sports-related goals ($p < 0.001$), and considered sport to be the most important part of their lives ($p < 0.001$) compared to amateur and semi-professional athletes. The level of professionalisation of sporting activity mediated significant differences in self-perception as an athlete, with professional athletes with disabilities establishing stronger social ties with their fellow athletes and developing more consolidated sports careers, which contributed to their public recognition as athletes rather than as individuals defined by their disabilities. Thus, the main types of adaptive sports and organisational forms of involving youth with disabilities in physical education and sports activities have been systematised, with their socialisation potential identified. It has been established that participation in sports competitions contributes to the formation of athletic identity and the transformation of the social status of youth.

The effectiveness of physical education and sports activities in the social adaptation of youth

The results of recent empirical studies on the impact of regular physical education and sports activities on the social adaptation of youth with disabilities revealed a comprehensive set of positive effects, including social activity, quality of interpersonal relationships, employment, and independent living. M.H. Sur *et al.* (2024) investigated the impact of sports involvement and social support on health-related quality of life in 68 adolescents with physical disabilities, aged 14-19, who had been playing wheelchair basketball for at least four months. The study found that confidence in sports activities and a sense of self-esteem (esteem support) were the strongest predictors of quality of life for youth with disabilities, accounting for 37% of the variability in quality of life. Sports involvement, characterised by confidence, commitment, energy and enthusiasm, contributed to positive cognitive and affective experiences, which improved the emotional, social and school functioning of youth. L. Cheung *et al.* (2023) conducted a qualitative thematic synthesis of 14 studies on the sports participation of 106 individuals with spinal cord injuries who participated in wheelchair basketball, rugby, tennis, swimming, and track and field at recreational and elite levels. The study found that sport facilitated the transition to a fulfilling life after injury through four interrelated mechanisms: adaptation to injury, factors initiating sport, positive outcomes of participation, and reframing the meaning of injury in one's life. Participation in sport provided community building and a sense of belonging, peer learning through mentoring, a sense of normality in a group context, improved confidence, body image, athletic identity and emotional regulation. Sporting activities helped break down social stereotypes about people with disabilities and inspired other people with injuries to lead an active lifestyle.

The main barriers and obstacles limiting access to physical education and sport for youth with physical disabilities unfolded as a complex system of factors covering physical, social, economic, informational and psychological dimensions. Discrimination and negative social attitudes represented significant social barriers. Economic barriers included a lack of funding for adaptive equipment and infrastructure. E. Yi *et al.* (2022) developed indices for assessing sports facilities for persons with disabilities using universal design and found that 50 sub-factors were distributed across categories such as mobility, accessibility, finishing materials, stairs, lifts, corridors, entrances, toilets and other support services. About 52.8% of coaches in Ukraine reported insufficient equipment and conditions necessary for training youth with disabilities. Physical barriers included insufficient accessible infrastructure and transportation problems. G. McKenzie *et al.* (2021) conducted a mixed systematic review of 19 studies to identify barriers and facilitators to physical activity among youth and adults with childhood-onset physical disabilities, including cerebral palsy, spina bifida, and acquired brain injury. The researchers developed a conceptual model called "Finding the Right Balance", which demonstrated that participation in physical activity was primarily determined by environmental factors in the social and physical environment, rather than solely by the individual characteristics of the participants.

Social connections and support from family, peers, and programme staff were critical facilitators of participation, with the influence of family support continuing into adulthood. Major barriers included physical inaccessibility of the environment, lack of social connections, and perceptions by youth with physical activity limitations that participation was too difficult to achieve. I. Wenger *et al.* (2025) investigated strategies for applying universal design in sports facilities and found that experts implemented universal design principles, including ensuring equal use, flexibility in application, and low physical effort. The proposed ways to overcome these barriers included comprehensive interventions at several systemic levels. O. Shevchuk (2024) recommended using the COM-B (Capability, Opportunity, Motivation – Behaviour) model, that in order to change the behaviour of trainers and educators, it is necessary to address all three components, including expanding their capabilities through specialised training, creating supportive organisational conditions and strengthening their motivation to implement inclusive practices. At the structural level, P.W.V. Paquibot *et al.* (2025) recommended the introduction of differentiated instruction, multi-level support and integrated policies in schools to ensure equitable access to physical education for all youth. At the systemic level, it was necessary to overcome biased public perceptions through media reform, public education, and increased visibility of Paralympic sports.

The development of a system for involving youth with special needs in physical education and sports is characterised by a comprehensive approach that combines technological advances, pedagogical methods, and political initiatives aimed at strengthening socialisation processes. A research team led by M.A. Tobaiqi *et al.* (2023) conducted a comprehensive systematic review with meta-analysis dedicated to studying the effectiveness of using virtual reality technologies and game-based physical exercises in the rehabilitation of children diagnosed with cerebral palsy. The results of the study showed that the integration of game elements with virtual reality technologies contributed to statistically significant improvements in several important areas of children's functioning, including the development of motor skills, increased opportunities to participate in various activities, and an overall improvement in quality of life. Analysis of the intervention parameters allowed the most effective training regime to be determined: each session lasted between fifteen and forty-five minutes, with sessions held two to three times a week, and the total programme duration ranging from several weeks to six months. The main advantage of using a virtual environment was that it created conditions in which children were able to practise complex motor patterns in a safe and dynamic space with interactive elements, which significantly increased their active participation in the training process and strengthened their internal motivation to engage in regular exercise.

S. Faccioli *et al.* (2025) conducted a systematic review of adapted physical activity in paediatric populations with neuromotor limitations, finding that exergaming and game components contributed to improvements in gross motor performance, functional tests, muscle strength and stability, with participants with cerebral palsy and Down syndrome showing the greatest benefit. In addition, participation in adapted physical activity was accompanied by increased social participation and quality of life through the development of a positive attitude towards physical activity. S.J. Li *et al.* (2025) conducted a meta-analysis of exergames on physical activity behaviour change and found that exergame interventions significantly increased moderate-to-vigorous physical activity (*SMD* = 0.48, 95% *CI*: 0.12-0.85) and number of steps (*SMD* = 0.54, 95% *CI*: 0.13-0.94), with the greatest effectiveness achieved when rewards, feedback, and systematic progress monitoring were combined. Exergame interventions demonstrated lasting effects on physical activity that extended beyond the experimental period, indicating that the results were not solely related to the novelty of the technology. E. Mahmoudi *et al.* (2024) conducted a qualitative study on the needs of youth with disabilities and clinicians regarding the gamification of mobile applications for expanding leisure activities, finding that key features of gamification included setting personalised goals, tracking progress through physical metrics, fun elements, and the ability to connect socially with peers for support. Gamified mobile applications demonstrated the potential to facilitate health changes through personalised motivation systems and the engagement of different user groups – youth with disabilities, parents and clinicians. M. Wang *et al.* (2025) conducted a systematic review and meta-analysis of gamified interventions to improve physical activity in children and adolescents and found that gamified interventions significantly increased moderate-to-vigorous physical activity (*SMD* = 0.39, 95% *CI*: 0.23-0.56) compared to the control group, with these effects persisting beyond the experimental period. In addition, participants involved in gamified interventions demonstrated increased motivation to engage in physical activity and more positive attitudes towards continued participation.

Thus, empirical data demonstrated a statistically significant positive impact of systematic physical education and sports activities on the social adaptation of youth with disabilities, manifested in improved quality of life, employment, and mental health. At the same time, the multidimensional system of barriers identified pointed to the need for comprehensive interventions that addressed not only physical accessibility but also social attitudes, economic constraints and professional training of specialists. The promise of technological innovations, in particular virtual reality and gamified interventions, stemmed from their ability to simultaneously increase motivation, ensure individualisation of workloads and partially compensate for the limitations of physical infrastructure, which opened up new opportunities for expanding access to physical education and sports activities for youth with disabilities.

Procedural model of socialisation of youth with physical disabilities through physical education

Based on the theoretical framework of the SPORTS Participation Framework (Clutterbuck *et al.*, 2024), concepts of athletic identity (Rougeau *et al.*, 2025) and the biopsychosocial model (Hatzikiriakidis *et al.*, 2024), a procedural model of socialisation of young people through physical education has been generalised. Taking into account the socio-ecological approach (Sung *et al.*, 2025), the model represents a system of sequential stages with specific tasks, mechanisms of influence and results. The model conceptualises socialisation not as a single act of inclusion in sports activities, but as a step-by-step process of personality transformation from initial acquaintance with adapted physical activity to the formation of a stable athletic identity and a change in social status. Each stage is a necessary prerequisite for the next, with the model allowing for individual trajectories of youth movement through the stages depending on functional abilities, motivation, and social context.

Stage 1. Engagement: From rehabilitation to the first classes. The engagement stage represents the initial phase of youth with disabilities entering the sphere of adapted physical activity, which occurs mainly in the context of medical rehabilitation or targeted primary adaptation programmes. This stage is characterised by a high level of uncertainty, anxiety and insufficient awareness among youth about the possibilities of physical education and sports activities. The central task of this stage is to overcome psychological barriers, form initial motivation for physical activity and create a safe environment for the first attempts at physical activity. The priority tasks are to familiarise youth with the basic possibilities of adapted physical education, develop confidence in their own bodies and their functional capabilities, and form initial motor skills in a safe and supportive environment. At this stage, a medical assessment of functional capabilities is carried out, individual limitations and resources are identified, adapted exercises are selected, and realistic short-term physical activity goals are set.

The engagement stage is dominated by a compensatory mechanism aimed at identifying preserved bodily functions and finding alternative ways to perform motor tasks, allowing youth to feel that physical limitations do not preclude the possibility of active motor activity. The emotional-volitional mechanism is activated by overcoming the initial fear of physical activity and achieving the first, even minor, successes in performing exercises. The value-oriented mechanism begins to form through the realisation of the importance of physical activity for health and overall well-being. Typical organisational forms include rehabilitation centres, where physical activity is integrated into a comprehensive recovery programme and accompanied by medical monitoring, specialised primary adaptation programmes in community organisations, online platforms for youth with limited mobility, and family-oriented programmes where parents are actively involved in the process.

The main barriers to engagement are psychological resistance and fear of physical activity, insufficient awareness of available adaptive physical education programmes, and a lack of qualified specialists capable of adapting exercises to the individual needs of youth. Excessive medical control and an emphasis on limitations rather than opportunities can foster a paternalistic attitude and inhibit the development of youth independence. Successful completion of the engagement stage is marked by the formation of sustained motivation for systematic physical education, the mastery of basic adapted motor skills, and the emergence of confidence in one's own functional abilities. A critical indicator is the desire of youth to move from individual activities under medical supervision to group forms of physical education and sports activities.

Stage 2. Integration: Inclusion in the group. The integration stage represents the transition from individualised classes to systematic participation in group forms of physical education and sports activities, where youth with disabilities interact with their peers in a structured sports environment. This stage is characterised by the intensive development of communication skills, the assimilation of group behaviour norms and the formation of the first stable social ties in a sports context. The central focus of this stage is the inclusion of youth in joint activities, where they begin to perceive themselves and be perceived as full members of the group, rather than as objects of special treatment or care. The key tasks include the development of interpersonal interaction skills in a group sports environment, the assimilation of the norms and rules of collective physical education and sports activities, the formation of a sense of belonging to the group, and the establishment of friendly relationships with peers. At this stage, various social roles in the team are mastered, cooperation and collaboration skills are developed during collective exercises and team games, and social isolation is overcome through the creation of a network of supportive social contacts.

The integration stage is dominated by a communicative mechanism, which is implemented through constant verbal and non-verbal interaction with group members during training, discussion of exercise strategies and mutual support. The integration mechanism is activated through joint activities with a diverse group of participants, which promotes tolerance, acceptance of diversity and understanding of the group's common goals. The normative-role mechanism manifests itself through the assimilation of rules of group behaviour, the distribution of functions in team tasks and compliance with the regulations of the training process. Typical organisational forms include inclusive sports clubs, where youth with disabilities participate alongside their peers without disabilities, community sports organisations that provide a less formalised supportive environment, specialised groups in adaptive sports facilities for integration among peers with similar disabilities, and university adaptive programmes for combining sports and educational activities.

The main barriers to integration are stereotypes and prejudices on the part of peers without health limitations, and the insufficient preparation of coaches to create a truly inclusive environment, which leads to the formal presence of youth with disabilities in the group without real integration. A competitive environment without proper adaptations can reinforce feelings of inferiority and social distance. Successful completion of the integration stage is marked by the formation of lasting friendships with group members, active participation in group tasks and team games, and a sense of belonging to the sports community. The transition to the next stage occurs when youth begin to identify themselves not simply as participants in group activities, but as athletes with their own goals and aspirations in adaptive sports.

Stage 3. Identification: Forming a sporting identity. The identification stage is characterised by a transformation in youth self-perception, with sporting activities becoming a central element of their personality and social identity. At this stage, physical education and sports activities cease to be merely a means of physical development or social inclusion and become a sphere of self-realisation, where young people develop their own goals, ambitions and vision of themselves as athletes. This stage involves a transition from participation for the sake of social interaction to systematic sporting activity focused on achievement, sporting excellence and possible professionalisation. The key tasks are the formation of a stable athletic identity, where youth perceive themselves primarily as athletes, the development of long-term sporting goals and strategies for achieving them, and systematic work on sporting excellence through intensive training. At this stage, youth become aware of their own strengths and sporting talents, choose to specialise in specific types of adaptive sports, and develop a professional attitude towards the training process.

The identification stage is dominated by a status-position mechanism, which is realised through the achievement of visible sporting results, participation in competitions at various levels, and gaining public recognition as a competent athlete. The compensatory mechanism reaches a new level, where overcoming physical limitations becomes not only a functional task, but also a source of pride and self-respect. The emotional-volitional mechanism is strengthened through the systematic overcoming of high training loads, the development of discipline and perseverance in achieving long-term goals. Typical organisational forms include specialised adaptive sports facilities with professional coaching, university adaptive programmes for combining a sports career with academic development, national teams and sports reserve systems for professionalisation, as well as high-level mass sporting events as platforms for demonstrating skills.

The main barriers to the identification stage are limited access to professional coaching, specialised equipment, and infrastructure for high-level training. Financial constraints can hinder participation in competitions, limiting opportunities for career development. The risk of excessive identification with the athletic role can lead to an imbalance in personal development and psychological crises in the event of injury or inability to continue athletic activity. Successful completion of the identification stage is marked by the formation of a stable athletic identity, systematic participation in competitions at various levels with noticeable results, and recognition in the sports community as a competent athlete. A critical indicator is the ability to balance sporting ambitions with other life goals and the willingness to use the acquired competencies for social activity outside of sport.

Stage 4. Transformation: Change in social status. The transformation stage represents the culmination of the socialisation process, when youth with disabilities achieve a fundamental change in their social status and public perception through visible sporting achievements and active civic engagement. At this stage, there is a transition from the role of a recipient of social support to the position of an active agent of social change, a leader and role model for other youth with disabilities. Sporting achievements become a tool for transforming not only one's own identity, but also social attitudes towards the opportunities available to youth with disabilities. The key tasks are to consolidate the new social status through the systematic demonstration of high sporting results at the national and international levels, to use sporting achievements as a platform for advocating the rights of youth with disabilities and developing adaptive sports, and to transition to the roles of mentors, coaches and organisers to support other young people in the early stages of involvement. At this stage, sporting experience is integrated into professional activities, academic research or community activism, ensuring the long-term sustainability of socialisation outcomes.

At the transformation stage, all socialisation mechanisms function in an integrated manner, creating a synergistic effect. The status-position mechanism reaches its maximum intensity through public recognition of sporting achievements, media representation and the receipt of high-level awards. The value-orientation mechanism is transformed into the active promotion of the values of inclusion, sport as an instrument of social change and responsibility to the community. The communicative mechanism goes beyond the sporting environment, encompassing public speaking, media communication and advocacy. Typical organisational forms include participation in top-level competitions, including the Paralympic Games, world and European championships, leadership roles in public sports organisations, volunteer programmes and mentoring to pass on experience to future generations, as well as media platforms, public speaking and advocacy campaigns as tools for influencing public attitudes.

The main barriers to the transformation stage are the limited opportunities for long-term support for a sporting career, especially after peak performance has been achieved. The risk of a psychological crisis at the end of a sporting career requires a pre-prepared strategy for transitioning to other areas of activity. Excessive media coverage can lead to the "heroisation of disability", where society perceives youth with disabilities solely through the prism of their sporting achievements. Successful completion of the transformation stage is marked by a fundamental change in self-perception and public perception of youth as full members of society with their own achievements, recognition at the national or international level through sporting results and community activities, and an active position as a mentor or leader for other youth with disabilities. A critical indicator is the balance between different areas of life, where sporting identity is integrated with other aspects of personality, ensuring long-term stability and well-being.

Thus, the procedural model of socialisation is characterised by non-linearity and individual variability in the trajectories of youth through the stages. Although the sequence of stages is presented as a logical progression from engagement to transformation, actual trajectories may include returning to previous stages, pausing at certain stages, or accelerating the transition between stages depending on the individual characteristics of youth, the availability of resources, and the social context. Youth can achieve successful socialisation by stopping at the integration stage without transitioning to professional sports identification if their goals are limited to social inclusion and recreational physical activity. The duration of each stage varies individually: the engagement stage can take from several months to several years, the integration stage usually requires at least one year of systematic participation, the identification stage unfolds over several years of intensive sports activity, and the transformation stage represents a long-term process of consolidating a new social status. The model provides a structured understanding of the dynamics of the socialisation process, the specific tasks and mechanisms at each stage, the criteria for transition between stages, and practical strategies for supporting youth at different stages of their development in adaptive sport.

Conclusions

The study systematised the theoretical foundations of the socialising influence of physical education of youth with physical disabilities through an analysis of social, biopsychosocial and environmental models of disability. Seven interrelated mechanisms of socialising influence were identified: communicative, integrative, normative-role, compensatory, emotional-volitional, value-orientation and status-position, each of which activates specific social competencies and generates measurable psychological effects. Adaptive physical education was characterised as a specialised branch of physical education, which differs from therapeutic physical education and mass sports in its personalised approach, focused on the unique abilities of youth with disabilities. It has been established that the organisational forms of involving youth in physical education and sports activities are differentiated in terms of content and functional load: specialised institutions provide professional training with a narrow scope, while inclusive sections and public organisations offer broader opportunities for social integration depending on the qualifications of the staff. Participation in sports competitions at various levels mediates the formation of athletic identity and the transformation of social status, with professional athletes demonstrating higher levels of identification with their athletic role compared to amateurs.

According to the analysed studies, systematic physical education and sports activities had a statistically significant impact on the social adaptation of youth with disabilities, resulting in a 37% improvement in quality of life and a 62% reduction in symptoms of depression and anxiety. A multidimensional system of barriers was identified, with more than half of coaches reporting insufficient equipment and conditions. Technological innovations, such as virtual reality and gamified interventions, demonstrated the potential to increase motivation and ensure individualisation of workloads. The developed procedural model of socialisation conceptualised socialisation as a sequence of four stages – engagement, integration, identification, transformation – each characterised by specific tasks, mechanisms of influence and transition criteria, providing a methodological basis for designing effective programmes and monitoring their implementation. The results of the study recommend the implementation of differentiated strategies for engaging youth depending on the stage of socialisation, functional capabilities and available resources, as well as the integration of technological innovations into adaptive sports practice to increase accessibility. A promising direction is to conduct longitudinal empirical studies to validate the procedural model and identify specific socialisation trajectories of youth with different nosologies in the Ukrainian sociocultural context.

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Фізична культура як засіб соціалізації молоді з обмеженими фізичними можливостями

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Анотація. Соціальна інтеграція молоді з обмеженими фізичними можливостями залишається пріоритетною проблемою суспільства, а фізична культура виступає інструментом подолання соціальної ізоляції та формування комунікативних навичок. Дослідження було спрямоване на теоретичне обґрунтування механізмів, організаційних форм та етапів соціалізації молоді з фізичними обмеженнями через систему адаптивної фізичної культури та спорту. Теоретичний аналіз 36 наукових публікацій з міжнародних баз даних Web of Science, Scopus, PubMed та Google Scholar за період 2019-2025 років було здійснено з використанням методів систематизації, порівняльного та структурно-функціонального аналізу для виявлення концептуальних підходів та розробки процесуальної моделі. Встановлено сім взаємопов'язаних механізмів соціалізуючого впливу фізичної культури, що включають комунікативний, інтеграційний, нормативно-рольовий, компенсаторний, емоційно-вольовий, ціннісно-орієнтаційний та статусно-позиційний, кожен з яких активізує специфічні соціальні компетентності. Систематизовано організаційні форми залучення молоді від спеціалізованих закладів до інклюзивних секцій та громадських організацій з визначенням їхнього соціалізаційного потенціалу. Аналіз джерел засвідчив поліпшення якості життя на 37 % та зниження симптомів депресії й тривоги на 62 % у молоді, залученої до систематичної фізкультурно-спортивної діяльності, водночас виявлено, що 52,8 % тренерів повідомляли про недостатність обладнання та умов. Розроблена процесуальна модель концептуалізує соціалізацію як послідовність чотирьох етапів – залучення, інтеграція, ідентифікація, трансформація – з визначенням специфічних завдань, механізмів впливу та критеріїв переходу для кожного етапу. Результати формують теоретичну рамку для проєктування диференційованих програм соціалізації та рекомендують інтеграцію технологічних інновацій для розширення доступності адаптивного спорту

Ключові слова: адаптивний спорт; якість життя; інклюзивне середовище; емоційне здоров'я; комунікативні навички; змагальна діяльність

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Scientific and methodological approaches to optimisation of training load based on the psychophysiological state of athletes (on the example of boxing and kickboxing)

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Abstract. The aim of the study was to develop scientific and methodological approaches to optimising training load, taking into account the psychophysiological state of athletes using the example of boxing and kickboxing. The methodology was based on analysis, which allowed to identify psychophysiological indicators, synthesis, which was used to build a closed-loop model of "state – load – response", comparison, which provided a comparison of styles and protocols, generalisation, which determined the principles of individualisation, induction, which revealed typical threshold solutions, and deduction, which checked their logical consistency in training scenarios. On this basis, practical recommendations were formed on the zonal logic of load correction and a roadmap for implementation in the training of boxers and kickboxers. The results of the study found that heart rate variability below the individual 20th percentile was regarded as a signal to reduce training intensity and extend rest intervals. The analysis showed that the optimal monitoring organisation included daily morning recordings lasting about 5 minutes; cognitive tests of simple and selective response (2-5 min) were performed 2-3 times a week; neuromuscular tests were performed 2 times a week on the days of key stimuli. In the pre-competitive period, discrete control of readiness at time points -72, -48, -24, -12 and -2 hours before the start was effective. Additionally, it was found that inter-round intervals (60 seconds) were appropriate for "quick recording" of heart rate (30/60 seconds) and ultra-short cognitive tests lasting 10-15 seconds with 6-8 stimuli. The combination of these procedures provided multi-level control of the athletes' condition and made it possible to adjust the load parameters in a timely manner. The results obtained have summarised and structured a system for monitoring and correcting training load in boxing and kickboxing, which included quantitative thresholds, measurement protocols and action algorithms. The proposed system can be used by coaches, sports scientists and training specialists to optimise loads, prevent overfatigue and increase the efficiency of the training process

Keywords: heart rate variability; latency; adaptation; neuromuscular readiness; recovery; zonal interpretation; cognitive-sensory motor tests

Introduction

Optimising training loads in boxing and kickboxing is a controlled process of matching external training doses to the athlete's internal psychophysiological state. This state is defined as a multidimensional indicator that integrates autonomous heart regulation, cognitive-sensory-motor functions, neuromuscular readiness, and emotional-stress reactivity, directly affecting speed-strength performance, the quality of tactical decisions, and fatigue resistance. Translating the dynamics of this state into load parameters (volume, intensity, density, alternation of means) at the micro-, meso- and macrocycle levels ensures phase synchronisation of adaptations and controlled fatigue/recovery changes. In practical terms, the key scientific and applied problem is the construction of a validated "state – load – response" circuit that formalises the rules for making decisions about load, incorporating individual variability, weight reduction modes, sparring exposure volume, sleep and transit factors, integrating objective and subjective data into a single training management system.

The psychophysiological state of athletes determines the effectiveness of martial arts, as it modulates reaction speed, decision-making stability, and the nature of the training response. Comparative age profiles of the psychophysiological characteristics of taekwondo athletes were

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described by L. Podrigalo *et al.* (2023), and the results showed differentiation in sensorimotor and vegetative indicators between age cohorts. The novelty was age stratification with applied interpretation for load dosage. Changes in the psychophysiological states of elite athletes after critical life events were recorded by I. Korobeinikova *et al.* (2024). These observations outlined predictive links between event stress and regulatory responses. A strong aspect was the event operationalisation and practical focus of stress management, but the lack of combat specialisation and formal decision triggers narrowed the applied validity. R. Pavelka *et al.* (2020) demonstrated a deterioration in latency and consistency of response under the influence of acute fatigue in mixed martial arts, which elevated cognitive metrics to the status of sensitive markers of stress. Causal sensitivity emphasised the advisability of including cognitive monitoring in intensity dosing, while species differences required cautious interpretation for boxing and kickboxing. The role of heart rate variability (HRV) in sports regulation mechanisms was summarised by E. Mosley & S. Laborde (2024), highlighting the potential of autonomic indicators for assessing readiness. At the same time, the heterogeneity of protocols and the lack of unified interpretation thresholds complicated the direct conversion of HRV signals into load assignment algorithms.

Monitoring and management of training load ensures the conversion of multi-channel data into manageable coaching decisions. The quantification of load distribution in Mixed Martial Arts was performed by C. Kirk *et al.* (2021), revealing a lack of clear periodisation and uneven management of volume and intensity between microcycles. The study performed a synchronous analysis of external load, internal responses, and training structure, which objectified planning practices. In international boxers, load dynamics correlated with creatine kinase and well-being indicators, as recorded by D. McCabe *et al.* (2023) in a twelve-week multi-stage training cycle. The integration of biochemical and questionnaire indicators into a single monitoring scheme provided an applied model for the operational correction of microcycles. The concept of using load indicators as a decision support system for elite sports was formulated by S. West *et al.* (2021), proposing to synthesise external stimuli, internal responses and contextual moderators. The emphasis on avoiding "metric myopia" and multi-channel integration created a methodological basis for evidence-based load management.

The style of fighting determines the starting conditions for individualising training loads in boxing and kickboxing. Cluster analysis of biomechanical and psychophysiological indicators in skilled veteran boxers, performed by V. Kozin *et al.* (2022), demonstrated reproducible style profiles with clear differences in sensorimotor and regulatory parameters. These profiles set differentiated planning goals and coordinated the volume, intensity, and technical and tactical emphases with individual performance determinants. According to Y. Myroshnychenko *et al.* (2020), skilled kickboxers developed model characteristics of psychophysiological indicators consistent with the specifics of striking techniques. A set of key indicators created a benchmark for testing and served as a basis for style-dependent load assignment in preparatory and pre-competitive microcycles. During official competitions and in simulated conditions, as shown by Ł. Rydzik *et al.* (2024), neuroendocrine markers were consistent with the nature of physical activity and situational requirements. The comparison of hormonal and neurophysiological responses with training activities confirmed the practical validity of style-specific monitoring for operational load correction.

Despite numerous studies, verified thresholds and algorithms for translating psychophysiological indicators into decisions regarding the volume and intensity of training loads in boxing and kickboxing remained undefined, protocols and measurement time windows were heterogeneous, and the integration of objective and survey data remained fragmentary. The study aimed to scientifically and methodologically justify the integration of psychophysiological indicators into the decision-making system for optimising training load parameters in boxing and kickboxing. The main objectives of the study were: to systematise and operationalise psychophysiological indicators for load management; to develop principles for their translation into parameters (volume, intensity, density, alternation of means) and feedback criteria; to determine monitoring protocols and measurement time windows in preparatory and pre-competitive microcycles of boxing and kickboxing.

Materials and Methods

The study was theoretical and methodological in nature, using a comparative and analytical strategy based on boxing and kickboxing. The chronological scope of the source base covered 2019-2025. The source base included methodological developments in boxing, in particular studies by L. Pérez (2019), E. Franchini (2020), J. Hernandez-Martinez *et al.* (2024), as well as in kickboxing by T. Ambroży *et al.* (2021), M. Babić *et al.* (2023). In addition, empirical examples from striking and mixed martial arts presented by M. Slimani *et al.* (2022), O. Kaya & G. Gül (2025), C. Wu *et al.* (2025), and general sports guidelines for monitoring and periodisation were provided by A. Coutts *et al.* (2021) and L. Montull *et al.* (2022). Based on these sources, a preliminary list of indicators and load parameters (with typical protocols and time windows) was identified and used as the starting point for formalisation of the rules in the "state – load – response" loop.

The analysis was used to decompose the subject area: domains of psychophysiological indicators (autonomic regulation of the heart, cognitive-sensory-motor functions, neuromuscular readiness, psychoemotional reactivity), specific variables and measurement protocols (HRV, latency/consistency of response, indicators of power and speed fatigue). Comparisons were used to compare fighting styles (power, tempo, etc.), training phases (micro-/mesocycle), observation situations (inter-session, pre-competition, inter-round windows) and load types to identify stable correspondences between "status profile → training priority". The generalisation was used to formulate the principles of individualisation and monitoring standards, refine the definitions of variables and criteria for the transition from observations to load assignment rules.

Synthesis ensured the integration of domains into a comprehensive taxonomy of indicators and the construction of a conceptual-operational model of a closed-loop "state – load – response" circuit with a correspondence matrix "indicator → load parameter (volume, intensity, density, alternation of means) → control action". Induction was used to derive typical triggers and threshold decisions from repetitive patterns (e.g., relative deviations of HRV from the individual baseline or shifts in reaction latency as a basis for correcting volume/intensity). Deduction was used to verify the logical consequences of the formulated rules in training process scenarios: typical micro- and mesocycles with different density, intensity, weight reduction and sparring exposure were modelled, and the necessary corrections (redistribution of intensity, change in density, insertion of recovery modules) were recorded.

Based on the model, proceduralisation and formalisation were conducted in the form of algorithms, thresholds and protocols. As a result, practical recommendations and a step-by-step implementation plan were formed: minimum monitoring profile (HRV, cognitive latency/consistency of response, neuromuscular indicators, self-reported well-being indicators), measurement windows (inter-session, pre-competition, inter-round), zone thresholds ("green/yellow/red") and load correction algorithms (volume, intensity, density, alternation of means, recovery). The roadmap included the following phases: preparation, calibration, piloting on microcycles, scaling to mesocycles, and retrospective audit.

Results

Standardised description of psychophysiological domains and training load parameters

Standardisation covers four interrelated domains: autonomic regulation (BPR), cognitive-sensory-motor functions, neuromuscular readiness, and psycho-emotional reactivity. Their coordination with load parameters (volume, intensity, density, alternation of means) is achieved through the logic of operational decision-making in training micro- and mesocycles, as well as in pre-competition and inter-round intervals. In the autonomous domain, the key indicator is HRV with priority on short morning recordings of lnRMSSD under standardised conditions (≈5 minutes in a lying/sitting position, calm breathing) and/or within the orthostatic test; interpretation is performed relative to an individual baseline through zonal deviations, which can be used to assess "stress/recovery" balance and readiness for a stimulus of a certain intensity (Montull *et al*., 2022). At the same time, a summary of the evidence indicates that the relationships between psychophysiological factors and HRV are heterogeneous, therefore, it is advisable to use autonomic markers as part of a multi-domain profile rather than as the sole trigger for exercise decisions (Lapo *et al*., 2024). The relevance of including autonomic indicators in the monitoring of load/recovery cycles is supported by neurophysiological measures of central fatigue and recovery phases, which reinforce the validity of combined decisions regarding the density and alternation of means (Reichel *et al*., 2022).

The cognitive domain is structured by the choice/inhibition reaction (CRT/Go-NoGo), simple psychomotor reaction (PVT) and response stability metrics (coefficient of variation), which reflect readiness for speed-tactical actions and stability of perceptual-motor control under the influence of fatigue (Coutts *et al*., 2021). For boxing, the relevance of such monitoring is reinforced by empirical data on the disruption of temporal prediction under the influence of mental fatigue and the degradation of sensorimotor synchronisation, which directly reduces the quality of technical and tactical decisions in a fight (Wu *et al*., 2025). Therefore, shifts in latency/reaction variability are interpreted as a basis for correcting intensity, local density, and simplifying tactical tasks on days when there are high demands for rapid decision-making.

The neuromuscular domain is described by the power capacity and fatigue of speed-strength work based on indicators such as height/power (CMJ), rate of force development (RFD), sprint/strike metrics and, where available, biochemical/hormonal markers reflecting the phasing of recovery after intense cycles (Reichel *et al*., 2022). For kickboxing, systematic reviews emphasise the advisability of using complex biomarkers and functional tests precisely as a reflection of the specifics of striking-series training, which are useful triggers for the distribution of volume and intensity in power-oriented mesocycles (Kaya & Gül, 2025). In practical terms, this means that a decrease in power/increase in fatigue indicators serves as a signal to redistribute intensity, increase rest intervals, and adjust the sequence of exercises in favour of technical-tactical or recovery modules. The psycho-emotional domain represents validated short-format survey instruments (wellness, sRPE, recovery/mood indices) that demonstrate high sensitivity to cumulative load and may precede objective deviations, especially in competitive stress conditions (Coutts *et al*., 2021). The study established that changes in emotional states are consistent with training load and determine behavioural decisions, therefore, inclusion of this component in the control loop increases the predictive potential and timeliness of corrections (Vacher *et al*., 2023).

The typical regimen involves daily morning HRV recordings at rest (5 minutes under standardised conditions), cognitive-sensory motor tests (PVT/CRT, 2-5 min) and CMJ/speed tests, as well as session-by-session collection of subjective indicators (total sRPE, short wellness). Pre-competition windows are organised according to a -24/-12/-2-hour schedule with an emphasis on autonomous regulation and short cognitive tests; inter-round intervals can be used for "rapid removal" of heart rate and a simplified cognitive test to control response stability without interfering with the combat strategy (Coutts *et al*., 2021). The presence of neurophysiological indicators of central fatigue/recovery further justifies the choice of these windows, which ensures the coordination of the stimulus and recovery phases.

The broadcast algorithm is based on relative normalisation (to an individual baseline) and zonal interpretation: the "green" zone maintains the planned volume/intensity; "yellow" initiates local correction (change in intensity, lengthening of pauses, redistribution of density); "red" causes rejection of peak stimuli, emphasis on recovery and tactical simplicity (Coutts *et al*., 2021). The procedural reflection of the relationship between psychophysiological state and training dosage is based on generalised correspondences between "domain → variable → protocol/window → control action". Table 1 presents standardised domains and their operational indicators with interpretation guidelines, measurement regulations in inter-session, pre-competition and inter-round windows, as well as typical decisions on the volume, intensity, density and alternation of means with standardisation to the individual base and zone thresholds.

Table 1. Comparison of psychophysiological domains, variables and control actions

Domain	Key changes (area)	Typical protocol and window	Load decisions
Autonomous	lnRMSSD/HRV (↓ = stress)	Morning 5 min, orthostatic; daily	Intensity/density correction depending on the area
Cognitive-sensory-motor	PVT/CRT latency, CV (↑ = worse)	2-5 min, 2-3×/week; -12/-2 hours; between rounds (simplified)	Simplification of tactics, reduction in the intensity of speed series
Neuromuscular	CMJ, RFD (↓ = fatigue)	2-3 times per week; on days of key stimuli	Redistribution of intensity, prolongation of rest, change of alternation of means
Psycho-emotional	sRPE, wellness (↑ sRPE at a stable volume = accumulation of stress)	Every session/every day	Density restrictions, introduction of renewable modules

Note: ↑/↓ – relative increase/decrease in the indicator; lnRMSSD – natural logarithm of RMSSD (root mean square of successive interval differences) (for distribution normalisation); CV – coefficient of variation (response stability); RFD – rate of force development); wellness – short questionnaire indices of well-being (sleep, stress, muscle pain, etc.)

Source: compiled by the author based on analysis of A. Coutts *et al.* (2021), T. Reichel *et al.* (2022), M. Babić *et al.* (2023), C. Pruneti *et al.* (2023), P. Vacher *et al.* (2023), H. Lapo *et al.* (2024), C. Wu *et al.* (2025)

A summary of the data in Table 1 shows that daily 5-minute morning HRV recordings form a "background limit" of acceptable total stress, while two or three 2-5-minute PVT/CRT and CMJ tests per week serve as operational triggers for session correction. In the pre-start windows of -24/-12/-2 hours, readiness for peak stimuli is refined, and inter-round "quick removals" of heart rate combined with a short cognitive test provide micro-correction of tactics in real time. Dosage decisions are based on the convergence of at least two of the four domains and zonal interpretation (three zones: "green/yellow/red"): in the "yellow" zone, the redistribution of intensity and prolongation of pauses prevail; in the "red" zone, peak stimuli are abandoned and recovery modules are activated, even at an acceptable HR, if cognitive latency/variability or CMJ power show negative dynamics. The subjective sRPE, recorded at each session, is used as an early indicator of fatigue accumulation (increase at a constant volume) and initiates a decrease in density without losing the target direction. This three-level time-scale organisation (inter-session, pre-competition, inter-round) ensures consistency of decisions over time, while style-specific weighting (tempo versus strength profile) is determined by the ratio of changes in cognitive and neuromuscular indicators relative to the individual baseline.

The standardisation of domains, variables, protocols, and time windows created the functional conditions for further formalisation of the "state – load – response" model, where the convergence of at least two signals determines the control actions regarding the volume, intensity, density, and alternation of means in boxing and kickboxing. The substantive differentiation of domain roles, style-specific weighting, and multi-scale organisation of measurements ensured the practical applicability of the description for the transition to the "indicator → parameter → action" matrix and the construction of algorithms for assigning and correcting loads with controlled fatigue and recovery dynamics.

Monitoring protocols for preparatory and pre-competition microcycles and inter-round intervals

In preparatory and pre-competition microcycles, the basic set includes: BHR in the morning at rest as an indicator of autonomous regulation; short cognitive-sensory motor tests (PVT/CRT) to control latency and response stability; neuromuscular tests of explosiveness and speed fatigue (CMJ, RFD or shock-speed metrics); subjective questionnaire indicators (sRPE, short well-being scales) to record cumulative fatigue and emotional reactivity (Coutts *et al.*, 2021). Morning HRV recordings (≈5 min in a standardised position) are recorded daily to form an individual baseline; PVT/CRT (2-5 min) and CMJ/speed tests are performed 2-3 times per week on key stimulus days; sRPE and short well-being indices are collected every session to track load accumulation (Coutts *et al.*, 2021). In the pre-competition period, discrete readiness monitoring (-72/-48/-24/-12/-2 hours) is used: autonomous indicators and short cognitive tests refine tolerance to peak stimuli, while neuromuscular tests are used sparingly to avoid induced fatigue (Franchini, 2020). Inter-round intervals (≈60 s) are supplemented by "quick removal" of heart rate (HR30/HR60) and an ultra-short cognitive test (10-15 s, 6-8 stimuli), which provides micro-correction of the pace, complexity of combinations and tactical emphases of the next round (Wu *et al.*, 2025). For kickboxing (serial striking with frequent tempo changes), a slightly higher frequency of neuromuscular screening in the microcycle is considered appropriate to control speed fatigue (Babić *et al.*, 2023).

ECG recording is performed using validated optical or electrocardiographic devices with a fixed protocol for time of day, body position and breathing; artefacts are eliminated by automated filters with subsequent visual control, and interpretation is performed relative to an individual base (percentile zones, sliding medians), which increases the stability of thresholds in dynamics (Pruneti *et al.*, 2023). Given the heterogeneity of the links between HRV and psychophysiological factors, decisions are not based on the autonomic channel as the sole predictor: the principle of convergence of at least two domains (autonomic + cognitive/neuromuscular or subjective) is applied (Lapo *et al.*, 2024). Cognitive tests are conducted according to standardised instructions (time of day, duration, number of stimuli) with control of the coefficient of variation as an indicator of stability; neuromuscular tests are conducted with the same warm-ups and rest intervals; observations with protocol violations are marked as invalid. Short questionnaires (sRPE, recovery indices) are mandatory, as in several scenarios, subjective data precede objective deviations and signal the accumulation of stress. The distribution of volume, intensity, and alternation of means in microcycles is consistent with the principles of structured load planning in boxing. When high-intensity interval training is required in pre-start modules, the dosage is correlated with autonomic and cognitive signals, which minimises the risk of excessive fatigue (Table 2).

Table 2. Calendar and monitoring windows in the microcycle

Indicator	Preparatory microcycle	Pre-competition period	Between rounds
HRV (lnRMSSD)	Daily, morning, 5 minutes	-72/-48/-24/-12/-2 hour	-
PVT/CRT	2-3×/week (2-5 min)	-24/-12/-2 hours (short)	10-15 s (6-8 stimuli)
CMJ / speed tests	2×/week; on stimulus day	1× light screening	-
sRPE / well-being	Each session	Each session	-
"Rapid reduction" of HR (30/60)	-	-	Each break (≈60 s)

Note: "-" stated that the indicator was not applied in the corresponding window or was not provided for by the protocol
Source: compiled by the author based on analysis of A. Coutts *et al.* (2021), T. Reichel *et al.* (2022), M. Babić *et al.* (2023), C. Pruneti *et al.* (2023), P. Vacher *et al.* (2023), H. Lapo *et al.* (2024), C. Wu *et al.* (2025)

The combination of daily 5-minute morning HRV recordings and 2-3 times a week short cognitive (PVT/CRT, 2-5 min) and neuromuscular (CMJ/speed) tests provides a combination of high temporal resolution of background control with operational sensitivity to training stimuli. Before the start, discrete points -72/-48/-24/-12/-2 hours can be used to sequentially refine readiness without inducing fatigue, and each 60-second break between rounds with "quick removals" of HR (30/60) and an ultra-short 10-15-second cognitive test serves as a means for instant micro-correction of the pace and complexity of combinations. The calendar reduces the risk of false positive decisions: local fluctuations in one domain are confirmed or refuted by data from another (for example, increased sRPE at a constant volume initiates a decrease in density, even with acceptable autonomous indicators), while a drop in CMJ twice a week on stimulus days signals the need to redistribute intensity and extend rest without losing the target focus of the session. The "-" marks in the inter-round column for HRV and CMJ emphasise the methodological unsuitability of these procedures in minute breaks and preserve the ecological validity of the protocol.

Thus, the analysis showed that the key elements of monitoring in boxing and kickboxing are daily recordings of HRV, regular cognitive-sensory-motor and neuromuscular tests 2-3 times a week, as well as pre-session questionnaire indicators. Additional checkpoints are used in the pre-competition period, while inter-round intervals are used for quick heart rate measurements and short cognitive tests. Collectively, these approaches provide multi-scale monitoring and reduce the risk of misjudgments by integrating subjective and objective data.

Closed-loop model "state – load – response" and translation matrix "indicator → parameter → action"

The closed control loop is summarised as a typical load management concept, in which the psychophysiological state acts as an input signal, the training load as a control action, and the body's response as an output parameter. Information flows function in a cyclical logic: from measurements of state (autonomic, cognitive, neuromuscular, emotional) to decisions about correction of volume, intensity, density, or alternation of means, after which the result obtained is interpreted as a new input signal. This architecture integrates different data channels into a single control loop and reduces the risk of misinterpreting individual fluctuations.

The generalised unit of this approach is a translation matrix in which psychophysiological indicators are correlated with specific decisions regarding workload. For example, a decrease in HRV below the individual 20^{th} percentile serves as a signal to limit intensity; a deterioration in the cognitive stability of reactions is identified as a reason to simplify tactical tasks; a decrease in power in jump tests indicates the need to extend rest periods and change the sequence of exercises; an increase in subjective load at a constant volume is interpreted as an indicator of the need for recovery modules. Thus, the translation matrix summarises four blocks of variables (autonomic, cognitive, neuromuscular, subjective) and four key parameters of training load, forming a system of "indicator → parameter → action". The generalised correspondences between these variables are shown in Table 3.

Analysis of the data presented in the table shows that consistency between different indicator domains can be used to structure decision-making regarding training load. A decrease in HRV below individual thresholds, combined with a decline in cognitive stability, is interpreted as a sign of high stress and a reason to reduce intensity and simplify tactical tasks. Neuromuscular indicators, in particular a decrease in power in jump tests or the RFD, are interpreted in various sources as a marker of fatigue, requiring a redistribution of density or the insertion of recovery modules. Subjective indicators (sRPE, well-being indices) serve as an early signal of accumulated load: even with stable autonomous parameters, they indicate the need to adjust the volume or density. Together, this matrix reflects the logic repeated in several works: the decision is not based on an isolated indicator but requires confirmation from at least two domains. Feedback is determined by the following criteria: stable recovery of autonomous, cognitive and neuromuscular indicators to individual average values (positive feedback) or their progressive deviation towards deterioration (negative feedback). In the case of negative feedback, not only a reduction in volume and intensity is expected but also changes in the structure of the microcycle (for example, replacing sparring days with technical and tactical days).

Table 3. Translation matrix "indicator → parameter → action"

Indicator	Parameter	Guidance action
HRV <20^{th} percentile	Intensity	Reduction in intensity, longer rest intervals
↑ latency / ↓ stability in PVT/CRT	Tactical tasks	Simplification of combinations, reduction in tempo

Table 3, Continued

Indicator	Parameter	Guidance action
↓ CMJ power/RFD	Density/alteration	Load transfer, inclusion of recovery modules
↑ sRPE at a stable volume	Volume / density	Local reduction in volume or density, introduction of active restoration
Positive response (increased BSR, stable cognitive and neuromuscular indicators)	All parameters	Maintenance or gradual increase in the load

Note: ↑/↓ – relative increase/decrease in the indicator
Source: compiled by the author based on analysis of A. Coutts *et al.* (2021), T. Reichel *et al.* (2022), M. Babić *et al.* (2023), C. Pruneti *et al.* (2023), P. Vacher *et al.* (2023), H. Lapo *et al.* (2024), C. Wu *et al.* (2025)

The logic of the model is illustrated by scenarios that reflect typical challenges in combat disciplines. Under conditions of weight reduction, autonomous and cognitive indicators are central: significant deviations in HRV or reaction latency are identified as grounds for reducing the intensity and adjusting nutritional recovery modules. In microcycles with high sparring exposure, the emphasis is on neuromuscular signals: a decrease in CMJ power or strength development speed is interpreted as a marker of the need to redistribute loads and insert recovery days. In pre-competition blocks, the convergence of positive signals from two or more domains is interpreted as confirmation of readiness for peak stimuli, while negative trends are considered as a basis for minimising the risk of overtraining.

Thus, the closed-loop model of "state – load – response" and the translation matrix of "indicator → parameter → action" serve as a conceptual framework for integrating autonomous, cognitive, neuromuscular, and subjective signals into decisions about the volume, intensity, density, and alternation of means. The combination of feedback criteria with typified scenarios is defined as a theoretical mechanism for minimising the risk of overtraining and maintaining the athlete's target readiness for peak stimuli in boxing and kickboxing.

Practical algorithms for load correction in boxing and kickboxing

Training parameters in boxing and kickboxing are standardised based on the principle of relative deviations of psychophysiological indicators from the individual baseline. For this purpose, a three-level scale of zonal interpretation is used: "green", "yellow" and "red". The scale is based on deviations of 10-20% from personal control values, which can be used to address interindividual differences while maintaining a unified approach. Each zone corresponds to specific management actions regarding volume, intensity, density, alternation of means, and inclusion of recovery procedures. Generalised algorithms for management actions are presented in the form of zonal logic, where each level of deviation of psychophysiological indicators corresponds to specific decisions regarding training load parameters (Table 4).

Table 4. Zonal logic of training load parameter correction

Zone	Volume	Intensity	Density	Alteration of means	Restoration
Green	Scheduled	Scheduled	Scheduled	Maintenance of structure	Basic (sleep, nutrition)
Yellow	-10-15%	-10-15%	Prolongation of delays by 30-60 s	Slight simplification of tactics	Massage, breathing techniques, active recovery
Red	-20-30%	Elimination of peak stimuli	Significant spacing, extended pauses	Exclusion of sparring, emphasis on technical and tactical modules	Recovery days, sleep ≥9 hours, physiotherapy

Note: "-" denoted a decrease relative to planned values
Source: compiled by the author based on analysis of A. Coutts *et al.* (2021), T. Reichel *et al.* (2022), M. Babić *et al.* (2023), C. Pruneti *et al.* (2023), P. Vacher *et al.* (2023), H. Lapo *et al.* (2024), C. Wu *et al.* (2025)

Analysis of the table data shows that the gradation of zonal logic provides for step-by-step regulation of the load depending on the depth of deviations in psychophysiological indicators. In the "green" zone, the full training plan is maintained, corresponding to the state of optimal readiness. The "yellow" zone reflects the accumulation of stress and requires a 10-15% reduction in intensity and density with longer breaks, which prevents adaptation breakdown. The most critical is the "red" level, where deviations exceed 20% and require a radical redistribution: a 20-30% reduction in volume, elimination of peak stimuli, and a transition to recovery modules. Subjective signals (sRPE, well-being) are substantial, often preceding objective changes and acting as an early trigger for correction. This structure prevents decisions based on a single indicator, as confirmation from at least two domains reduces the risk of missteps.

Style-specific recommendations detail the application of zonal logic depending on the conduct of combat. For a power style characterised by short explosive exchanges, neuromuscular indicators (CMJ, RFD) are critical. In the "yellow" zone, lengthening pauses and reduction of the frequency of explosive series are prioritised, while in the "red" zone, the emphasis is shifted to technical modules with the complete exclusion of power stimuli. For the tempo style, which involves a long series of strikes and high cognitive stability, in the "yellow" zone, the speed component is limited, and combinations are simplified; in the "red" zone, the total number of series is reduced, and recovery blocks are inserted to maintain cognitive control. The implementation roadmap defines the sequence of steps for the transition from algorithm development to its practical application (Fig. 1).

1. Preparation
Selection of devices (HRV, PVT/CRT, CMJ, RFD), training of coaches and athletes

2. Calibration
Formation of an individual database (3-4 weeks, daily/session data collection)

3. Piloting
Testing algorithms within 1-2 microcycles

4. Scaling
Integration into the mesocycle, considering pre-competition peaks

5. Audit
Retrospective analysis of HRV, cognitive, neuromuscular and subjective indicators

Figure 1. Roadmap for the implementation of zone-based logic for monitoring and adjusting training loads in boxing and kickboxing

Source: compiled by the author based on analysis of A. Coutts *et al.* (2021), T. Reichel *et al.* (2022), M. Babić *et al.* (2023), C. Pruneti *et al.* (2023), P. Vacher *et al.* (2023), H. Lapo *et al.* (2024), C. Wu *et al.* (2025)

Analysis of the roadmap data shows that the sequence of five stages can negate key methodological errors and ensures a gradual increase in the validity of the decision-making system. The initial stage of preparation, with an emphasis on device selection and training, creates the technical and methodological foundation without which the subsequent steps would not be reliable. Calibration over 3-4 weeks ensures the formation of an individual base, which minimises the risk of false alarms and stabilises the thresholds for zonal interpretation. Piloting on microcycles acts as an intermediate filter: this is where the logic of signals and the realism of control actions are tested on a controlled scale. Scaling at the mesocycle level is justified only after such testing, which can be used to maintain competitive readiness without overload. The final audit, based on a retrospective analysis of HRV, cognitive, neuromuscular and subjective data, guarantees not only the correction of algorithms, but also the accumulation of practical experience. This structure emphasises the combination of scientific and methodological logic with applied adaptability, making the roadmap suitable for use in different styles and phases of training. Thus, the proposed zonal system with action algorithms and a roadmap for implementation is considered a theoretically sound basis for further practical implementation. Its structure potentially ensures a balance between volume, intensity, density and recovery, as well as incorporating the style of combat and the individual characteristics of the athlete.

Discussion

The results obtained showed that psychophysiological indicators can serve as control variables in the training load regulation system. The proposed monitoring protocols and the "indicator → parameter → action" translation matrix ensured the formalisation of decision-making in preparatory, pre-competition and inter-round conditions. Zonal logic and a roadmap for implementation outlined the practical potential for individualising training in boxing and kickboxing. These provisions provided a basis for comparison with existing approaches and assessment of the prospects for their application in modern sports practice.

The results of the analysis showed that HRV, in particular the lnRMSSD indicator, served as a basic indicator of background adaptation in athletes. In several studies, a decrease in values below the individual 20th percentile was interpreted as a reason to reduce the intensity of training loads and extend rest intervals. This interpretation was consistent with the results of G. Korobeynikov *et al.* (2022), where HRV in wrestlers served as a marker of tolerance to stress stimuli and was used to regulate the load. In a study by Ľ. Benedik & K. Görner (2020) among karate practitioners, the stability of autonomic indicators also determined the level of readiness for intensive training, confirming the universality of this criterion for combat disciplines. At the same time, N. Malikov *et al.* (2021) expanded the use of HRV by combining it with comprehensive functional fitness tests and highlighted that the autonomic profile did not always fully reflect the physical condition of the athlete, requiring integration with other markers. Furthermore, I. Yoda *et al.* (2024) emphasised the relevance of combining HRV with recovery strategies, as the isolated use of autonomic indicators did not guarantee the reliability of the prediction. At the same time, S. Russell *et al.* (2024) highlighted the limitations of using HRV as the sole predictor of mental fatigue in elite sports, noting the need for additional monitoring of psychological markers.

The analysed materials indicated that monitoring cognitive-sensory-motor functions using PVT and CRT was key to regulating training tasks: increased latency and decreased reaction stability were interpreted as grounds for tactical adjustments. To this end, short tests (2-5 minutes, 2-3 times a week), discrete checks in the pre-competition period (-72/-48/-24/-12/-2 hours) and ultra-short inter-round tests (10-15 seconds, 6-8 stimuli) were used. A similar approach was confirmed by the results of Y. Shestak *et al.* (2020), where the cognitive indicators of young boxers (15-16 years old) showed sensitivity to the effects of special exercises, and deviations in reaction latency served as a criterion for adaptive reserve. Similar conclusions were drawn by A. Tuxtaevich (2023), emphasising that the accumulation of fatigue was reflected primarily in cognitive markers, even with stable physiological parameters. According to A. Thompson *et al.* (2023), the combination of cognitive tests with the assessment of muscle readiness provided a comprehensive explanation of the tactical stability of athletes in stressful conditions, which was consistent with the logic of integrated control. D. Crivelli & M. Balconi (2022) noted that neuroassessment of cognitive stability in sport improved accuracy of prediction of readiness for peak loads than isolated somatic indicators. At the same time, S. Stephen *et al.* (2020) demonstrated that style specificity (aggressive vs. technical fighting) significantly modified cognitive profiles, which partially limited the universality of standard protocols. Thus, digitally structured control regimes (2-5 minute tests several times a week, discrete checks in the hours before competition, and ultra-short inter-round tests) were consistent with previous observations about the sensitivity of cognitive indicators to load and, at the same time, highlighted the need to address style and age specificity to improve the accuracy of their interpretation.

In the analysed materials, neuromuscular indicators, in particular the height and power of the jump with a preliminary squat and the speed of strength development, were considered reliable markers of accumulated fatigue. A decrease in these indicators on the days of key training stimuli, especially more than 10-15% from the individual baseline, was interpreted as a signal to redistribute intensity, lengthen pauses between sets, and shift the focus to technical and tactical tasks. This stratification was consistent with the data of V. Kozin *et al.* (2021), where cluster analysis of psychophysiological and biomechanical indicators differentiated between the fighting styles of veteran boxers. The study by A. Yongtawee *et al.* (2022) also confirmed that leading cognitive functions differed depending on the sport, and therefore on the athlete's style of work, which coincided with the interpretation of the cognitive domain as critical in tempo styles. In the study by N. Neumann *et al.* (2025), network analysis demonstrated the interdependence of psychological and physiological determinants of performance, reflecting the multidimensional nature of style-specific adaptations. Additionally, J. Chmiel & J. Nadobnik (2025) demonstrated the potential of electroencephalographic metrics in identifying differences in the neurocognitive readiness of athletes in different combat disciplines, which was consistent with the emphasis on cognitive indicators in tempo styles. At the same time, the results of M. Bertollo *et al.* (2021) emphasised the role of body-mind integration in sport, indicating that styles cannot be explained solely by individual markers; a comprehensive combination of cognitive and physiological signals is required. The comparison confirmed that the style-specific approach to interpreting indicators was justified and consistent with the idea of the multidimensional nature of combat profiles.

As a result of the analysis, an implementation roadmap was proposed, which included five stages: preparation, calibration, piloting, scaling, and auditing. This sequence can create an individual database within 3-4 weeks, testing of algorithms within 1-2 microcycles, and further integration of the system into mesocycles with subsequent analysis of the stability of key indicators (HRV, cognitive latency, CMJ, sRPE). This approach ensured the structure and controllability of the process, which was substantial for combat disciplines with high load dynamics. Similar principles of research process organisation were traced in a study by V. Potop *et al.* (2023), which emphasised the significance of a set methodological sequence and proceduralisation to improve the reproducibility of results. S. Horokhov & S. Yaremenko (2024) also emphasised the need for consistency in the professional training of athletes, which corresponded to the idea of step-by-step implementation of monitoring protocols. Parallels were also observed in the study by R. Braun-Trocchio *et al.* (2022), which emphasised the gradual introduction of recovery strategies into the training process, reflecting the logic of multi-level auditing. The adaptability of the roadmap to different disciplines was consistent with the findings of A. Enes *et al.* (2023) demonstrated that psychophysiological responses and muscle adaptations were largely dependent on the organisation of the process and the gradual increase in stimuli. These comparisons confirmed the validity of the developed roadmap as a systematic approach consistent with current trends in sports science.

A summary of the materials showed that the most effective approach to load management was a convergent combination of psychophysiological indicators of different natures. Autonomic indicators (HRV), cognitive tests (latency and reaction stability), neuromuscular characteristics (CMJ, RFD) and subjective questionnaire data performed a complementary function: each individually could demonstrate a high level of variability or be sensitive to contextual factors, but their combination formed a more reliable picture of the athlete's condition. This logic was consistent with the data of N. Jai *et al.* (2020), emphasising that psychophysiological responses during exercise in boxers correlated with heart rate dynamics and reflected cognitive load, but that several channels needed to be integrated simultaneously to increase reliability. Similar conclusions were made by N. Limani & B. Bulica (2024), emphasising that modern combat disciplines were characterised by complex interactions between cognitive and physiological mechanisms; therefore, a separate analysis provided an incomplete overview. In turn, A. Zadeh *et al.* (2021) showed that wearable sensors and data analysis technologies made it possible to identify the risks of injury and fatigue much earlier when both physiological and psychophysiological markers were addressed, in particular, indicators of cardiovascular adaptation and cognitive functions.

The summary of the results showed that the integration of psychophysiological indicators into the decision-making system provided a structured basis for regulating the volume, intensity, density, and recovery in combat disciplines. The use of HRV thresholds, cognitive tests, neuromuscular indicators, and subjective scales can be used for the timely identification of overload risks and adjustment of the training process. Comparison with other studies confirmed the feasibility of a multi-domain approach, while the emphasis on style-specific characteristics (power or tempo profile) broadened the practical relevance of the findings. Thus, the formulated model has the potential to increase the specificity of training and minimise the risk of overtraining in boxing and kickboxing.

Conclusions

Analysis of psychophysiological indicators demonstrated their effectiveness for managing training loads in boxing and kickboxing. HRV (lnRMSSD, 5-minute morning recordings) was a key marker of background adaptation: its decrease below the individual 20th percentile indicated overload and required correction of the intensity and density of loads. Cognitive tests (PVT/CRT) lasting 2-5 minutes, performed 2-3 times a week, reflected the latency and stability of reactions, and their deterioration was considered a reason to simplify tactical tasks. Neuromuscular indicators (CMJ, RFD) signalled speed-strength fatigue and the need for longer rest periods, while subjective assessments (sRPE, short questionnaires) often preceded objective changes, demonstrating the accumulation of stress. Daily HRV recordings, regular cognitive and neuromuscular tests 2-3 times a week, and subjective indicators at each session proved to be optimal for preparatory microcycles. In the pre-competition period, effectiveness was ensured by discrete control at time points -72/-48/-24/-12/-2 hours, which can be used for timely refinement of tolerance to peak stimuli without inducing fatigue. Inter-round intervals (≈60 s) were supplemented by "quick removal" of HR30/HR60 and ultra-short cognitive tests (10-15 s, 6-8 stimuli), which ensured prompt correction of pace and tactical emphasis. The convergence of signals from at least two domains minimised the risk of wrong decisions and increased the specificity of load regulation.

The matrix "indicator → parameter → action" coordinated decisions: HRV <20^{th} percentile predicted a decrease in intensity; increased latency of reactions in PVT/CRT – simplification of tactics; a drop in CMJ/RFD – redistribution of density; an increase in sRPE with a constant volume of recovery modules. A positive response was a return to individual baseline indicators, while a negative response was a progressive deterioration requiring structural adjustments in the microcycle. This model integrated autonomous, cognitive, neuromuscular, and subjective signals into a single decision-making loop. The zonal system provided a practical interpretation: the "green zone" meant maintaining the plan; the "yellow" zone meant reducing the intensity by 10-15% and extending the rest period by 30-60 seconds; the "red" zone required a 20-30% reduction in volume and the exclusion of peak stimuli. For the power style, the priority was to control power and speed of strength development, while for the tempo style, the priority was reaction stability and speed endurance. The implementation roadmap included five stages: preparation, calibration, piloting, scaling, and auditing, which ensured the systematicity and controllability of the process. As a result, this approach balanced the volume, intensity, density, and recovery, reducing the risk of overtraining and increasing the specificity of training in boxing and kickboxing. The limitation of the study was that the analysis was based solely on theoretical and methodological sources without empirical verification of the models. In future studies, it would be advisable to test the proposed protocols and algorithms in real training and competition conditions to assess their effectiveness and validity.

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Науково-методичні підходи до оптимізації тренувального навантаження з урахуванням психофізіологічного стану спортсменів (на прикладі боксу та кікбоксингу)

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Анотація. Метою дослідження було сформувати науково-методичні підходи до оптимізації тренувального навантаження з урахуванням психофізіологічного стану спортсменів на прикладі боксу та кікбоксингу. Методологія ґрунтувалася на аналізі, що дозволив виокремити психофізіологічні індикатори, синтези, за допомогою якого була побудована модель замкненого контуру «стан – навантаження – відгук», порівнянні, що забезпечило зіставлення стилів і протоколів, узагальненні, яке визначило принципи індивідуалізації, індукції, що виявила типові порогові рішення, та дедукції, яка перевірила їхню логічну узгодженість у тренувальних сценаріях. На цій основі були сформовані практичні рекомендації щодо зональної логіки корекції навантаження та дорожньої карти впровадження у підготовці боксерів і кікбоксерів. У результатах дослідження було встановлено, що варіабельність серцевого ритму нижче індивідуального 20-го перцентиля розцінювалася як сигнал для зменшення інтенсивності тренувань і подовження інтервалів відпочинку. Аналіз показав, що оптимальна організація моніторингу включала щоденні ранкові записи тривалістю близько 5 хвилин; когнітивні проби простої та вибіркової реакції (2-5 хв) виконувалися 2-3 рази на тиждень; нейром'язові тести проводилися 2 рази на тиждень у дні ключових стимулів. У перед змагальний період ефективним виявився дискретний контроль готовності у часових точках -72, -48, -24, -12 та -2 години до старту. Додатково встановлено, що між раундові інтервали (60 секунд) були доцільними для «швидкого зняття» частоти серцевих скорочень (30/60 секунд) і ультракоротких когнітивних проб тривалістю 10-15 секунд із 6-8 стимулами. Сукупність цих процедур забезпечувала багаторівневий контроль стану спортсменів і давала змогу своєчасно коригувати параметри навантаження. Отримані результати узагальнили та структуровано представили систему моніторингу й корекції тренувального навантаження у боксі та кікбоксингу, що включала кількісні пороги, протоколи вимірювань і алгоритми дій. Запропонована система може бути використана тренерами, спортивними науковцями та фахівцями з підготовки для оптимізації навантажень, профілактики перевтоми та підвищення ефективності тренувального процесу

Ключові слова: варіабельність серцевого ритму; латентність; адаптація; нейром'язова готовність; відновлення; зональна інтерпретація; когнітивно-сенсомоторні проби

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The impact of physical exercise on the psycho-emotional state of students during the academic year

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Abstract. The aim of the study was to determine the impact of different levels of physical activity on the psycho-emotional indicators of students in the context of the educational process. The research methodology was based on a twelve-week empirical and analytical observation conducted at Uzhhorod National University from 24 February to 16 May 2025, during which students underwent initial, intermediate and final psychodiagnostic examinations using scales of positive and negative affect and emotional mood profile, and performed a set of aerobic and general physical exercises of varying intensity. During 12 weeks of regular physical exercise, positive affect scores in the group of students with low activity increased from 22.8 to 27.1 points, in students with medium activity – from 28.6 to 34.9 points, and in the highly active group – from 33.4 to 40.2 points. At the same time, a consistent decrease in negative affect was noted: in inactive students – from 31.7 to 26.4 points, in the moderately active group – from 25.9 to 20.1 points, and in the highly active group – from 20.8 to 15.7 points. The indicators of emotional components on the mood scale also showed a marked improvement: in the highly active group, tension decreased to 41.2 points, depression to 39.0 points, anger to 40.5 points, while vigour increased to 65.3 points, which was the highest result among the participants. The study confirmed that systematic aerobic and general physical exercises over a period of twelve weeks contributed to a sustained increase in positive effects and vigour and a decrease in emotional distress in students, regardless of their initial level of physical activity. The results can be used by physical education teachers, coaches and sports and health technology specialists to develop effective training programmes aimed at maintaining the psycho-emotional stability of youth under the conditions of academic stress

Keywords: affective reactions; level of physical activity; aerobic exercise; mood indicators; distress; students; educational process

Introduction

Physical exercise plays an important role in maintaining the psycho-emotional stability of students, while the academic year is associated with significant cognitive load, lack of time for recovery, and long periods of sedentary activity. According to a Eurobarometer survey conducted as part of European Union initiatives, 45% of the adult population in European countries do not engage in any form of physical activity, indicating a high prevalence of sedentary lifestyles in contemporary European society (European Union, 2022). When such low levels of physical activity are combined with chronic stress and an intense learning process, this can lead to increased emotional exhaustion, a decrease in the body's adaptive reserves, and a disruption of stress regulation mechanisms, which in turn exacerbates psycho-emotional difficulties and worsens the functional state of students.

Studying the impact of physical activity on the psycho-emotional state of students allows to identify the mechanisms of emotional regulation in the context of academic workload. Z. Zhang *et al.* (2022) found that increased

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physical activity is associated with a reduction in negative emotional manifestations among students. It was also demonstrated that tolerance to stress and resilience mediate this relationship by strengthening protective psycho-emotional mechanisms. According to C. Herbert *et al.* (2020), regular physical exercise contributes to a reduction in emotional stress and an increase in subjective well-being. In addition, the authors showed that short-term training interventions have a positive effect on mental health indicators even in a remote interaction format. A study by I. Kalashchenko *et al*. (2021) found that insufficient physical activity among medical students is associated with a deterioration in psycho-emotional health, with negative changes exacerbated by an increase in sedentary behaviour during distance learning. An analysis presented by M. Yaroshyk *et al*. (2020) showed that differences in physical activity levels cause significant variations in emotional stability: more active students demonstrated better psycho-emotional characteristics compared to those who were less active.

Sports activities are emerging as a factor that modulates students' psychophysiological responses to academic and stress loads. According to X. Huang *et al.* (2023), structured physical interventions reduce anxiety and depression among students. These interventions also help stabilise emotional reactions under conditions of intense cognitive stress. The combination of aerobic activity with elements of mindfulness practices, as shown in the study by L. San Román-Mata *et al*. (2020), contributes to a more pronounced recovery of the psychophysiological state of students who are under stressful learning conditions. The results of M. Bejtka *et al*. (2022) showed that the level of sports activity of students of pedagogical universities affects vegetative and orthostatic parameters. Students with higher motor activity showed more optimal psychophysiological reactions. The authors L. Korobeinikova *et al.* (2024) also identified differences between active and inactive students in terms of nervous regulation indicators: increased motor activity is associated with higher emotional stability.

Low levels of physical activity are considered a factor that increases students' vulnerability to psycho-emotional disorders and reduces their ability to regulate their emotions during academic stress. It has been established that insufficient physical activity is accompanied by an increase in negative emotional states (irritability, tension, and low mood) and at the same time correlates with an increase in psycho-emotional instability, which increases the risk of stress reactions, as evidenced by the results of Y. Li *et al.* (2022). In a study on the impact of sedentary behaviour, I. Jiang *et al.* (2020) showed that increased sitting time is associated with higher levels of anxiety, depression and suicidal ideation among students. The authors proved that limited physical activity impairs the ability to compensate for emotional stress. Scientists A.M. Rogowska *et al*. (2020) found that a decrease in physical activity is associated with a deterioration in students' emotional well-being, increased mental stress, and intensified dysfunctional emotional reactions. The results obtained by the authors indicate a weakening of emotional regulation mechanisms in conditions of prolonged physical inactivity. O. Byshevets *et al*. (2024) determined that low levels of physical activity among students in stressful conditions are accompanied by an increased risk of emotional disorders and a decrease in the adaptive abilities of youth.

Despite previous studies, the relationship between the level of physical activity of students and the characteristics of changes in their psycho-emotional state during the academic year in the context of physical education and sports remains insufficiently understood. The aim of the study was to establish the influence of different levels of physical activity on the indicators of the psycho-emotional state of higher education students during the academic year. To achieve this aim, the following objectives were set: to characterise the level of physical activity of students; to analyse the indicators of the psycho-emotional state of students; to compare the psycho-emotional characteristics of individuals with different levels of physical activity.

Materials and Methods

The essence of the study consisted in the development and implementation of a specialised physical exercise programme aimed at optimising the psycho-emotional state of students over the course of an academic semester. The training intervention was based on a modular structure of the exercise programme, within which each module performed a specific function in ensuring students' psychophysiological and psycho-emotional adaptation. The aerobic module was designed to create stable cardiorespiratory load and included cyclic exercises of moderate intensity: jogging on a Horizon Adventure 3 treadmill (USA), brisk walking, as well as training on cardio machines such as the Kettler Giro S cycle ergometer (Germany) and the Sportop E5000 elliptical trainer (Taiwan). The duration of the aerobic module averaged 20-25 minutes and was performed at a steady pace, ensuring uniform activation of the cardiovascular and respiratory systems. In parallel with aerobic load, a general physical conditioning module was implemented, which included strength exercises using body weight (squats, lunges, planks and press-ups), performed in 2-3 sets of 10-15 repetitions (for planks, 30-40 seconds). This module was aimed at developing muscular endurance, maintaining muscle tone and ensuring stable activation of major muscle groups. To standardise the load, universal exercise mats and modular rubber platforms were used, allowing the difficulty of exercises to be adapted to the individual fitness level of participants.

To expand the functional variability of the programme, a sensorimotor module was included in the structure of the session and implemented in the second half of training. This module comprised exercises focused on movement coordination and static balance. Its content included static holds in a single-leg stance, dynamic movements with controlled changes in body position, as well as coordinated movements involving simultaneous use of upper and lower limbs, which required maintenance of postural stability. Exercise execution involved control of trunk position, balance maintenance during slow positional changes and spatial coordination of movements without abrupt accelerations. Control of training intensity was carried out within a regulatory – monitoring module by tracking heart rate using wrist-worn heart rate monitors Xiaomi Mi Band 7 (China), produced by Xiaomi. Heart rate was recorded at the beginning of the session, in the middle of the main training module and immediately after its completion, ensuring that the load corresponded to students' individual capacities and preventing overload. The final stage of the session was the recovery – regulatory module, which consisted of two consecutive components. The first component included stretching exercises for major muscle groups lasting 8-10 minutes, aimed at normalising muscle tone and restoring breathing rhythm. The second component was represented by a meditative psycho-emotional self-regulation module lasting 3-6 minutes, implemented in the form of guided breathing relaxation. The meditative module included thematically oriented exercises focused on mindful breathing and attention concentration, aimed at reducing emotional tension, forming a sense of bodily relaxation and stabilising emotional background after physical exertion. The themes of short meditative instructions varied depending on the stage of the programme and included focusing on breathing, a sense of calm, restoration of inner balance and awareness of training session completion. Application of this module contributed to improved subjective well-being and the formation of a positive affective state at the end of the session.

The programme was implemented at the sports hall of Uzhhorod National University over a period of 12 weeks (from 24 February to 16 May 2025) within the autumn-winter academic semester, without holiday breaks or examination-related workload. Training sessions were held three times per week (Monday, Wednesday and Friday) after the completion of scheduled classes (between 16:00 and 18:00), which ensured a rational balance between academic activities and the body's recovery capacity. The duration of one session was 45-55 minutes, corresponding to recommendations regarding the volume of organised physical activity for young people and allowing maintenance of a stable training effect throughout the entire period of programme implementation (World Health Organization, 2020).

The study involved 84 full-time students of Uzhhorod National University aged 17 to 23 years ($M = 20.1 \pm 1.4$ years), enrolled in the 1st-4th years of study across various educational fields. The sample was formed on the basis of voluntary participation following student briefing; all participants provided written informed consent, and ethical procedures were aligned with the requirements of the International Code on Social Research ICC/ESOMAR (2016) and approved by the Ethics Committee (Protocol No. 2/2025 dated 13 September 2024). In terms of gender distribution, the sample comprised 44.0% males ($n = 37$) and 56.0% females ($n = 47$), ensuring adequate gender representation. Following initial questionnaire assessment (Table 1), students were stratified into three groups according to their level of physical activity: low level – 27 participants (15 females, 12 males), moderate level – 29 participants (17 females, 12 males), and high level – 28 participants (15 females, 13 males). The study included full-time students without medical contraindications to physical exertion, who were willing to complete all stages of measurement and attended sessions regularly. Individuals with acute or chronic conditions limiting physical activity, as well as participants with incomplete data, missed training periods or withdrawal at any stage, were excluded; one respondent was withdrawn due to absence from the repeated measurement, and their results were not included in the analysis.

Table 1. Questionnaire for determining the level of physical activity

Question/parameter	Answer options/ numerical values	MET (metabolic equivalent of task) values for calculation
I. Intense physical exercise		
Number of days per week when intense exercise was performed (running, sports, strength training)	___ days (0-7)	8 MET
Average duration of one session of intense exercise	___ minutes	
II. Moderate physical activity		
Number of days per week when moderate exercise was performed (brisk walking, cycling, fitness)	___ days (0-7)	4 MET
Average duration of one moderate exercise session	___ minutes	
III. Active walking		
Days per week when ≥10 minutes of active walking was performed	___ days (0-7)	3.3 MET
Average duration of one episode of active walking	___ minutes	
IV. Sports activities		
Participation in sports clubs/sections	☐ yes ☐ no	
Type of sport		
Training sessions per week	___ times	*intensity is recorded separately*
Duration of training	___ minutes	
Intensity of training	☐ low ☐ medium ☐ high	(3 MET / 4 MET / 8 MET)
V. Daily activity		
Time spent sitting per day (studying, computer, phone)	___ hours/day	-
Time spent actively moving per day	___ minutes/day	-
Number of steps per day (according to tracker, if available)	___ steps	-
Self-assessment of overall physical activity level	☐ low ☐ medium ☐ high	-
VI. Formula for calculating MET minutes		
MET × minutes × days	To be completed by the researcher	
VII. Grouping criteria		
Low activity level	< 600 MET min/week	
Medium activity level	600-2,999 MET min/week	
High activity level	≥ 3,000 MET min/week	

Note: MET – Metabolic Equivalent of Task, a unit for assessing the intensity of physical activity; activity levels were stratified according to the sum of MET-min/week: low level – <600 MET-min, moderate – 600-2,999 MET-min, high – ≥3,000 MET-min
Source: made by the authors

All psychodiagnostic procedures were conducted in university classrooms by a sports psychology specialist with relevant education and practical experience in applying standardised methods, in collaboration with a physical education teacher competent in organising the training process. Initial testing was performed before the start of the programme intervention, intermediate testing was performed in the sixth week to record early changes in the psycho-emotional state, and final testing was performed after the completion of the programme, which allowed for the assessment of the cumulative effects of systematic physical activity. The assessment of the students' psycho-emotional state was carried out using two internationally validated psychodiagnostic techniques, which allowed for a comprehensive characterisation of affective reactions and changes in the emotional profile under the influence of physical activity. The main tool was the PANAS (Positive and Negative Affect Schedule) scale, created on the basis of a two-factor model of affect (Watson *et al.*, 1988), which measured the level of positive affect, reflecting vigour, inspiration and interest, as well as negative affect associated with anxiety, tension and emotional arousal. The intensity of affective manifestations was interpreted based on the percentile distribution of total scores: values below the 25th percentile corresponded to a low level, the 25th-75th percentile interval corresponded to an average level, while values above the 75th percentile were interpreted as a high level of affective expression. For an extended characterisation of mood states, the BRUMS (Brunel Mood Scale) was used, validated in the field of sports psychology (Terry *et al.*, 1999), which allowed to assess the intensity of six emotional components – tension, depression, anger, fatigue, confusion, and vigour – with the formation of a structured mood profile in the context of training influence. The obtained indicators were converted into standardised T-scores, where the mean value corresponded to 50 points ($M = 50$) and the standard deviation was 10 points ($SD = 10$), after which they were interpreted according to the normative limits: 40-60 T-scores – as a conditional norm, 60-69 T-scores – as an increase in individual emotional components, ≥70 T-scores – as pronounced mood changes, while values below 40 T-scores were interpreted as reduced vigour or suppression of emotional characteristics.

Statistical processing of the obtained data was performed using IBM SPSS Statistics 28.0 software. The normality of the distribution of indicators was checked using the Kolmogorov-Smirnov criterion. The analysis of the dynamics of psychoemotional indicators was performed using Student's t test for dependent samples, while intergroup differences were determined using one-way analysis of variance (ANOVA). In case of violation of the normality of distribution, the non-parametric Wilcoxon and Mann-Whitney criteria were used. The level of statistical significance was set at $p < 0.05$, and the results were presented in the format $M \pm SD$. Additionally, a gender analysis was performed using Student's t test for independent samples, which did not reveal any statistically significant differences between men and women in any of the studied psycho-emotional indicators ($p > 0.05$).

Results

Initial indicators of students' psycho-emotional state

The initial testing made it possible to outline the basic psycho-emotional profile of students with different levels of physical activity and to determine the initial intergroup differences before the start of the training influence. Based on the results of the first measurement, a comparative analysis of affective and mood indicators in three groups was carried out, which allows to identify general trends in emotional stability, mobilisation resources and the intensity of negative emotional manifestations. The summarised mean values and standard deviations were presented in Table 2, which provided further opportunity to track the dynamics and compare the reactions of students during the 12-week training period.

Table 2. Initial indicators of the psycho-emotional state of students according to PANAS and BRUMS ($M \pm SD$)

Indicator	Low activity ($n = 28$)	Medium activity ($n = 29$)	High activity ($n = 27$)
PANAS			
Positive affect	22.8 ± 6.4	28.6 ± 5.9	33.4 ± 6.2
Negative affect	31.7 ± 7.1	25.9 ± 6.3	20.8 ± 5.4
BRUMS (T-scores)			
Tension	63.2 ± 8.1	54.6 ± 7.3	48.9 ± 6.8
Depression	59.1 ± 7.4	51.3 ± 6.6	45.8 ± 6.2
Anger	56.4 ± 7.2	49.8 ± 6.5	44.7 ± 6.0
Fatigue	61.4 ± 7.9	52.7 ± 6.9	46.1 ± 6.5
Confusion	58.7 ± 7.5	50.2 ± 6.4	45.7 ± 6.1
Vigour	41.5 ± 6.8	50.8 ± 7.1	58.4 ± 7.6

Note: T-scores – standardised values; $M \pm SD$ – mean value and standard deviation
Source: compiled by the authors

The results showed clearly structured differences in the psycho-emotional state of students with different levels of physical activity, which already at the initial stage creates unequal conditions for their adaptation to further training loads. According to the PANAS scale, students with low activity levels had the lowest positive affect scores (22.8 ± 6.4), indicating reduced vigour, motivational engagement, and overall emotional tone. Such indicators are characteristic of states of emotional fatigue, loss of interest, and insufficient readiness for activity, which is often observed in students with a sedentary lifestyle. Conversely, in the high activity group, positive affect was maximal (33.4 ± 6.2), indicating higher initiative, emotional uplift, and a predominance of adaptive emotions. At the same time, negative affect showed the opposite dynamic: students with low activity had the highest level (31.7 ± 7.1), while in the high activity group this indicator was the lowest (20.8 ± 5.4). This correlation means that inactive students experienced more anxiety, internal tension, and emotional instability. This is due to the imbalance between intellectual loads and a lack of physical activity, which is typical for an educational environment. In contrast, active students had a more stable emotional background, indicating higher adaptive reserves and a natural ability to counteract stressors.

Analysis of the BRUMS scale provided a more detailed picture of the structure of emotional states. Indicators of tension, depression, anger, fatigue, and confusion in the low-activity group exceeded the normative range (63.2-58.7 *T*-scores). This indicates emotional exhaustion, mental strain, and impaired stress regulation. Increased fatigue (61.4 ± 7.9) combined with decreased vigour (41.5 ± 6.8) demonstrated the dominance of asthenic states characteristic of students with a sedentary lifestyle and low overall physical fitness. In the medium activity group, the indicators were within the normal range (mainly 49-54 *T*-points), which indicates a balanced emotional state without significant disturbances. These students demonstrated a relatively stable mood and an medium level of vigour (50.8 ± 7.1), which corresponds to medium physical activity, capable of partially compensating for the effects of academic stress. Students with high activity had the most favourable profile: indicators of depression, anger and confusion were below average normative values (44.7-45.8 *T*-scores), indicating emotional stability and a low level of negative experiences. Fatigue and tension were within the lower norm, and the vigour indicator was the highest among all groups (58.4 ± 7.6). This corresponds to the optimal functional state of the nervous system and high mobilisation readiness.

A comparison of the three groups showed a clear gradient dependence: the lower the motor activity, the worse the psycho-emotional state, and vice versa – high activity was associated with optimal emotional characteristics. Such differences are of important functional significance. Students with low activity entered the experimental period with higher emotional vulnerability and lower stress resistance, which limits their ability to adapt to physical activity. In contrast, students with high activity demonstrated psychological readiness for the training process and greater potential for positive change. The data obtained confirm that physical activity is a significant moderator of the psycho-emotional state of students. It affects not only the general emotional background, but also individual structural components: energy level, severity of asthenic states, emotional stability, and the ability to maintain balanced affective reactions. Thus, the initial differences between the groups determined different initial sensitivity to the training effect and created the basis for further analysis of the dynamics during the twelve-week cycle.

Changes in psycho-emotional indicators in the sixth week of the study

An interim measurement conducted in the sixth week of the training cycle allowed to record the early emotional and psychophysiological reactions of students to systematic physical activity and to assess the rate of adaptive changes in three groups with different initial levels of physical activity. Analysis of the obtained values showed stable positive dynamics in all groups, but the degree and speed of change varied, indicating that emotional responses depend on previous training and the development of regulatory mechanisms. The results presented in Table 3 demonstrate the intermediate values of affective and mood components within PANAS and BRUMS, which allows to identify the first signs of adaptive processes and compare them with the initial data.

Table 3. Interim indicators of students' psycho-emotional state ($M \pm SD$)

Indicator	Low activity ($n = 28$)	Medium activity ($n = 29$)	High activity ($n = 27$)
PANAS			
Positive affect	24.5 ± 6.2	31.2 ± 5.8	36.8 ± 6.1
Negative affect	29.8 ± 6.9	23.4 ± 6.1	18.1 ± 5.0
BRUMS (*T*-scores)			
Tension	60.1 ± 8.1	51.2 ± 7.1	46.0 ± 6.5
Depression	56.0 ± 7.4	48.9 ± 6.4	43.0 ± 6.0
Anger	54.1 ± 7.1	47.3 ± 6.3	42.8 ± 6.0
Fatigue	58.3 ± 7.8	49.5 ± 6.6	44.9 ± 6.3
Confusion	55.9 ± 7.4	47.8 ± 6.2	43.5 ± 6.0
Vigour	44.0 ± 6.7	53.2 ± 7.0	60.5 ± 7.5

Note: *T*-scores – standardised values; $M \pm SD$ – mean value and standard deviation
Source: compiled by the authors

The interim results demonstrate systematic changes in psycho-emotional parameters that characterise the early stages of students' adaptation to organised physical activity. Comparison of the three groups made it possible to determine not only the direction of changes but also their intensity and stability depending on the initial level of physical activity, which is important for further interpretation of the effectiveness of the developed programme. In the low physical activity group, positive affect increased from 22.8 to 24.5 points, indicating the initial formation of an emotional-energetic uplift under the influence of training load. However, these values remained at the lower boundary of the range, confirming slower emotional adaptation. The reduction in negative affect from 31.7 to 29.8 points indicates a moderate decrease in anxiety and emotional tension, yet its level remained significantly higher than in the other two groups. This dynamic is consistent with the baseline emotional instability of this category of students and their lower stress resistance.

Analysis of the BRUMS indicators also demonstrates characteristic early improvements, although the trends remain limited. Tension decreased from 63.2 to 60.1 *T*-scores, depression from 59.1 to 56.0 *T*-scores, while anger, fatigue and confusion changed within 2-3 *T*-scores. Importantly, these indicators still remained above the normative zone, indicating incomplete adaptation. Vigour increased from 41.5 to 44.0 *T*-scores but remained below average values. Thus, this group demonstrates only a primary phase of normalisation of emotional responses, typical of poorly trained individuals experiencing initial load-related stress. In the medium activity group, the training effect was more pronounced. Positive affect increased from 28.6 to 31.2 points, reflecting activation of the motivational-energetic sphere, while negative affect decreased from 25.9 to 23.4 points. These changes indicate optimal adaptive mechanisms formed against the background of a moderate level of fitness. The BRUMS indicators show more structured positive shifts: tension decreased to 51.2 *T*-scores, depression to 48.9 *T*-scores, and all other indicators fell below 50 *T*-scores, which already corresponds to the conditional normative zone. Vigour increased to 53.2 *T*-scores, indicating the formation of adaptive emotional uplift. This dynamic reflects mid-term stabilisation of emotional components and the emergence of stable compensatory responses. In the high activity group, the most intensive positive dynamics were observed. The positive affect score increased from 33.4 to 36.8 points, while negative affect decreased to 18.1 points, the lowest among all groups. This indicates a high level of emotional regulation characteristic of students with a good level of physical fitness. BRUMS values demonstrate normalisation and even optimisation of the mood profile: tension decreased to 46.0 *T*-scores, depression to 43.0 *T*-scores, while anger and confusion stabilised at around 43 *T*-scores. Vigour increased to 60.5 *T*-scores, indicating a high level of psychophysiological activation and a pronounced adaptive effect.

Comparative analysis of the three groups clearly demonstrates the dependence of the rate and magnitude of changes on the initial level of physical activity. The slowest and least structured changes are characteristic of sedentary students, which corresponds to the concept of lower adaptive reserve capacity. The medium activity group approached normative indicators by the sixth week, confirming the effectiveness of moderate training experience. The highest activity level ensured the most harmonious and stable profile of positive changes, indicating the advantages of a systematic motor regime and well-formed physical and psycho-emotional resilience. Thus, the interim results demonstrate a clearly expressed positive training effect that is already formed by the sixth week but varies in intensity depending on the initial level of physical activity.

Final indicators of psycho-emotional state after 12 weeks of training

Final testing conducted after the training intervention allowed for a comprehensive assessment of the depth of adaptive changes in students with different levels of physical activity and determined the stability of the psycho-emotional effects of physical exercise. A comparison of the final and initial indicators showed a systematic improvement in emotional and mood parameters in all three groups, but the nature and intensity of this improvement remained significantly differentiated. The most pronounced positive changes were observed in students with medium and high levels of activity, while individuals with low physical activity demonstrated a slower but consistent trajectory of emotional process stabilisation. The final values are presented in Table 4.

Table 4. Final psycho-emotional indicators of students depending on the level of physical activity ($M \pm SD$)

Indicator	Low activity ($n = 28$)	Medium activity ($n = 29$)	High activity ($n = 27$)
PANAS			
Positive affect	27.1 ± 6.0	34.9 ± 5.6	40.2 ± 5.8
Negative affect	26.4 ± 6.5	20.1 ± 5.7	15.7 ± 4.9
BRUMS (*T*-scores)			
Tension	55.4 ± 7.9	45.8 ± 6.8	41.2 ± 6.2
Depression	52.8 ± 7.1	43.7 ± 6.1	39.0 ± 5.8
Anger	50.3 ± 7.0	44.8 ± 6.0	40.5 ± 5.9
Fatigue	52.9 ± 7.6	45.1 ± 6.4	40.3 ± 5.8
Confusion	51.4 ± 7.2	44.6 ± 6.1	40.7 ± 5.8
Vigour	48.7 ± 6.6	57.1 ± 7.2	65.3 ± 7.4

Note: *T*-scores – standardised values; $M \pm SD$ – mean value and standard deviation
Source: compiled by the authors

Comparison of the three groups showed that in the low activity group positive affect was 27.1 points, indicating a medium level of emotional activation that was lower than in students with medium and high activity levels. Negative affect in this group remained at 26.4 points, which was the highest among all groups. This suggests that even after the training intervention, emotional and stress-related reactions in physically inactive students remained pronounced. The BRUMS profile further confirms this observation: tension, depression, anger, fatigue and confusion were maintained within the range of 50-55 *T*-scores, reflecting only partial normalisation of the emotional state. Vigour, at 48.7 *T*-scores, although increased, remained below the average norm, demonstrating limited psychophysiological resources and insufficient mobilisation capacity of the nervous system. Students with medium activity demonstrated a more balanced psycho-emotional profile. Positive affect at 34.9 points approached optimal values, while negative affect decreased to 20.1 points, reflecting a more effective reduction in emotional tension. BRUMS indicators in this group were characterised by a shift of most values into the normative zone: tension, depression, anger and confusion were within the range of 43-46 *T*-scores. Particularly notable were fatigue (45.1 *T*-scores) and vigour (57.1 *T*-scores), indicating optimal recovery processes and a sufficient level of internal motivation and activity. This configuration of results reflects a formed adaptive type of emotional response typical of individuals with moderate training status.

The high activity group demonstrated the most structured and optimised profile. Positive affect reached 40.2 points – the highest value among all groups – indicating the dominance of emotions associated with energy, interest and inspiration. Negative affect was only 15.7 points, reflecting a minimal level of anxiety and emotional tension. BRUMS indicators confirm this pronounced adaptive pattern: tension, depression, anger, fatigue and confusion were maintained within the range of 39-42 *T*-scores, corresponding to a low level of negative emotional responding and high stress resistance. The most indicative value was vigour (65.3 *T*-scores), which was significantly higher than in the other groups and reflects maximal mobilisation of psychophysiological resources and a high degree of emotional regulation. For a clearer interpretation of the dynamics of affective changes during the twelve-week training intervention, a separate diagram was constructed to illustrate trends in positive and negative affect in groups with different levels of physical activity. The graph demonstrates stepwise changes across three measurement points (T1, T2, T3) and allows comparison of the rate and direction of affective shifts depending on students' baseline training status (Fig. 1).

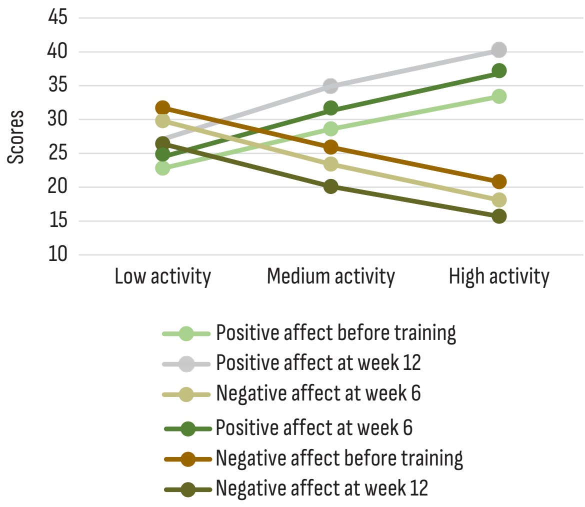

Figure 1. Dynamics of positive and negative affects in three groups during the experiment
Source: compiled by the authors based on data obtained in the study

To clearly demonstrate the dynamics of emotional components on the BRUMS scale, three analytical graphs were constructed, reflecting the key directions of psycho-emotional changes in students with different levels of physical activity at three stages of measurement. The selection of pairs of indicators was made taking into account their functional content: emotional distress (tension and depression), reactivity and vigour depletion (anger and fatigue), as well as cognitive-emotional disorientation and mobilisation resources (confusion and vigour). The set of graphic materials is presented in Figure 2.

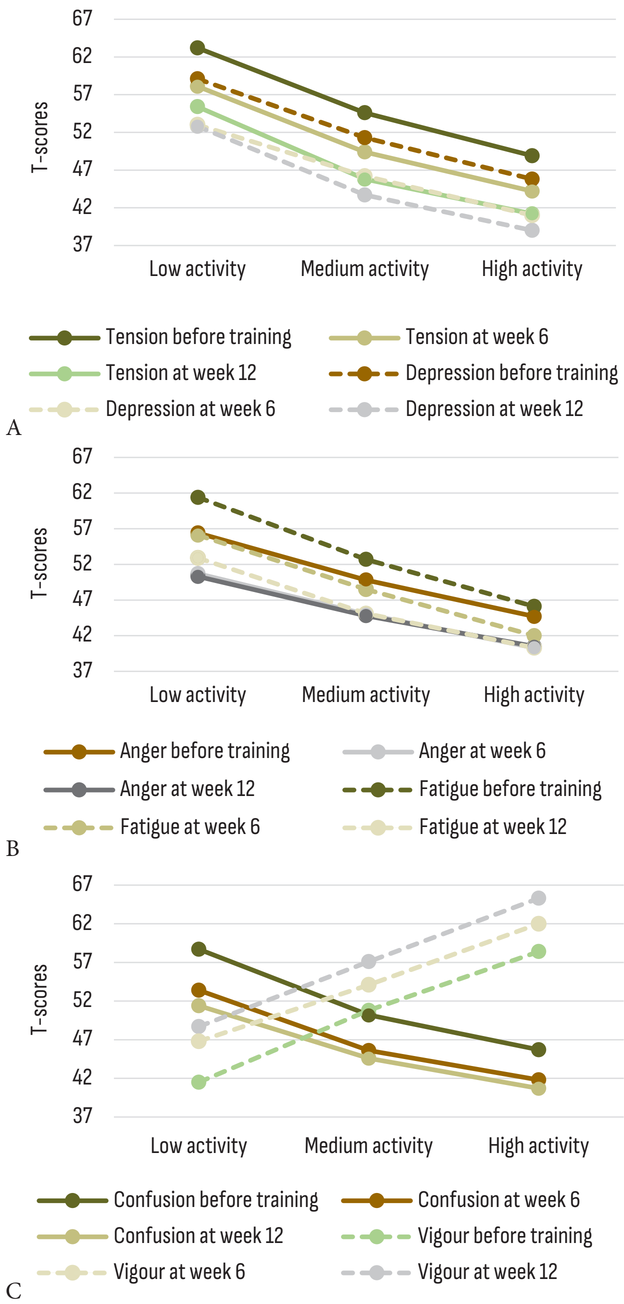

Figure 2. Dynamics of BRUMS emotional indicators by activity levels
Note: A – tension and depression; B – anger and fatigue; C – confusion and vigour
Source: compiled by the authors based on data obtained in the study

Comparing the results of all the graphs, which cover both positive and negative affect indicators on the PANAS scale and the dynamics of emotional components on the BRUMS scale, makes it possible to form a comprehensive picture of the psycho-emotional changes in students over the 12 weeks of the training intervention. All groups showed an increase in positive affect and a decrease in negative affect, as well as a gradual decrease in the intensity of tension, depression, anger, fatigue, and confusion, along with an increase in vigour. These trends indicate the systemic impact of physical exercise on the emotional sphere and improved psychophysiological regulation.

Intergroup comparisons revealed significant differentiation in the depth of positive changes. Students with low levels of physical activity retained the most tense and unstable emotional profile, despite gradual positive changes; their indicators remained closer to the upper limit of the norm or slightly exceeded it. The medium activity group showed clearly balanced and close to optimal values, indicating a sufficient level of adaptation and the formation of more effective emotional regulatory mechanisms. The most harmonious and resourceful profile was formed in the high activity group, which is characterised by the lowest values of negative emotional components, the highest levels of energy and a consistently high positive affect. The overall picture shows that the structural differences between the groups reflect not only different initial levels of physical activity, but also varying degrees of development of psycho-emotional regulation mechanisms. This allows to conclude that regular physical exercise is an important modulating factor of emotional stability and psychophysiological balance, ensuring better adaptation of students to prolonged academic and physical stress.

Generalised effects of regular physical exercise on the psycho-emotional state of students

Summarising the results of the three measurement stages allows to trace a complete picture of the impact of systematic physical exercise on the psycho-emotional state of students. The data obtained indicate that a structured training load integrated into the educational process causes consistent positive changes in the affective sphere, regardless of the initial level of motor activity. This effect confirms the significant role of physical education as a pedagogical tool aimed at reducing emotional tension, increasing the level of subjective activity and strengthening the stress resistance of students. An integrated analysis of PANAS and BRUMS indicators confirms the general direction of emotional shifts: there was a gradual increase in positive affect, a decrease in the intensity of negative affect, and a normalisation of key emotional components associated with psychophysiological stress. Indicators such as tension, fatigue, depression, and vigour, which most closely reflect the adaptation of the nervous system to physical activity, proved to be particularly sensitive to the training effect. The reduction in manifestations of nervous and emotional exhaustion and the increase in energy indicate the formation of a positive functional state, which is one of the key goals of the academic discipline "Physical Education".

It is also important to conduct a comparative analysis of students with different levels of activity, which demonstrates the graduated nature of the adaptation effect. Individuals with low physical activity showed gradual but less intense improvement, which indirectly confirms a lower level of initial physical fitness and more limited adaptation reserves. Participants with an average level of activity showed the most harmonious normalisation of emotional components, which manifested itself through the stabilisation of mood indicators and a significant reduction in distress. Students with high activity levels were characterised by the most optimal emotional profile, reflecting the stable formation of emotional regulation mechanisms associated with systematic involvement in physical culture and sports exercises. A comparison of the groups in terms of dynamics allows to identify a key trend: the higher the level of regular physical activity, the faster emotional processes stabilise and the more clearly the resource type of emotional response is formed. This pattern is consistent with sports psychology models that interpret physical activity as a factor in enhancing serotonergic reactivity, activating dopaminergic pathways of motivation, and normalising vegetative balance (Chen & Nakagawa, 2023). The stabilisation of these mechanisms contributes to improved mood, reduced periods of emotional exhaustion, and faster recovery from academic stress.

Systematic training programmes based on a combination of aerobic, strength and recovery exercises have been shown to not only reduce the manifestations of psycho-emotional distress, but also to form lasting adaptive changes that remain pronounced after the completion of a twelve-week cycle. This provides grounds for including regular medium-intensity training modules as mandatory components of physical education in higher education institutions, emphasising the importance of gradually involving sedentary students. Thus, a generalised analysis of the effects of training intervention proves that systematic physical education classes are an effective means of improving the psycho-emotional state of students and create conditions for increasing their emotional stability, adaptability and overall psychophysiological well-being throughout the academic yea.

Discussion

The results demonstrate consistent positive changes in the psycho-emotional state of students under the influence of training intervention integrated into the structure of physical education. All groups showed an increase in positive affect, a decrease in negative affect, and normalisation of key emotional components according to PANAS and BRUMS. The most pronounced effects were observed among students with medium and high levels of physical activity, while in less active individuals the dynamics were slower and less structured. The combination of changes indicates the systemic influence of physical exercise on affective reactions, psychophysiological regulation, and resistance to academic stress.

The initial testing revealed significant intergroup differences in the structure of emotional state: students with low physical activity had the lowest level of positive affect (22.8 points) and the highest negative affect (31.7 points), while physically active individuals had the most favourable emotional profiles. The consistency of these trends can be seen in the study by J. Gaia *et al*. (2022), where regular physical activity is associated with reduced tension and improved overall mood in youth. At the same time, this study showed that sedentary people are more prone to fluctuations in emotional background, which is fully consistent with the results obtained. Similar patterns were demonstrated in a meta-analysis by O. Cho (2020), where physical education contributes to increased emotional competence. This is consistent with higher levels of positive affect in students with medium and high activity levels. However, the researcher also noted that the effects of physical activity are less pronounced in insufficiently trained individuals, which is consistent with the highest values of negative affect in the inactive group. The results of L. Gasiūnienė & B. Miežienė (2021), where low activity levels are accompanied by increased academic stress, confirm the increased tension and fatigue found in this study. Researchers M. Grasdalsmoen *et al*. (2020) also noted that students with low physical activity showed a higher risk of emotional difficulties, which confirms the vulnerability of this group at the initial stage and directly corresponds to the results obtained.

The interim results of the sixth week showed clear early changes: in students with medium and high physical activity, positive affect increased to 31.2 and 36.8 points, respectively, while negative affect decreased to 23.4 and 18.1 points. BRUMS scores for tension, fatigue, and depression also showed a gradual decline in all groups, indicating the initial phase of emotional adaptation to systematic physical activity. These trends are consistent with the findings of C. Herbert (2022), where a decrease in emotional tension and an improvement in psychophysiological well-being were recorded in the first weeks of the training programmes, confirming the accelerated adaptive nature of the changes obtained. The authors found that early emotional reactions are sensitive to the intensity of the sessions, which corresponds to more pronounced changes in the high-activity group. The results of R. Jiang *et al*. (2021) showed that during the first month of training, fatigue, disorganisation and psychophysiological tension decreased – indicators that also decreased in this study. The partial increase in positive affect and decrease in negative affect is consistent with the proposition that early emotional shifts are shaped by increased self-efficacy, as shown in L. Li *et al.* (2024). The study found that it is the increase in the sense of control over physical activity that serves as a key mediator of the initial reduction in emotional tension, which is fully consistent with the dynamics observed in students of medium and high activity levels. The regular decrease in negative emotional modalities is consistent with the model of gradual emotional adaptation described by Y. Lu & B. Wang (2024), which emphasised that the first weeks of training intervention are characterised by the dominance of processes of reducing stress sensitivity. The authors demonstrated that at this stage, it is the reduction of distress that precedes the formation of a stable positive emotional background, which fully coincides with the interim results obtained.

The final results of the intervention showed the most pronounced positive dynamics: in the high activity group, positive affect increased to 40.2 points, while negative affect decreased to 15.7 points. BRUMS indicators showed a steady decrease in tension (to 41.2-55.4 T-points), fatigue (to 40.3-52.9 *T*-points) and depression (to 39.0-52.8 *T*-points) in all groups, but the most optimised emotional profile was formed in physically active students. The results are consistent with the conclusions of A. Martinez *et al*. (2024), where prolonged engagement in physical activity contributes to improved emotional regulation and reduced risk of negative mood reactions. The study also emphasised that lasting emotional changes are formed only with regular exercise, which fully corresponds to the final indicators in the high activity group. The differences between active and sedentary students identified in this study coincide with the results of T. McGuine *et al*. (2021), where athletically active adolescents demonstrated better psychological well-being during stressful periods. The authors emphasised the protective role of regular physical activity, which reduces the likelihood of anxiety and distress. This trend is fully reflected in the lowest negative affect scores among active students. The reduction in depression and emotional exhaustion is consistent with the data from A. Murray *et al.* (2022), where physical activity shows the ability to stabilise the emotional state in students with high stress levels. The researchers noted that the effects increased gradually, which corresponds to the most significant changes in the final stage of the study. The overall configuration of the final indicators is consistent with the results of J. Ren & H. Xiao (2023), in which prolonged physical activity is associated with the normalisation of neurobiological mechanisms of mood regulation. The researchers emphasised that it is the duration of the intervention that determines the depth of positive emotional changes, which directly corresponds to the pronounced effect in the medium and high activity groups.

The results of the study indicate a stable positive dynamic of the psycho-emotional state over 12 weeks: in all groups, the indicators of negative emotional modalities BRUMS gradually decreased, while energy and positive affect increased. The most pronounced changes were observed in students with high physical activity, confirming the leading role of systematic sports-oriented physical exercises in the formation of sustainable adaptive effects. The patterns identified are consistent with the data of C. Chen & S. Nakagawa (2023), who showed that prolonged physical activity activates neurobiological mechanisms of resilience and normalises emotional responses through the regulation of serotonergic and dopaminergic pathways. This corresponds to a significant reduction in depression and tension in students with high physical activity. The findings are also consistent with those of M. Monserrat-Hernández *et al*. (2023), who found that regular physical activity reduces academic stress and stabilises mood in young people, which correlates with a reduction in fatigue and confusion in all groups. There is a partial coincidence with the findings of I. Ullah *et al*. (2023), who showed that increased physical activity is associated with a reduction in anxiety symptoms and improved emotional states, although the authors emphasised slower dynamics in sedentary individuals, which is consistent with the moderate changes in the low-activity group. At the same time, the results of J. Magallón & P. Catalán (2024) partially disagree with this study, as the authors found that sedentary behaviour can negate the positive effects of training, whereas in this study, even inactive participants showed positive dynamics.

The final analysis emphasised that systematic physical exercise and sports-oriented training programmes contribute to the formation of stable emotional regulatory mechanisms, which manifests itself in a marked increase in positive affect, a decrease in negative emotional modalities, and increased energy at the end of the intervention. This combination of emotional effects indicates the key role of the intensity and regularity of physical activity in the formation of holistic psychophysiological adaptation in students. The results obtained are consistent with the conclusions of M. Bigliassi *et al*. (2024), where it was found that an increase in tolerance to physical activity is accompanied by a decrease in psychophysiological reactivity and stabilisation of the emotional state during stress. This corresponds to the reduction in tension and fatigue observed in all groups. The study by K. Wang *et al*. (2020) emphasised that physical activity increases students' emotional intelligence and self-efficacy, and these factors act as mediators of improved emotional stability, which is consistent with the observed increase in positive affect and energy in physically active participants. The findings of E.M. Wiedenman *et al*. (2024) also confirmed that participation in sports programmes enhances psychological resilience and the satisfaction of basic needs, which correlates with the most optimised emotional profile in highly active students. Partial correspondence was demonstrated by the results of G.H. Zieff *et al*. (2024), where aerobic exercise contributes to stress reduction in young people with high levels of tension. In this study, similar effects were pronounced but had a broader coverage of emotional components.

A summary of the discussion results showed that regular physical activity is an effective means of stabilising the psycho-emotional state of students, contributing to a reduction in negative emotional manifestations and an increase in vigour and positive affect. The most pronounced adaptive changes were observed in students with medium and high levels of activity, which emphasises the importance of regular physical exercise for maintaining emotional balance. The patterns obtained are consistent with data from other studies, which indicates the universality of the positive impact of physical exercise on the psycho-emotional stability of youth.

Conclusions

Initial testing confirmed clear intergroup differences in the psycho-emotional state of students depending on their level of physical activity. Students with low activity demonstrated the lowest positive affect (22.8 points) and the highest negative affect (31.7 points), as well as increased levels of tension, depression and fatigue within the range of 58-63 *T*-points. In the medium activity group, the values were close to normal, while physically active students had the most optimal profile – high positive affect (33.4 points), low negative affect (20.8 points) and the lowest indicators of negative emotional components of BRUMS, which remained stable at the lower limit of the normative zone (tension – 48.9, depression – 45.8, anger – 44.7, fatigue – 46.1, confusion – 45.7 *T*-points). The data obtained indicate that the initial level of motor activity determines emotional stability and initial adaptability before training intervention.

In the sixth week, a systematic positive dynamic was recorded in all groups, but its severity depended on the initial activity. In low-activity students, positive affect increased from 22.8 to 24.5 points, and negative affect decreased from 31.7 to 29.8 points, reflecting only the initial phase of adaptation. In the medium activity group, these changes were more significant: positive affect increased to 31.2 points, negative affect decreased to 23.4 points, and most BRUMS indicators approached normal. The most intense dynamics were observed in highly active students, where positive affect increased to 36.8 points and negative affect decreased to 18.1 points, accompanied by a marked decrease in negative emotional components of BRUMS to a level close to the norm. The results show that early emotional changes directly depend on the level of training, and adaptation mechanisms are more active in better-prepared participants.

The final measurements showed the most significant improvement in emotional indicators and the completion of the formation of an adaptive emotional profile. In low-activity students, positive affect increased to 27.1 points, negative affect decreased to 26.4 points, and BRUMS indicators decreased to 50-55 *T*-points, indicating a partial normalisation of the condition. In the medium activity group, positive affect reached 34.9 points, negative affect decreased to 20.1 points, and all mood indicators entered the normal range (43-46 *T*-points). The most favourable profile was found in the highly active group: positive affect was 40.2 points, negative affect was only 15.7 points, while tension, depression, anger and fatigue decreased to 39-42 *T*-points, and vigour reached a maximum of 65.3 *T*-points. This emphasises that long-term training intervention has a pronounced adaptive effect, especially in students with high physical activity. The overall trajectory of change indicates that regular exercise integrated into the learning process normalises emotional responses, reduces distress and forms an optimal functional state of the nervous system. Thus, physical culture is an effective means of ensuring psycho-emotional stability throughout the academic year. A limitation of the study was that it covered only one type of organised physical activity (a set of moderate-intensity aerobic and general physical exercises), while other forms (dancing, swimming, sports games) could cause different dynamics of emotional changes. A promising direction for future research would be to compare the effectiveness of different types of physical activity for optimising the psycho-emotional state of students.

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Conflict of Interest

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Вплив фізичних вправ на психоемоційний стан здобувачів під час навчального року

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Анотація. Мета дослідження – визначити вплив різних рівнів фізичної активності на психоемоційні показники студентів в умовах навчального процесу. Методологія дослідження ґрунтувалася на дванадцятитижневому емпірично-аналітичному спостереженні, проведеному на базі Ужгородського національного університету з 24 лютого до 16 травня 2025 року, у межах якого студенти проходили первинне, проміжне та підсумкове психодіагностичне обстеження за шкалами позитивного і негативного афекту та емоційного профілю настрою й виконували комплекс аеробних та загальнофізичних вправ різної інтенсивності. Протягом 12 тижнів регулярних фізичних вправ показники позитивного афекту у групі студентів з низькою активністю підвищилися з 22,8 до 27,1 бала, у студентів із середньою активністю – з 28,6 до 34,9 бала, а у високоактивної групи – з 33,4 до 40,2 бала. Одночасно відзначено послідовне зменшення негативного афекту: у малорухомих студентів – з 31,7 до 26,4 бала, у групі середньої активності – з 25,9 до 20,1 бала, у високоактивних – з 20,8 до 15,7 бала. Показники емоційних компонентів за шкалою настрою також продемонстрували виражене покращення: у групі високої активності напруженість знизилася до 41,2 бала, депресивність – до 39 бала, гнів – до 40,5 бала, а енергійність підвищилася до 65,3 бала, що стало найвищим результатом серед учасників. Дослідження підтвердило, що систематичні аеробні та загальнофізичні вправи протягом дванадцяти тижнів сприяли стійкому підвищенню позитивного ефекту, енергійності та зниженню емоційного дистресу у студентів незалежно від їхнього вихідного рівня рухової активності. Результати можуть бути використані викладачами фізичного виховання, тренерами та фахівцями зі спортивно-оздоровчих технологій для розробки ефективних програм занять, спрямованих на підтримання психоемоційної стабільності молоді в умовах навчального навантаження

Ключові слова: афективні реакції; рівень рухової активності; аеробні вправи; показники настрою; дистрес; студенти; освітній процес

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Olympic education as a component in forming the culture of health and physical activity of lower secondary school pupils

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Abstract. The purpose of the study was to determine the influence of elements of Olympic education on the formation of a culture of health, motivation for physical activity, and the development of physical qualities in pupils of 7-9 grades. The methodology included a comparative analysis of modern elements of Olympic education and traditional elements of physical culture, as well as the conduct of a pedagogical experiment. The main results of the study demonstrated a positive impact of Olympic education on the motivational and value sphere and on pupils' physical fitness. The experimental group showed a higher dynamics of change compared with the control group. The share of "4-5" responses regarding satisfaction with physical activity, interest in competitions, readiness to train, and the perception of Olympic values increased by 20-35%, whereas in the control group changes did not exceed 2-3%. Indicators of physical fitness also confirmed the advantages of the implemented programme. In the 30 m run, speed improved from 6.4 to 5.9 s, and in the 60 m run – from 12.2 to 11.3 s. The mean indicators of the test exercise ("shuttle run" 4×9 m) decreased from 12.8 to 11.9 s. A similar trend was observed in changes in strength indicators, namely: muscular endurance increased from 12 to 17 repetitions, explosive strength – from 157 to 173 cm. The greatest increase was recorded in the PACER test: from 56 to 78 laps, which represents an increase in distance from 1,120 to 1,560 m – an indicator that directly reflects improved aerobic endurance. The practical value of the work lies in the development of recommendations on integrating elements of Olympic education into the school physical education course, which proved its effectiveness in real conditions. The data obtained can be used by physical education teachers, school administrators, curriculum developers, coaches of children's and youth sports schools, and specialists in out-of-school education

Keywords: value orientation; competitive forms; team interaction; intrinsic motivation; physical fitness; adolescents

Introduction

Olympic education is regarded as an effective means of forming a culture of health and physical activity among pupils, since it combines motor activity with the cultivation of value orientations, moral norms, and social responsibility. The educational process, supplemented by the ideas of Olympism, is directed not only at the development of physical qualities, but also at forming a personal attitude towards a healthy lifestyle, fair competition, self-development, and respect for others. In the school environment, Olympic education helps to increase the level of motivation for engaging in physical culture and sport, strengthen teamwork skills, form a positive self-esteem, and foster a responsible attitude towards physical activity. The dissemination of Olympic values in educational institutions creates conditions for a systematic impact on health-preserving behaviour, contributes to strengthening social and emotional health, and forms a holistic understanding of physical activity as a natural component of one's lifestyle.

Olympic education promotes the formation of a culture of health and the development of physical activity among young pupils by combining sporting values, knowledge about a healthy lifestyle, and skills of physical

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self-improvement. Researchers study this topic and distinguish different approaches to its implementation, focusing on the combination of physical training, the formation of moral and ethical guidelines, and motivation for an active lifestyle. For example, the study by Y. An *et al*. (2022) emphasised that, in Chinese schools, the introduction of health-oriented physical education contributes to the sustainable development of pupils' physical activity, forming habits of regular movement and an awareness of the importance of physical culture in everyday life. At the same time, the use of innovative approaches in the educational process makes it possible to combine practical classes with theoretical knowledge about health and safe physical activity. In France, according to M. Attali & F. Le Yondre (2022), Olympic education is considered both as a tool for preserving sporting heritage and as a means of popularising the values of Olympism among pupils. The implementation of programmes is aimed at forming moral and ethical norms, cooperation skills, and a conscious attitude towards one's own health, which stimulates regular participation in sports events. The work of O. Danysko *et al*. (2023) showed that, in the USA (United States of America), the introduction of innovative models of physical education in secondary schools increases pupils' levels of physical activity through a combination of wellness programmes and mass sports events. Such programmes form stable motivation for an active lifestyle and develop the ability to plan physical activity independently. In the study by T. Dorofieieva & V. Prikhodko (2020), it is noted that the decentralisation of the management of sports education in Ukraine facilitates the adaptation of curricula to the needs of specific schools and local communities, which increases the effectiveness of Olympic initiatives and healthy lifestyle programmes. According to H. Ivanenko (2021), the organisational and methodological conditions for integrating Olympic education into the educational process ensured the systematic inclusion of the values of Olympism and the principles of physical culture in school curricula, which contributes to forming pupils' motivation for regular physical activity and self-control over the health.

The historical analysis of the development of Olympic education conducted by S. Ivashchenko *et al*. (2022) showed that the formation of sporting culture through educational programmes has gradually evolved from the simple inclusion of sports lessons to a comprehensive approach that combines physical activity with the promotion of healthy lifestyle values. Such a combination helps pupils to understand the importance of physical culture for personal development and health maintenance. D. Kelmendi *et al*. (2024) noted that Olympic values form pupils' moral and ethical guidelines, motivating pupils to participate in sporting events and to develop communication and leadership skills through team sports. The authors emphasised that the introduction of these values into the educational process contributes to forming a responsible attitude towards health and regular physical activity. The implementation of Olympic programmes in the education system in India contributes to the formation of a healthy nation, since pupils receive knowledge about the importance of physical activity, healthy nutrition, and a conscious attitude towards the bodies, as noted by R. Kumar (2024). The scholar stressed that the systematic inclusion of Olympic values in the educational process stimulates regular participation in sporting events and forms sustainable healthy habits over a long period. R. Orhan (2020) emphasised that school education significantly influences pupils' participation in physical activity, as it forms habits of regular sports practice and develops physical abilities, which are important in later life. Early involvement in systematic physical exercises increases pupils' motivation for an active lifestyle and contributes to the formation of social skills through team sports. Y. Theodorakis *et al*. (2024) noted that the Olympic movement adapts to global challenges, encouraging pupils to lead an active lifestyle through innovative educational programmes, sports events, and the promotion of health principles. The use of practical classes in combination with educational lectures forms a comprehensive understanding of the importance of physical activity for pupils' physical and psycho-emotional development.

Despite the aspects highlighted by the aforementioned studies, there are gaps in solving the identified problem, which include insufficient examination of the influence of Olympic education on the formation of systemic healthy lifestyle skills among schoolchildren. There is a shortage of empirical data on the integration of Olympic values into school programmes of physical activity and health. The significance of Olympic education in developing motivation for regular physical education and in supporting pupils' psychophysical well-being has been insufficiently studied. The purpose of the study was to determine the influence of elements of Olympic education on the formation of a culture of health, motivation for systematic physical activity, and the development of physical qualities in pupils of 7-9 grades. The objectives of the study were: a comparative analysis of traditional and modern elements of Olympic education; experimental verification of the effectiveness of integrating Olympic educational components into the process of school physical education; and the development of practical recommendations on implementing elements of Olympic education in the school physical education system.

Materials and Methods

The study compared modern elements of Olympic education with traditional elements of physical culture. Traditional elements of pupils' physical culture included standard physical education lessons without special thematic content, classical exercises for the development of speed, strength, coordination, and endurance, as well as regular extracurricular sports events. Within the study of elements of Olympic education, thematic mini-lectures in physical education lessons, the viewing of short video materials about the history and values of the Olympic Games, participation in school mini-Olympics, athletics relays, tournaments in team sports, Olympic Week, and the conduct of interactive discussions on "fair play", respect, equality, and self-improvement were analysed. These categories were compared according to such criteria as the level of pupils' physical activity and motivation, the mastery of Olympic values, the development of physical qualities (speed, strength, endurance, coordination), and the ability for team interaction and adherence to the principles of fair play.

The study of the influence of Olympic education on the formation of a culture of health and physical activity among pupils was conducted from January to March 2025 at the Volodymyr Monomakh Lyceum (Pereiaslav, Kyiv Region). The study involved 124 pupils in 7-9 grades aged 12 to 15 (63 boys and 61 girls). All participants and the parents provided voluntary informed consent to take part in the study. Classes and testing were conducted offline, within the framework of the regular educational process. Inclusion criteria comprised pupils of 7-9 grades, the absence of medical contraindications to participation in physical education lessons, attendance of at least 70% of classes during the study, and consent to participate. Exclusion was applied to pupils with acute or chronic diseases limiting physical activity, pupils on individual forms of education, and those who missed more than one third of classes. All participants were divided into two groups. The experimental group (EG, 62 pupils) studied under a programme that included elements of Olympic education: thematic mini-lectures in physical education lessons, the viewing of short video materials about the history and values of the Olympic Games, participation in school mini-Olympics, athletics relays, tournaments in team sports, Olympic Week, and interactive discussions on “fair play”, respect, equality, and self-improvement. The control group (CG, 62 pupils) followed the standard curriculum without the use of Olympic components.

At the initial stage of the study, in order to determine the level of motivation for physical activity, interest in sport, and the formation of value orientations related to Olympism, an adapted Questionnaire on motivation for physical activity (PACES) (n.d.) was used. It contained 15 statements assessed on a five-point Likert scale from 1 (“strongly disagree”) to 5 (“strongly agree”). The questions for assessment before and after the experiment were as follows:

1. I enjoy doing physical activity.
2. I feel better after physical education lessons.
3. I would like to be more physically active.
4. I like taking part in sports competitions.
5. I am interested in the Olympic Games.
6. Olympic values inspire me to do sport.
7. I believe that a healthy lifestyle is part of my development.
8. I like team sports.
9. I respect opponents in competitions.
10. I am ready to take part in additional sports events.
11. I try to follow a training or physical activity regime even outside school.
12. It is important for me to achieve better results in sport and physical exercises.
13. I am ready to work on myself in order to improve my sporting skills.
14. I believe that regular physical education classes help me to feel confident.
15. I strive to take part in team and individual competitions, even if this requires effort and training.

The level of physical fitness was assessed using a set of standardised school tests. Speed abilities were determined from the results of 30 and 60 metre runs. Coordination qualities were assessed by performing a 4×9 metre shuttle run. Muscular endurance was measured by the number of press-ups (bends and extensions of the arms in the lying support position) in 30 seconds. Explosive leg strength was determined from the results of the standing long jump. To assess aerobic endurance, a 20-metre progressive load test was used (PACER Beep-test, n.d.). Pupils ran between two lines 20 metres apart, responding to sound signals whose frequency gradually increased. The test ended when a pupil twice in a row failed to cross the line before the sound signal. The number of completed laps was recorded, and the total distance was calculated. Observations were carried out by three independent experts.

The formative stage lasted 12 weeks. The experimental group followed a specially designed Olympic education programme, integrated into the structure of physical education lessons and extracurricular activities. The control group worked according to the standard curriculum without changes. The study was conducted in accordance with ethical standards (American Sociological Associations, 1997); all participants and their parents were informed about the purpose and procedures, participation was voluntary, the results were anonymous and confidential, and the loads were safe and age-appropriate. Attention was given to preventing physical overexertion during tests and classes.

At the final stage, all measurements were repeated: the questionnaire, physical fitness testing, and pedagogical observation. Quantitative data were processed using methods of descriptive statistics with the use of Student’s *t* test to compare dynamics in the control and experimental groups, to analyse percentage changes, and to examine correlations between the level of motivation and physical fitness indicators. During lessons, standardised pedagogical observation of pupils’ activity was conducted. Parameters such as exercise intensity, participation in team games, adherence to the principles of fair play, manifestation of initiative, and level of engagement in competitive forms of work were recorded. Observations were carried out by three independent experts – physical education teachers. On the basis of the study, recommendations were developed for implementing elements of Olympic education in the educational process.

Results

Comparison of traditional and modern elements of Olympic education

Olympic education, as a component in shaping a culture of health and physical activity among school-age young people, is based on the combination of knowledge, values, and practical activities aimed at the comprehensive development of the individual through physical culture and sport. It rests on several key concepts, each of which plays a role in forming health-preserving behaviour in schoolchildren. The concept of Olympic values encompasses such ideas as friendship, respect, striving for excellence, fair play, equality, and tolerance. These values form the moral and ethical foundation of interaction in the sporting environment and teach pupils to take responsible attitudes to the actions, respect opponents, and work on self-improvement (Zhang & Powell, 2022). Physical culture is viewed more broadly than just a lesson or training session – it is part of an individual’s general culture, reflecting a person’s attitude to physical activity, the willingness to maintain physical health, follow a daily routine, form healthy habits, and systematically develop physical qualities. Physical activity, in turn, is the practical manifestation of this culture: it refers to any motor actions that contribute to strengthening health and developing endurance, strength, speed, and coordination. It includes both organised forms of activity (lessons, training sessions, clubs) and children's independent activity in everyday life. A healthy lifestyle is the end result of mastering the knowledge and values of Olympic education (Hwang & Henry, 2021). It covers a responsible attitude to one's own physical and mental health, the ability to make conscious choices in favour of physical activity, rational nutrition, a daily routine, and the prevention of harmful habits.

In the educational environment, elements of Olympic education are clearly traceable, such as thematic mini-lectures during physical education lessons, viewing short videos about the history and values of the Olympic Games, participation in school mini-Olympics, athletics relays, team sports tournaments, the holding of an Olympic Week, and the organisation of interactive discussions on fair play, respect, equality, and self-improvement (Ribeiro *et al.*, 2020). Alongside these, traditional elements of physical education continue to function, involving standard physical education lessons, the performance of basic exercises to develop physical qualities, familiar sports competitions, and extracurricular club activities without special thematic reinforcement. A comparison of modern and traditional elements of Olympic education and physical education is presented in Table 1.

Table 1. Comparison of modern and traditional elements of Olympic education

Criterion	Modern elements of Olympic education	Traditional elements of physical education
Level of pupils' physical activity and motivation	High: due to active mini-Olympics, athletics relays, team tournaments, and thematic events; it motivates through values (fair play, self-improvement) and the use of videos and discussions	Moderate: ordinary school physical education lessons without thematic reinforcement may be less stimulating; motivation is often based only on marks or competitions, rather than on values
Mastery of Olympic values	Direct teaching through lectures, discussions, videos, and Olympic Week – pupils master respect, fair play, equality, and striving for excellence	Minimal or incidental: values are not a central content element, with greater emphasis on physical exercises than on the moral components of sport
Development of physical qualities (speed, strength, endurance, coordination)	Relays, competitions, and varied sporting formats make it possible to develop all qualities: speed, endurance, strength skills, and coordination, since pupils are constantly active and competing	Classical exercises: running, gymnastic elements, basic strength exercises, but with fewer variations and "play-based" loads, so development may be less diverse
Ability for team interaction and adherence to fair play principles	Thanks to team games, mini-Olympics, and discussions, pupils learn to work in a team, respect opponents, and follow the rules of fair play. For example, in the study "#OLYMPICLAB as a new form of Olympic education" such formats are described	Team activities are possible (for example, physical education lessons in team sports), but the emphasis is often placed only on technique, without an in-depth discussion of fair play values or ethics

Source: compiled by the authors on the basis of V.M. Yermolova (2009), S. Saprun (2014), V. Perederiy (2019), O. Nikolaychuk (2025)

The comparison of modern and traditional elements of Olympic education shows that the introduction of innovative approaches has a positive effect on the formation of a culture of health and physical activity among school-age young people. Modern forms of work, oriented towards interactivity, competition, and value-based content, ensure a higher level of pupils' engagement and motivation compared with traditional methods. These approaches contribute not only to increased physical activity, but also to better mastery of Olympic values, which is reflected in a more conscious attitude to fair play, respect, and team cooperation. Such approaches also demonstrate a broader impact on the development of physical qualities, since the combination of competitive, play-based, and interactive formats allows for the comprehensive stimulation of speed, strength, endurance, and coordination. In contrast, traditional forms primarily provide a basic level of preparedness but do not always stimulate pupils' intrinsic motivation and interest. Summarising the results obtained, it can be stated that modern elements of Olympic education create more favourable conditions for the harmonious combination of pupils' physical, value-based, and social development. The integration into the educational process makes it possible to strengthen the educational potential of physical culture, increase the effectiveness of forming a culture of health, and promote more sustainable motivation for regular physical activity.

A pedagogical experiment to test the effectiveness of integrating Olympic educational components

To determine the effectiveness of the Olympic education programme, indicators of motivational-value attitudes towards physical activity and physical fitness results in the control and experimental groups were compared before and after the 12-week formative stage. Table 2 presents summarised results for the questionnaire statements, as well as the dynamics of physical fitness in the main tests. This makes it possible to trace how the introduction of elements of Olympic education influenced motivation, interest in sport, attitudes to Olympic values, and pupils' physical fitness indicators.

Table 2. Results of the questionnaire and physical testing of pupils in the control and experimental groups before and after the formative stage

Questions/Tasks		CG before	CG after	EG before	EG after
Adapted Questionnaire on motivation for physical activity (PACES)	1. I enjoy doing physical activity.	1-12%, 2-21%, 3-38%, 4-22%, 5-7%	1-10%, 2-20%, 3-36%, 4-25%, 5-9%	1-11%, 2-23%, 3-37%, 4-21%, 5-8%	1-2%, 2-6%, 3-20%, 4-44%, 5-28%
	2. I feel better after physical education lessons.	1-14%, 2-24%, 3-33%, 4-20%, 5-9%	1-13%, 2-22%, 3-34%, 4-22%, 5-9%	1-12%, 2-25%, 3-34%, 4-20%, 5-9%	1-3%, 2-7%, 3-22%, 4-42%, 5-26%

Table 2, Continued

Questions/Tasks		CG before	CG after	EG before	EG after
Adapted Questionnaire on motivation for physical activity (PACES)	3. I would like to be more physically active.	1-18%, 2-27%, 3-32%, 4-16%, 5-7%	1-17%, 2-26%, 3-31%, 4-18%, 5-8%	1-17%, 2-27%, 3-31%, 4-17%, 5-8%	1-4%, 2-10%, 3-25%, 4-38%, 5-23%
	4. I like taking part in sports competitions.	1-20%, 2-28%, 3-30%, 4-15%, 5-7%	1-18%, 2-27%, 3-31%, 4-16%, 5-8%	1-19%, 2-28%, 3-31%, 4-14%, 5-8%	1-6%, 2-14%, 3-24%, 4-36%, 5-20%
	5. I am interested in the Olympic Games.	1-22%, 2-30%, 3-28%, 4-14%, 5-6%	1-21%, 2-29%, 3-29%, 4-15%, 5-6%	1-23%, 2-31%, 3-27%, 4-13%, 5-6%	1-5%, 2-10%, 3-25%, 4-37%, 5-23%
	6. Olympic values inspire me to do sport.	1-25%, 2-29%, 3-27%, 4-13%, 5-6%	1-23%, 2-28%, 3-28%, 4-14%, 5-7%	1-25%, 2-29%, 3-27%, 4-13%, 5-6%	1-4%, 2-9%, 3-23%, 4-38%, 5-26%
	7. I believe that a healthy lifestyle is part of my development.	1-8%, 2-16%, 3-38%, 4-26%, 5-12%	1-7%, 2-15%, 3-36%, 4-28%, 5-14%	1-9%, 2-17%, 3-37%, 4-25%, 5-12%	1-1%, 2-4%, 3-22%, 4-41%, 5-32%
	8. I love team sports.	1-13%, 2-25%, 3-35%, 4-18%, 5-9%	1-12%, 2-24%, 3-34%, 4-19%, 5-11%	1-14%, 2-25%, 3-35%, 4-17%, 5-9%	1-4%, 2-9%, 3-23%, 4-39%, 5-25%
	9. I respect opponents in competitions.	1-10%, 2-22%, 3-36%, 4-22%, 5-10%	1-9%, 2-21%, 3-35%, 4-23%, 5-12%	1-11%, 2-23%, 3-36%, 4-21%, 5-9%	1-2%, 2-6%, 3-20%, 4-42%, 5-30%
	10. I am willing to take part in additional sports events.	1-18%, 2-29%, 3-32%, 4-15%, 5-6%	1-17%, 2-28%, 3-31%, 4-17%, 5-7%	1-18%, 2-29%, 3-31%, 4-16%, 5-6%	1-5%, 2-11%, 3-24%, 4-37%, 5-23%
	11. I follow a training regime outside school.	1-30%, 2-32%, 3-25%, 4-9%, 5-4%	1-28%, 2-31%, 3-26%, 4-10%, 5-5%	1-29%, 2-32%, 3-25%, 4-9%, 5-5%	1-10%, 2-20%, 3-28%, 4-27%, 5-15%
	12. It is important for me to achieve better sports results.	1-16%, 2-28%, 3-36%, 4-14%, 5-6%	1-15%, 2-27%, 3-35%, 4-16%, 5-7%	1-16%, 2-27%, 3-36%, 4-15%, 5-6%	1-3%, 2-12%, 3-27%, 4-39%, 5-19%
	13. I am willing to work on myself to improve my skills.	1-13%, 2-24%, 3-39%, 4-17%, 5-7%	1-12%, 2-24%, 3-37%, 4-19%, 5-8%	1-13%, 2-25%, 3-38%, 4-17%, 5-7%	1-3%, 2-10%, 3-24%, 4-41%, 5-22%
	14. Regular physical education classes help me feel confident.	1-15%, 2-26%, 3-37%, 4-16%, 5-6%	1-14%, 2-25%, 3-36%, 4-17%, 5-8%	1-16%, 2-26%, 3-36%, 4-16%, 5-6%	1-4%, 2-9%, 3-21%, 4-40%, 5-26%
	15. I strive to take part in competitions, even if it requires effort.	1-19%, 2-27%, 3-33%, 4-15%, 5-6%	1-18%, 2-26%, 3-32%, 4-16%, 5-8%	1-20%, 2-27%, 3-32%, 4-15%, 5-6%	1-5%, 2-11%, 3-24%, 4-38%, 5-22%
Expert assessment of physical load (group mean values)	30 m run (s)	6.4	6.3	6.4	5.9
	60 m run (s)	12.1	12.0	12.2	11.3
	4×9 m shuttle run (s)	12.8	12.7	12.8	11.9
	Press-ups (number / 30 s)	12	12	12	17
	Standing long jump (cm)	156	158	157	173
	PACER (number of laps)	55	56	56	78
	PACER (metres)	1,100	1,120	1,120	1,560

Note: the questionnaire on motivation and value-based attitude to physical activity was assessed on a five-point scale (1-5), and the expert assessment of physical development was carried out using units of speed (s) for the first four questions and units of distance (cm/laps/m) for the next three questions
Source: compiled by the authors

The data analysis shows that, in the control group, the dynamics of pupils' motivation and physical activity indicators remained minimal. Before the formative stage, most statements received average scores of 3, and the percentage of positive assessments (4-5) ranged between 6-22%. After the study, changes were minor, at most 2-3%, which demonstrates stability but no progress and confirms that the traditional approach to physical education lessons provides only a basic level of motivation and does not stimulate pupils' intrinsic activity. In the experimental group, by contrast, after the introduction of elements of Olympic education there was a sharp increase in positive assessments. The greatest changes were observed in statements related to enjoyment of physical activity, interest in the Olympic Games, the influence of Olympic values, and willingness to take part in competitions. The share of "4-5" scores in these questions increased on average by 20-35%, indicating higher motivation, a positive attitude towards sport, and a value orientation towards fair play and team interaction. The smallest, but still noticeable, changes were seen in statements on adherence to a training regime outside school and independent striving for physical activity, which is logical, since these aspects require more discipline and time to form.

Pedagogical testing of physical fitness confirmed the effectiveness of the programme. In the control group, changes were minimal, whereas in the experimental group mean indicators for all physical abilities improved: speed qualities increased – the 30 m run time decreased from 6.4 to 5.9 s, and the 60 m run from 12.2 to 11.3 s; coordination improved – the 4×9 m shuttle run time fell from 12.8 to 11.9 s; muscular endurance increased – the number of press-ups in 30 s rose from 12 to 17; explosive strength increased – the standing long jump distance grew from 157 to 173 cm; aerobic endurance improved – pupils completed more laps in the PACER test, increasing the total distance from 1,120 m to 1,560 m. This indicates a comprehensive positive impact of elements of Olympic education on physical fitness and pupils' overall condition, while simultaneously strengthening the motivation and interest in sport.

The greatest improvement was observed in aerobic endurance indicators, which points to enhanced functional capacities in pupils after the integration of Olympic components into the educational process. Overall, the results show that the introduction of elements of Olympic education contributes not only to increased interest and motivation for physical activity, but also to real development of pupils' physical qualities. This approach creates conditions for the comprehensive formation of a culture of health, the cultivation of a value-based attitude towards sport, and encourages regular participation in physical education activities and competitions.

During pedagogical observation, differences between the behaviour of pupils in the experimental and control groups were recorded. In the control group, pupils' activity remained predominantly moderate: most performed exercises according to the standard programme, only a few showed initiative, and participation in team games was inconsistent. Frequent violations of game rules, a low level of interaction between participants, and moderate interest in competitive forms of work were observed. In the experimental group, where elements of Olympic education were implemented, teachers recorded a higher level of engagement in all types of activities. Pupils actively took part in exercises, showed initiative, suggested the ways of performing tasks, actively worked in teams, and demonstrated mutual respect and adherence to the principles of fair play. Noticeable increases in motivation were seen during athletics relays, mini-Olympics, and team sports tournaments, when pupils independently supported classmates, encouraged less-prepared participants to be active, and displayed leadership qualities. Observation also showed that the integration of thematic mini-lectures, video viewing, and discussions of Olympic values increased pupils' interest and stimulated the pupils to maintain physical activity independently, even outside lessons. Overall, the observation results confirmed that elements of Olympic education contribute to the formation of team interaction, active participation, and a high level of intrinsic motivation for sports activities.

Practical recommendations for implementing elements of Olympic education in the school physical education system

On the basis of the study, a set of practical recommendations for implementing elements of Olympic education in the educational process can be formulated. The main aim of such measures is to increase pupils' levels of physical activity, develop the physical qualities, form a healthy lifestyle, and foster the values of fair play, self-improvement, respect, and team interaction. Physical education lessons should be supplemented with thematic mini-lectures devoted to the history of the Olympic Games, the biographies of outstanding athletes, the principles of the Olympic movement, and sporting achievements. Such mini-lectures can be conducted once every two to three weeks, lasting 10-15 minutes before the practical part of the lesson. For better perception of information, presentations, video materials, and interactive tools should be used, allowing pupils to create visual associations and better assimilate the content of the lecture. For example, showing videos of Olympic opening ceremonies or short clips about athletes' victories stimulates the desire for self-improvement and supports pupils' intrinsic motivation. These lectures are integrated into the overall plan for physical education lessons and held in the gym or a multimedia classroom before the main practical part of the lesson. Regular use of video materials and online resources makes it possible to continue work on forming Olympic values outside school. Short videos showing examples of mutual respect between athletes, team interaction, training, and preparation for competitions can be viewed at the beginning or end of the lesson for discussion in a debate format. Pupils analyse what the pupils have seen, discuss the behaviour during exercises, and suggest ways to improve team interaction and apply the knowledge gained in everyday life. This promotes the development of critical thinking, awareness of the actions, and the assimilation of fair play values.

Holding school mini-Olympics and athletics relays is an effective tool for developing physical qualities and team skills. Such events can be organised once a month or timed to sports holidays, for example, Olympic Day. Participation in mini-Olympics includes individual disciplines such as 30 m and 60 m runs, standing long jumps, press-ups, as well as team relays and games. Teachers' observations of exercise intensity, rule compliance, and mutual respect among pupils make it possible to assess not only physical results, but also the level of social interaction and assimilation of Olympic values. Mini-Olympics are held on a sports field or in a gym with safe conditions and the necessary equipment, and pupils are divided into teams to stimulate mutual support and the development of leadership skills. Integrating Olympic values into regular physical education lessons through play-based and competitive forms of work allows physical development to be combined with the cultivation of moral and social skills. During exercises, the teacher encourages pupils not only to achieve results but also to help classmates, provide mutual support, and show mutual respect. During relays or team games, pupils evaluate team interaction, discuss strategies, and highlight each other's positive actions, which develops empathy and team spirit. Such elements should be consistently recorded by teachers in special observation charts for analysing each pupil's progress. Organising an Olympic Week or thematic sports days at school helps to create a holistic educational atmosphere. During the week, lectures, quizzes on Olympic sports, video viewing, relays, and team competitions can be combined. For example, lectures can be held on Monday, relays on Tuesday, team games on Wednesday, quizzes and discussions on Thursday, and final competitions and awards on Friday. This comprehensive approach stimulates interest in physical activity, shapes a positive attitude towards sport, and promotes the assimilation of Olympic values.

Interactive discussions after lessons or sports events allow pupils to analyse the actions and behaviour during exercises and compare these actions with the principles of fair play and team interaction. During discussions, pupils consider the mistakes and successes and propose ways to improve exercise performance or team cooperation. Discussions are held in small groups of 4-6 pupils, ensuring active participation by each pupil and stimulating the development of communication skills. The use of electronic and online resources makes it possible to continue learning and maintain interest in sport outside school. Pupils can take part in webinars and online quizzes, and create short videos about sporting achievements or the training process. These activities can be integrated as homework or extracurricular tasks, promoting independence and responsibility for the physical development. Individualisation of the approach to physical exercises makes it possible to take into account each pupil's level of preparedness. Teachers can form subgroups according to physical fitness level, adapt exercises to pupils' physical capabilities, and control the intensity of loads. This contributes to safe performance of exercises, supports the motivation of pupils with different levels of preparedness, and ensures equal conditions for participation in team and individual competitions. Regular assessment of the effectiveness of implemented elements of Olympic education is carried out using standardised tests of physical fitness and motivation, as well as pedagogical observation. Indicators of physical development, level of engagement, manifestations of team interaction, and adherence to fair play principles are recorded and analysed to adjust the educational process, choose the most effective methods, and maintain pupils' constant motivation. The involvement of parents and the local community in sports events increases the programme's effectiveness. Parents can take part in family relays, attend lectures and discussions, and motivate children to be physically active at home. This approach makes it possible to form an integrated environment in which physical activity and Olympic values are supported both in school and beyond.

A system of incentives promotes the formation of intrinsic motivation. Symbolic rewards, certificates, badges, diplomas, and publication of achievements in school information resources stimulate the desire for self-improvement, active participation in events, and involvement in team competitions. It is important that not only sports results but also manifestations of fair play, mutual support, and leadership qualities are recognised. Integrated lessons combining physical education and other subjects promote pupils' holistic development. For example, history lessons can include discussions of Olympic events; biology lessons can explain physiological processes during physical loads; geography lessons can focus on the locations of the Olympic Games and the conditions under which athletes train in different countries. This approach creates a comprehensive understanding of sport, increases interest in physical education, and strengthens motivation for regular physical activity. Rotation of roles during team games and relays allows pupils to experience responsibility for task performance and team results, and to develop leadership skills, self-control, and mutual respect. Each pupil can be a captain, organiser, or supporter for classmates, promoting the formation of comprehensive team competences. Attention is given to safety: teachers control the intensity of loads, adapt exercises to pupils' age and physical development, follow safety rules during team and individual exercises, and ensure the availability of necessary equipment. This helps to avoid injuries and creates favourable conditions for physical activity. Regular feedback gives pupils the opportunity to analyse the achievements, feelings, and difficulties, and allows teachers to adjust the programme and ensure an individual approach. Discussing results and well-being during classes stimulates self-reflection and increases responsibility for personal development.

The implementation of these recommendations creates a holistic educational model in which physical education lessons become a platform not only for the development of physical qualities but also for the formation of values, team interaction, and intrinsic motivation. Pupils gain the opportunity to systematically develop physical and psycho-emotional qualities, increase the interest in sports activities, and form a culture of health. This approach ensures pupils' comprehensive development by integrating educational, sports, and upbringing components and creates a stable foundation for fostering physical activity and Olympic values among young people.

Discussion

The conducted study confirms that the integration of elements of Olympic education into school physical education has a complex impact on pupils, combining physical, value-based, and social development. In the control group, motivation indicators remained low: scores of "4-5" on most PACES statements ranged from 6 to 22%, and after the formative stage the changes were minimal (2-3%). In the experimental group, after the introduction of elements of Olympic education, the share of positive scores "4-5" increased by 20-35% on questions concerning enjoyment of physical activity and interest in the Olympic Games. This is consistent with the findings of I. Estevan *et al.* (2020), which showed that motivation for physical activity is closely linked to adolescents' perceptions of the motor competences. The authors analysed various aspects of perceived motor competence in early adolescents and found that high self-perception scores increase interest in physical exercise. This is supported by V. Alcántara-Porcuna *et al.* (2022), who showed that a favourable school environment, including teacher support and the availability of sports equipment, raises children's level of physical activity. The authors analysed teachers' views on barriers and facilitating factors for activity and found that organisational and social conditions are precisely what shape pupils' positive motivation. Elements of Olympic education – thematic mini-lectures, video materials, interactive discussions and an Olympic Week – helped pupils to internalise the values of fair play, respect, equality, and self-improvement. This corresponds to the results of R.C. Veloso *et al.* (2020) and S. Hartoto *et al.* (2020), who showed that familiarisation with Olympic and humanitarian values shapes pupils' positive attitudes towards sport and the moral orientation. The researchers analysed teachers' and students' attitudes to the values of the Olympic Games and found that the systematic inclusion of a value component in teaching contributes to the formation of ethical norms of behaviour. M. Bisa (2023) emphasised that sports education develops students' character through social and moral values. The author analysed pedagogical approaches to character education through sport and established that specially structured programmes foster honesty, self-discipline, and responsibility. M. Bronikowska *et al.* (2024) demonstrated the effectiveness of programmes aimed at developing social and moral competence in physical education, examining various school interventions and identifying improvements in pupils' cooperation skills and teamwork.

The results of physical fitness tests confirmed the effectiveness of the programme: the average indicators of the experimental group improved in all components – speed abilities, coordination, muscular endurance, explosive strength, and aerobic endurance (in particular, the PACER test increased from 1,120 m to 1,560 m). The control group showed minimal progress. This is consistent with the findings of Z. Li *et al.* (2024), who showed that regular physical activity in Malaysian primary and lower secondary schools improves pupils' overall physical condition. The authors analysed the state of pupils' motor development and found that intensive physical training programmes increase children's endurance, strength, and coordination abilities. G. Chapman *et al.* (2023), in the study, emphasised the formation of a sports culture among upper secondary pupils, showing that active participation in physical exercise promotes the development of motor and social skills. The researchers analysed the influence of the sports environment on the formation of physical competences and found that pupils who systematically engage in sport demonstrate better results in speed, endurance, and coordination tests. J.D.D. Habyarimana *et al.* (2022) stressed that systematic physical education is a key element in shaping a healthy lifestyle and preventing diseases in adolescents. The authors investigated the role of school physical education in community development and found that schools that actively support sport improve pupils' physical condition and stimulate the engagement in a healthy lifestyle. The introduction of video materials, mini-lectures, and online resources activated pupils' independent work outside lessons. This corresponds to the conclusions of S. Asare *et al.* (2023), who showed that interactive technologies increase students' interest and activity in physical education. The authors analysed the use of digital and interactive tools in educational institutions and concluded that such methods promote more effective acquisition of knowledge and practical skills. An active role in forming a supportive environment is also noted by D. Widyawan *et al.* (2020) and C.C. Pan *et al.* (2023), who showed that involving parents and the school community in the process of physical education increases inclusion and social support for pupils with special needs. The researchers analysed parents' views and pupils' attitudes towards classmates with various physical and intellectual characteristics and found improvements in interaction, cooperation, and mutual support among children.

Pupils in the experimental group became more committed to independent sports activities, adherence to training regimes, and striving for self-improvement. This is consistent with the results of G.Z. Kohe *et al.* (2021), who showed that the formation of psychological identity through Olympic education stimulates intrinsic motivation for physical development. The authors analysed in detail educational programmes related to the Olympic Games and noted increases in pupils' independence, responsibility, and readiness for self-improvement. In addition, the study by Z. Jiang (2023) confirmed that pupils' value orientations and psychological identity are key factors in shaping motivation to participate in sports and educational activities. The author examined the impact of Olympic education on students in various educational institutions and showed that learners who are actively aware of the values of sport demonstrate higher levels of engagement and interest in physical activity. Broadening knowledge about Olympic culture and the characteristics of different countries, as shown by R.V. Ciomag & C. Pop (2024), shapes global sports awareness and promotes interest in international sporting events. The researchers analysed the cultural and sporting traditions of countries participating in various international competitions and concluded that familiarisation with these features broadens pupils' worldviews and fosters a value-based attitude towards sport. This is further supported by the study of A.K. Al-shanbary (2023), who showed that sources of sports culture, particularly participation in school and university sports programmes, influence students' formation of a global understanding of sport and the desire to take part in international sporting events. The author analysed the student environment of a faculty of physical education and sport and established that learners who actively study the sports culture of other countries demonstrate a higher level of value motivation for sport. L. Kirakosyan (2020) also highlighted the educational legacy of the Olympic Games for engaging young people in physical activity and fostering an interest in sport. The author analysed the experience of the 2016 Olympic Games (Rio de Janeiro) and found that participation in global sporting events stimulates young people's motivation for an active lifestyle and increases civic engagement. Furthermore, the study showed that integrating lessons on the history and values of the Olympic Games into physical education leads students to a more conscious attitude towards sport and encourages the students to exercise regularly. Thus, the introduction of elements of Olympic education into the educational process increases motivation and interest in physical activity, improves physical fitness, develops social and moral competences, teamwork and leadership skills, ensures the acquisition of the values of fair play, self-improvement, and respect for opponents, and also activates the use of technologies and interactive teaching methods.

Conclusions

The conducted study made it possible to comprehensively assess the impact of elements of Olympic education on the formation of a health culture, the motivational-value attitude to physical activity, and the level of physical fitness of lower secondary school pupils. It was found that the purposeful use of the content, motivational, and activity components of Olympic education contributes to increasing pupils' engagement in sport, strengthens the interest in physical activity, and ensures better dynamics in the development of physical qualities compared with the traditional model of physical education. As a result of the analysis of content characteristics, it was determined that elements of Olympic education – thematic mini-lectures, video materials, mini-Olympics, relays, and discussions of the values of Olympism – not only expand pupils' knowledge of sport, but also directly influence the behaviour in lessons, as well as the interest in and attitude towards teamwork.

Quantitative analysis confirmed that in the control group, positive changes remained minimal and did not exceed 2-3%, which indicates stability but the absence of real progress in the formation of motivation. In contrast, in the experimental group an increase in the share of "4-5" responses was recorded for most statements – on average by 20-35%. The greatest changes were observed in indicators of enjoyment of physical activity, willingness to take part in competitions, interest in the Olympic Games, the influence of Olympic values, and the desire to be more physically active. This testifies to the clear formation of intrinsic motivation, a positive emotional attitude to sports activity, and a conscious perception of the moral and ethical aspects of sport. The outcome was confirmation that Olympic education affects not only motivational and value attitudes but also the actual results of physical fitness. Pedagogical testing showed that the experimental group demonstrated improvements in all tests: speed increased in 30 m and 60 m running, coordination improved according to the results of the 4×9 "shuttle run", indicators of muscular endurance (press-ups) increased by 5 repetitions, the long jump increased on average by 16 centimetres, and aerobic endurance in the PACER test showed the most pronounced increase – more than 400 metres of additional distance. Such dynamics confirm that innovative methods combining play activities, competitive elements, and a value component are effective means of developing physical qualities.

The practical recommendations developed as a result of the study indicate the need for the systematic inclusion of thematic lectures, videos, mini-Olympics, team relays, interactive discussions, and comprehensive monitoring of physical condition. Such a combination strengthens intrinsic motivation and ensures the all-round development of pupils. The main direction for further research is the expansion of the sample and the study of the long-term effect of implementing Olympic education on different age groups of pupils.

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Conflict of Interest

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Олімпійська освіта як складова формування культури здоров'я та фізичної активності учнів середньої школи

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Анотація. Мета дослідження – визначення впливу елементів олімпійської освіти на формування культури здоров'я, мотивації до фізичної активності та розвиток фізичних якостей учнів 7-9 класів. Методологія включала порівняльний аналіз сучасних елементів олімпійської освіти з традиційними елементами фізичної культури та проведення педагогічного експерименту. Основні результати дослідження продемонстрували позитивний вплив олімпійської освіти на мотиваційно-ціннісну сферу та фізичну підготовленість школярів. Експериментальна група показала вищу динаміку змін порівняно з контрольною. Частка відповідей «4-5» щодо задоволення фізичною активністю, інтересу до змагань, готовності тренуватися та сприйняття олімпійських цінностей зросла на 20-35 %, тоді як у контрольній групі зміни не перевищували 2-3 %. Показники фізичної підготовленості також засвідчили переваги впроваджуваної програми. У бігу на 30 м швидкість покращилась з 6,4 до 5,9 с, у бігу на 60 м – з 12,2 до 11,3 с. Середні показники тестової вправи («човниковий біг» 4×9 м) зменшилися з 12,8 до 11,9 с. Аналогічна тенденція спостерігалася у зміні силових показників, а саме: силова витривалість зросла з 12 до 17 повторень, вибухова сила – з 157 до 173 см. Найбільше зростання зафіксовано у тесті PACER: з 56 до 78 відрізків, що становить збільшення дистанції з 1 120 до 1 560 м – показник, який безпосередньо відображає покращення аеробної витривалості. Практичне значення роботи полягає у розробці рекомендацій щодо інтеграції елементів олімпійської освіти у шкільний курс фізичної культури, що довело їх ефективність у реальних умовах. Отримані дані можуть бути використані вчителями фізичної культури, адміністраціями закладів освіти, розробниками навчальних програм, тренерами дитячо-юнацьких спортивних шкіл та фахівцями з позашкільної освіти

Ключові слова: ціннісна орієнтація; змагальні форми; командна взаємодія; внутрішня мотивація; фізична підготовленість; підлітки

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Aerobic exercise as a factor of adaptive changes in the physical and functional states of adolescent girls

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Abstract. The purpose of the study was to comprehensively characterise changes in indicators of physical fitness and functional capabilities of adolescent girls depending on the level of motor activity under the influence of aerobic loads. The study was conducted at the Pereyaslav Gymnasium No. 3 (Kyiv Oblast) during March 17 – May 25, 2025 and included an aerobic programme with two stages of measurement, which allowed analysing the dynamics of physical fitness and functional indicators of the cardiovascular system of adolescent girls with different levels of motor activity. It was found that in the high-activity group, the distance of six-minute running increased from 900 ± 100 m to 1,130 ± 90 m (+25.6%), while in the low-activity group – from 820 ± 95 m to 950 ± 85 m (+15.9%). The number of squats in 30 seconds increased by +45% (from 20 ± 4 to 29 ± 3) against +33.3% (from 18 ± 4 to 24 ± 3). The 4×9 m shuttle run performance improved moderately: -1.1 s in high-activity and -0.7 s in low-activity. Functional changes in the cardiovascular system were manifested by a decrease in the resting heart rate by -11.4% and -7.3%, respectively, an increase in recovery in the first minute by +54.5% against +44.4%, and a decrease in the Ruffier-Dixon Index by 29.7% and 21.6%, which reflects an improvement in the functional state. Correlation analysis confirmed that the level of motor activity was statistically associated with the scale of adaptive changes ($r = 0.68$-0.72; $p < 0.01$). Thus, the initial motor status determined the training sensitivity of adolescent girls and influenced the nature of changes in physical fitness and functional indicators. The obtained data can be used by physical education teachers, trainers, and specialists of health programmes to differentiate the load, taking into consideration the initial level of motor activity of girls

Keywords: motor activity; training effect; muscle endurance; recovery rate; cardiovascular system; girls aged 13-15; fitness programmes

Introduction

Aerobic exercise is a determining factor in the physiological changes in adolescent girls, since during this period an intensive development of the cardiovascular and respiratory systems and the physical performance takes place. According to the World Health Organization (n.d.), approximately 81% of teens aged 11-17 do not follow the recommendation of 60 minutes of moderate-to-high-intensity physical activity each day. Moreover, girls show a lower level of motor activity: only a small proportion of them meet the established recommendations, while the majority (about

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85%) do not reach the required standards. For boys, this indicator is slightly better and amounts to approximately 78%, which indicates a higher probability of insufficient physical activity among teenage girls. This trend leads to a decrease in aerobic performance, disruption of adaptation mechanisms, an increased risk of obesity, metabolic disorders, dysfunction cardiovascular system (CVS), and early development of chronic non-communicable diseases in later life. As a result, this leads to reduced functionality, poor quality of life, and an increased likelihood of medical complications.

Analysis of the influence of aerobic exercise on the physical fitness and morphological characteristics of adolescent girls allows outlining the most effective approaches to planning physical activity during extracurricular activities. The finding of O. Brezdeniuk *et al.* (2021) demonstrated that as a result of performing a combined aerobic-anaerobic programme, adolescents with different body weight components showed a decrease in body fat and an improvement in the somatic profile. The researchers have found that several weeks of systematic performance of training sessions provides an increase in endurance, which is considered as a formed adaptive response to the training impact. In programmes for girls aged 12-13 years, the use of structured wellness classes with an aerobic focus provided an increase in strength endurance and coordination abilities, which is reflected in the findings of Y. Galan *et al.* (2020). In the same study, early positive dynamics of morphofunctional indicators were found after several weeks of systematic exposure, which indicates a high training sensitivity in this age group. The correlation analysis described by I. Ivanyshyn *et al.* (2021) confirmed a close relationship between the level of aerobic performance and integral physical condition, which allows interpreting this indicator as a key indicator of adaptation. Variable aerobic fitness programmes contribute to an increase in functional capabilities and improvement in cardiovascular system indicators, as reported by V. Sliusarchuk *et al.* (2023). Researchers have also substantiated the effectiveness of comprehensive training through confirmed quantitative changes in endurance and cardiopulmonary parameters, which reinforces the importance of combining different aerobic components. The integration of fitness modules into the structure of physical training sessions leads to a steady improvement in the level of physical endurance, which was confirmed in the study by M. Chekhovska *et al.* (2020), where an increase in girls' involvement in motor activity was recorded.

Cardiorespiratory adaptations under the influence of aerobic training programmes in adolescents are characterised by a gradual improvement in the mechanisms of oxygen delivery and utilisation, which determines the level of endurance and load tolerance. In the long-term follow-up described in paper by T. Ingvarsdottir *et al.* (2024), a stable increase in maximum oxygen consumption was recorded in adolescent girls, accompanied by an improvement in cardiorespiratory efficiency. The researchers emphasised the importance of the duration of exposure for the development of persistent adaptive changes. The variability of the response to training loads depending on biological age and the level of athletic fitness was reflected by J.R. Padilla-Alvarado *et al.* (2025), who showed different aerobic power profiles in girls of different age groups. The researchers established a relationship between the rate of adaptation and the correspondence of training impact to individual capabilities. The school curriculum analysed by J. Wan *et al.* (2025) indicated an increase in physical fitness and cardiorespiratory parameters under controlled conditions. The high effectiveness of this programme was confirmed by the structure of the impact and the regularity of performing exercises.

Physiological mechanisms of adaptation to aerobic exercise in adolescent girls are determined by structural, hormonal, and metabolic changes that affect the effectiveness of the training response. The study by M.I. Forså *et al.* (2023) found the remodelling of cardiac structures under the influence of systematic training, which is characterised by an increase in stroke volume and improved pumping function. The researchers noted gender differences in cardiac adaptations that shape different developmental trajectories. Features of cardiorespiratory response and changes in exercise tolerance at different phases of the menstrual cycle were described by B. Rael *et al.* (2021), who recorded fluctuations in performance indicators depending on the hormonal background. It is these changes that determine the individual variability of adaptation to training. According to H.N. Willett *et al.* (2021), during aerobic exercise there is a shift in substrate use towards oxidative processes, which provides more efficient energy support for muscle work, and insufficient level of motor activity in girls forms the risk of metabolic shifts and reduced adaptive capabilities.

Despite the available scientific studies, the features of the development of adaptive changes in adolescent girls in conditions of different levels of motor activity under the influence of aerobic loads are not sufficiently covered. The purpose of the study was a comprehensive description of changes in indicators of physical fitness and functional capabilities of adolescent girls depending on the level of motor activity under the influence of aerobic loads.

Materials and Methods

The study involved female students ($N = 30$) aged 13-15 years from grades 7-9 of Pereyaslav Gymnasium No. 3 (Pereyaslav, Kyiv Region) who had no medical restrictions on performing aerobic exercises and regularly attended physical education classes. Students were excluded at the initial assessment stage if any restrictions on the cardiovascular, respiratory, or musculoskeletal systems were detected, or if there were factors that prevented stable attendance or significantly changed their usual motor activity (for example, participation in specialised sports sections). Parents and students received written information about the purpose, content, and potential physical exertion, and then confirmed their consent to the children's participation. All procedures were in accordance with the European Commission (2021) guidelines on ethics and processing of personal data. During the study, no medical interventions were used, and the information obtained was stored in an anonymous form in compliance with the requirements for preventing the disclosure of private information. The study lasted for two and a half months of the spring semester of 2025 (from March 15 to May 25, 2025).

Statistical processing was based on a consistent assessment of the properties of sample data, primarily their compliance with the normal distribution, which was tested using the Shapiro-Wilk criterion. After determining the type of distribution, a further analysis method was chosen: if parametric assumptions were met, the dynamics of changes were considered using repeated measurement analysis models of variance (ANOVA), while the nonparametric Friedman criterion was used for their violation with subsequent paired comparisons. Comparisons between the two independent groups were performed using the t-test or the corresponding non-parametric Mann-Whitney test. Spearman correlation analysis was used to assess the associations between the level of motor activity and the magnitude of adaptive changes. All calculations were performed in IBM SPSS Statistics 29.0 and Microsoft Excel 2021 Microsoft Excel 2019 environments.

Participants were divided according to their level of motor activity, as a result of which two comparison groups were formed: girls with a lower level of activity ($n = 17$) and girls with higher activity indicators ($n = 13$). To determine the individual level of activity, a version of the Physical Activity Questionnaire for Adolescents (PAQ-A) adapted to the school environment was used. During the adaptation, the wording of the questions was clarified and examples of typical activities were given, without changing the structure of the tool, the rating scale, and the algorithm for calculating the total score (Table 1).

Table 1. Questionnaire for determining the level of motor activity (modified version of PAQ-a)

No.	Question	Answer options (points)
1	How many times in the last 7 days have you done physical exercises or sports outside of physical education classes lasting ≥ 20 minutes?	1 – never; 2 – 1 time; 3 – 2-3 times; 4 – 4-5 times; 5 – ≥ 6 times
2	How often have you participated in outdoor games or active leisure activities (running, jumping, cycling, dancing, etc.)?	1 – never; 2 – rarely; 3 – sometimes; 4 – often; 5 – very often
3	What was your activity in physical education classes?	1 – almost did not participate; 2 – low; 3 – medium; 4 – active; 5 – very active
4	How much time did you spend sitting after school (phone, computer, TV)?	1 – ≥ 5 hours/day; 2 – 4 hours; 3 – 3 hours; 4 – 2 hours; 5 – ≤ 1 hour
5	How often have you attended sports clubs or clubs in the last 7 days?	1 – did not visit; 2 – 1 time; 3 – 2 times; 4 – 3-4 times; 5 – ≥ 5 times
6	How often were you physically active on weekends?	1 – not active at all; 2 – little active; 3 – medium active; 4 – active; 5 – very active
7	How do you rate your overall physical activity over the past week?	1 – very low; 2 – low; 3 – medium; 4 – high; 5 – very high

Source: adapted by the authors based on the original PAQ-A questionnaire by K.C. Kowalski *et al.* (2004)

For each participant, the average total score was calculated as the average value of responses to seven questionnaire questions. Based on the obtained scores, the level of motor activity was stratified by dichotomising PAQ-A indicators: girls with a total score <2.5 were assigned to the group with a lower level of activity, while participants with indicators ≥2.5 were assigned to the group with a higher level of activity. The applied threshold level was determined based on the median value of the obtained data, which helped to avoid artificially isolating the conditional "average" level of activity. Classes were conducted by a physical education teacher with the participation of the author of the study, who provided methodological support and monitoring of exercise performance. Training sessions were held three times a week (Monday, Wednesday, Friday) after school from 15:30 to 16:30 and lasted 50-60 minutes. The structure of classes provided for a warm-up, the main aerobic block, and the final part with a gradual increase in the duration of the active part of the lesson, which provided a gradual increase in the training load in accordance with the adaptive capabilities of the participants and contributed to the development of stable functional changes without the risk of overexertion (Table 2).

Table 2. Structure of the aerobic training programme

Duration	Content / exercises	Equipment
	Warm-up	
10 min	Light running 2 min; joint exercises 5 min (movements in the neck, shoulder, elbow, knee, and ankle joints, 8-10 repetitions); dynamic stretching 3 min	Cones, markers
	Main block	
30 min (weeks 1-2)	Jogging for 6-8 minutes; relay run with turns; jumps "star" 3×20 repetitions; jumps in place 3×30 s; general physical training complexes (squats 2×12, lunges 2×10 on the leg, "skipping" 2×30 s)	Cones, jump ropes
35 min (weeks 3-4)	Variable pace running 10 min (1 min faster / 1 min slower); jumping series 3×40 s; bodyweight exercises: squats 3×12, lunges 3×10, "skipping" 3×30 s, "plank" 2×30 s	Cones, mats
40 min (weeks 5-7)	Interval running 2 minutes of running / 1 minute of walking × 6 cycles; circular complexes of general physical training: 6 exercises were performed sequentially for 40 seconds out of 20 seconds of transition (squats, jumps "star", lunges, "plank", jumps, "skipping"), 2 sets	Cones, hoops, jump ropes, mats
40 min (weeks 8-10)	Training session consisting of 6 exercise sets: 1) running between cones; 2) jumping "star"; 3) squats; 4) lunges; 5) skipping rope; 6) jumps; performing 45 seconds with 15 seconds of transition, 2-3 sets or a long continuous run of 35-40 minutes	Cones, jump ropes
	Final part	
10 min	Breathing exercises 3 min; static stretching of the main muscle groups 7 min (holding 15-20 s)	Floor mats

Source: developed by the authors

If necessary, individual adjustments were made to the pace and volume of exercises performed for participants with a lower level of physical fitness, which was implemented through a temporary reduction in the duration of working intervals or an increase in rest pauses without changing the overall structure of the lesson. The menstrual cycle was considered as a potential factor affecting performance and well-being: before each training session and testing, a short survey was conducted regarding the presence of menstrual symptoms, and according to their severity, the intensity of the load was adjusted in a similar way. The test measurements were not postponed, but the protocols were marked relative to the cycle phase, which provided a more correct interpretation of the results obtained.

The level of physical fitness was assessed based on the results of standardised tests used in the school system of physical education and recommended for the adolescent contingent. The six-minute run was used to determine aerobic endurance and involved overcoming the maximum distance in 6 minutes on a marked 200-metre circle in the gym or on the school playground (the result was recorded in metres). The long jump from a standstill allowed assessing the speed and power abilities of the lower extremities, the performance was carried out from the starting position on the start line with a push-off with both feet, and the result was measured in centimetres from the push-off line to the nearest point of contact with the surface. 30-second squats were used to assess muscle endurance and included the maximum number of correct repetitions in a given time with control of the execution technique. The 4×9 m shuttle run evaluated coordination abilities and agility and included four movements between markers at a distance of 9 meters with a record of total execution time. Functional status was determined by resting and post-exercise heart rate (HR), recovery rate, and the Ruffier-Dixon Index, which allowed assessing aerobic performance and CVS response to a physical stimulus. The maximum heart rate was calculated using the generally accepted formula:

$$HR_{max} = 220 - age, \tag{1}$$

where HR_{max} – estimated maximum heart rate (bpm); *age* – participant's age in full years. The target training area was determined in the range of 60-75% of HR_{max}:

$$HR_{tr} = HR_{max} \times 0.60 - 0.75, \tag{2}$$

where HR_{tr} – target training heart rate (bpm) corresponding to the aerobic exercise zone; HR_{max} – maximum allowable heart rate; 0.60-0.75 – range of load intensity that ensures the aerobic nature of energy supply. The Ruffier-Dixon Index was used to determine the integral CVS response to exercise and recovery efficiency. The assessment was performed by a nurse by measuring heart rate by palpation of the radial artery on the wrist of the non-dominant hand for 15 seconds in a sitting position, repeated measurement immediately after performing 30 squats for 45 seconds, and after one minute of recovery. The index was calculated using the equation:

$$IR = \frac{(P_1+P_2+P_3)-200}{10}, \tag{3}$$

where P_1 – resting HR (bpm); P_2 – HR in the first 15 seconds after exercise (bpm); P_3 – HR in the first 15 seconds of the third minute of recovery (bpm). The effectiveness of recovery processes was further characterised by the difference between heart rate immediately after exercise and after one minute of rest (HRR1), calculated based on sample data.

Results

Dynamics of physical fitness in girls with different levels of motor activity

The obtained data helped to outline the specifics of the course of adaptive shifts in the indicators of physical fitness of adolescent girls under the influence of an aerobic training programme and determine the role of the initial level of motor activity in the development of a training response. Comparison of these measurement steps allowed tracking the sequence and rate of changes and assessing intergroup differences, which was important for confirming the assumption of a differentiated body response to the same training stimulus. The summary results of physical fitness indicators are shown in Table 3, which provides a holistic view of the dynamics of endurance, speed, strength, and coordination abilities in the study groups.

Table 3. Changes in girls' physical fitness indicators ($M \pm SD$)

Indicator	Measurement period	Low activity level ($n = 17$)	High activity level ($n = 13$)
6-min run, m	Beginning	820 ± 95	900 ± 100
	End	950 ± 85	1,130 ± 90
Long jump, cm	Beginning	145 ± 12	150 ± 13
	End	156 ± 11	168 ± 12
Number of squats in 30 s	Beginning	18 ± 4	20 ± 4
	End	24 ± 3	29 ± 3
Shuttle run 4×9 m, s	Beginning	12.8 ± 0.7	12.5 ± 0.6
	End	12.1 ± 0.5	11.4 ± 0.4

Source: compiled by the authors

A comprehensive analysis of the table data showed that the greatest dynamics of changes can be traced in the results of 6-minute running, which is an integral test of aerobic endurance and the effectiveness of the cardiorespiratory system. In the high-activity group, the distance increased from 900 ± 100 m to 1,130 ± 90 m, which was almost 25.6% increase, while in the low-activity group, the increase was about 15.9 % (from 820 ± 95 m to 950 ± 85 m). This difference indicated that the body of girls with a higher initial level of activity already had formed mechanisms of oxygen supply to the muscles, in particular, a larger stroke volume of the heart, more efficient peripheral blood circulation, and a better ability to use oxygen in tissues. In the low-activity group, positive changes reflected the initial phase of training adaptation, which is usually characterised by an increase in ventilation efficiency and an improvement in movement economisation. The long jump from a standstill showed an increase in speed and strength capabilities, but the growth rate also depended on the initial motor status. An 11 cm increase in the result in the low-activity group indicated improved coordination between lower limb muscle groups and increased strength response. In the high-activity group, the increase reached 18 cm, which indicated more effective neuromuscular control, faster involvement of motor units, and an optimal level of intermuscular coordination. Such changes are typical for the first stage of adaptation, when the training effect is manifested mainly due to neuromotor mechanisms, and not structural changes in muscle tissue, as evidenced by previous scientific data (Gillen *et al*., 2019).

Squat scores for 30 seconds reflected the development of muscle endurance in the lower extremities. Participants with high activity showed an increase in the number of repetitions from 20 ± 4 to 29 ± 3 (+45%), which indicated an increase in the ability to perform long-term repetitive work. In the low-activity group, the increase was from 18 ± 4 to 24 ± 3 (+33.3%), which was also an indicator of positive changes, but less intense. This is conditioned by the different efficiency of aerobic energy resynthesis, the rate of metabolite elimination, and local muscle endurance. According to available scientific evidence, girls with higher motor activity may have a higher proportion of type 1 oxidative muscle fibres and higher capillarisation, which potentially ensures more efficient use of oxygen and faster recovery during repeated loads (Shadiow *et al*., 2023). The smallest changes were recorded in the 4×9 m shuttle run, which is a test of coordination abilities and agility. An improvement of 0.7 s in the low-activity group (reduced time by -5.5%) and 1.1 s in the high-activity group (reduced by -8.8%) indicated a certain increase in the speed of movement and the effectiveness of changing the direction of movement, but the training programme was not aimed at specific development of coordination. This explains the limited training effect, since coordination abilities require exercises with complex motor structures, variable trajectory, and sensorimotor loads, which the programme practically did not contain.

Overall, the results showed that the aerobic programme provided the initial training adaptations, most pronounced in the development of aerobic and muscular endurance. It was found that a higher level of initial activity determines a greater adaptive reserve, faster growth rates, and more effective implementation of physiological mechanisms. This trend is consistent with the position that the training effect depends on the initial functional status, according to which the body with a higher level of fitness reacts more powerfully due to optimised metabolic and neuromuscular processes. Thus, the data obtained confirmed that the level of motor activity was a determining factor in the adaptive response to aerobic exercise in adolescence, and systematic training sessions became an effective means of improving the physical fitness of girls in the school environment, considering individual characteristics and initial functional state.

Changes in the functional parameters of the cardiovascular system

CVS indicators showed clear adaptive changes in response to the aerobic programme, with more pronounced positive dynamics in girls with a high level of motor activity. They showed a decrease in resting heart rate, faster recovery after exercise, and improved integral performance indicators, which was reflected in an increase in HRR1 and a decrease in the Ruffier-Dixon Index calculated using equations (1-3). In the low-activity group, the changes were more moderate, but also reflected the development of an adaptive response. The systematised data are presented in Table 4.

Table 4. Functional indicators of participants with different levels of motor activity ($M \pm SD$)

Indicator	Stage	Low activity (*n* = 17)	High activity (*n* = 13)
Resting HR, bpm	Beginning	82 ± 6	79 ± 5
	End	76 ± 5	70 ± 4
Post-exercise HR, bpm	Beginning	158 ± 10	152 ± 9
	End	146 ± 8	136 ± 7
HRR1, bpm	Beginning	18 ± 4	22 ± 5
	End	26 ± 5	34 ± 5
Ruffier-Dixon Index, C.U.	Beginning	13.4 ± 2.1	11.8 ± 1.9
	End	10.5 ± 1.8	8.3 ± 1.6

Source: compiled by the authors

The data obtained showed a gradual improvement in the functional state of the CVS in response to the aerobic programme, but the nature and pace of changes depended on the initial level of motor activity. The most significant marker of adaptation was a decrease in resting heart rate, which reflected the economisation of cardiac activity. In the high – activity group, the indicator decreased from 79 ± 5 to 70 ± 4 bpm (-11.4% decrease), while in the low-activity group-from 82 ± 6 to 76 ± 5 bpm (-7.3% decrease). This indicated an increase in the stroke volume of the heart and a strengthening of parasympathetic regulation, which is characteristic of aerobic fitness. A more pronounced decrease in girls with high activity indicated an initially better ability for central haemodynamic adjustment, which is consistent with the position on the dependence of the rate of adaptation on the initial functional level. Post-exercise heart rate showed a similar trend: in the high-activity group, the indicator decreased from 152 ± 9 to 136 ± 7 bpm (-10.5%), while in the low-activity group-from 158 ± 10 to 146 ± 8 bpm (-7.6%). A decrease in peak heart rate after standard exercise indicates an economisation of the heart response due to increased aerobic energy supply, improved oxygen delivery to working muscles, and more efficient use of oxidative substrates. This decrease reflects a lower level of internal physiological load under the same external stimulus, and its interpretation as signs of training adaptation is based on scientific data describing the corresponding cardiorespiratory changes in children and adolescents (Armstrong *et al.*, 2011).

HRR1 has become a key marker of recovery processes. In girls with high activity, it increased from 22 ± 5 to 34 ± 5 bpm (+54.5%), which indicates a sharp acceleration in the restoration of vegetative balance and more effective switching of regulation from sympathetic to parasympathetic after stopping the exercise. In the low-activity group, the increase was less significant: from 18 ± 4 to 26 ± 5 bpm (+44.4%). In the literature, high HRR1 values are associated with more efficient post-exercise recovery processes, which are manifested by a faster decrease in metabolic shifts and stabilisation of haemodynamic parameters (Buchheit, 2014). The Ruffier-Dixon Index showed the most integral improvement. In the high activity group, the value decreased from 11.8 ± 1.9 to 8.3 ± 1.6 C.U. (-29.7%), while in the low-activity group – from 13.4 ± 2.1 to 10.5 ± 1.8 C.U. (-21.6%), which, although it indicated positive dynamics, left this group within the limits of lower functional indicators. A decrease in the index reflects a simultaneous decrease in resting heart rate, a decrease in peak heart rate, and an improvement in the recovery rate, i.e., an integral restructuring of CVS activity. The most intense dynamics was observed during the first month, after which the rate of improvement decreased. This indicates the phasicity of adaptation: at the initial stage, functional mechanisms predominate (neurohumoural regulation, changes in cardiac output), while structural changes, in particular, an increase in capillarisation and an increase in mitochondrial density, are formed much more slowly, which is confirmed by previous scientific data (Blagrove *et al.*, 2018). Thus, the results confirmed that a higher initial level of motor activity provides a faster and more complete implementation of the adaptive mechanisms of CVS, which determines the training efficiency and aerobic potential of the body.

Features of adaptive changes depending on the level of motor activity

Analysis of the results showed that adaptive changes in response to the aerobic programme were differentiated depending on the initial level of motor activity. A comparison of the rates of increase in physical fitness indicators showed that girls with high motor activity demonstrated a more intense training response, which is characteristic of both aerobic endurance and muscular endurance and speed-strength abilities. Summary data on growth are shown in Figure 1, which allows visually comparing the dynamics between groups and determining the dominant components of physical fitness.

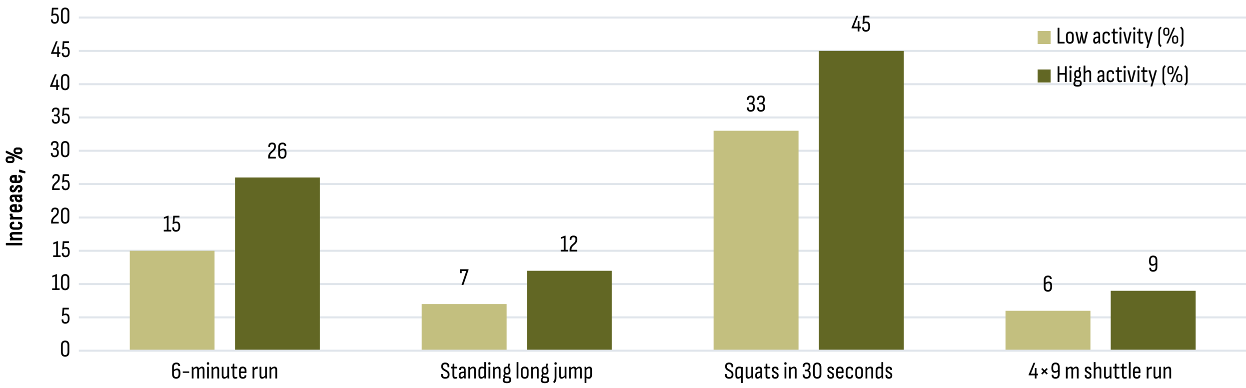

Figure 1. Increase in physical fitness indicators among adolescent girls

Source: created by the authors

The structure of changes in physical fitness showed that the greatest increase was observed in the 30-second squat test: +33.3% in the low-activity group and +45% in the high-activity group. This indicated an effective development of muscle endurance in the lower extremities due to regular repetition of cyclic loads of medium intensity. In the 6-minute run, the increase was +15.9% and +25.6%, respectively, which also confirmed a more pronounced aerobic adaptation in physically active girls. To a lesser extent, the changes affected coordination abilities (4×9 m shuttle run), where the increase was lowest in both groups. This indicated a lower training sensitivity of this component to the predominantly aerobic effects of the programme. Analysis of CVS functional indicators allowed establishing even clearer differences between the groups. Generalised growth data are shown in Figure 2. The decrease in heart rate at rest and after exercise, and the improvement in HRR1 and Ruffier-Dixon Index were systemically higher in the high-activity group, which indicates a qualitative shift in the mechanisms of cardiovascular regulation. The most pronounced effect was recorded for HRR1 (+44.4% vs. +54.5%), reflecting a faster switch of the autonomic nervous system from sympathetic activation to parasympathetic recovery, which is confirmed by data from a study in which HRR is considered as a key marker of vagal control and fitness level (Stanley *et al.*, 2013). Improvement of the Ruffier-Dixon Index (-21.6% vs. -29.7%) in physically active girls indicated not only a better ability to maintain heart function under load, but also a reduction in energy costs for its implementation, which increases the functional efficiency of activities. In the low-activity group, the changes were gradual, which is associated with an initially lower level of adaptive reserves and slower development of cardiorespiratory mechanisms.

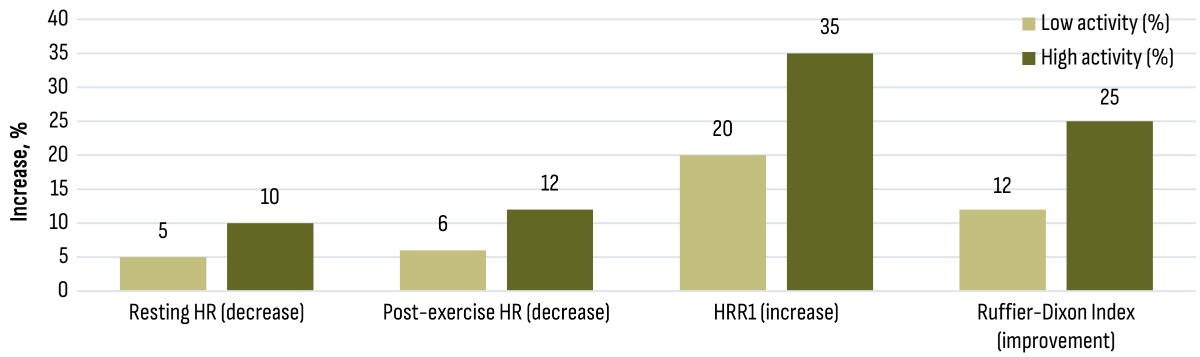

Figure 2. Increase in functional indicators of the cardiovascular system among adolescent girls
Source: created by the authors

The relationship between the degree of involvement in motor activity and adaptive changes was manifested in the form of statistically significant correlations, which allows not only stating the difference between groups, but also explaining the mechanisms through which the initial motor status affects the training response. The most pronounced association was established between the degree of motor involvement and the increase in the results of six-minute running ($r = 0.68$; $p < 0.01$), which indicates a high degree of dependence between previous motor involvement and the ability to increase aerobic endurance. This means that girls with higher PAQ-A already developed mechanisms for efficient oxygen use, a larger volume of functioning mitochondria, and better peripheral muscle perfusion, which provided a more intense adaptive effect during the programme. The negative association between PAQ-A and changes in resting heart rate ($r = -0.72$; $p < 0.01$) confirmed that high motor activity contributes to a more significant economisation of cardiac activity. A decrease in resting heart rate in physically active girls indicated an increase in stroke blood volume and an increase in vagal influence, that is, the heart performed the same work with less energy costs. This is a characteristic feature of a trained cardiovascular system.

The correlation of average strength between activity level and improvement in the Ruffier-Dixon Index ($r = -0.65$; $p < 0.05$) showed that physically active girls showed faster recovery after standard exercise and lower physiological cost of performing it. This reaction indicates a coordinated functioning of the cardiovascular and respiratory systems, which ensures more efficient recovery and faster elimination of metabolites. The association between PAQ-A and HRR1 ($r = 0.70$; $p < 0.01$) confirmed that it is the initial level of motor activity that significantly determines the rate of heart rate recovery after exercise. Higher HRR1 values in physically active girls indicated a rapid switch of the autonomic nervous system from sympathetic dominance to parasympathetic control, which is a sign of a high level of fitness and resistance to physiological stress. This allows interpreting PAQ-A as a sensitive predictor of the effectiveness of adaptation processes in the framework of physical education and recreation programmes. Comparison of the obtained correlations established a clear pattern: the higher the initial level of motor activity, the more intense and systematic adaptive changes are detected. This reflects a differentiated training sensitivity, where the same external influence causes a different response of the body depending on previous motor experience. The results confirm that the initial level of activity acts as a predictor of training effectiveness and can be used to predict the adaptive potential of adolescent girls.

The results show that systematic aerobic classes in extracurricular format, organised according to the principles of sports training (regularity, gradual increase in load, intensity control), contribute to the development of aerobic endurance and improvement of functional indicators of the cardiovascular system in adolescent girls. More pronounced adaptive changes in physically active students reflected the influence of previous motor experience, which is typical for sports training, where the developed training base provides a faster increase in functional capabilities. This was manifested in a greater increase in endurance and faster recovery from exercise, which corresponds to the body's response to an aerobic training stimulus in sports. The data obtained confirm the differentiated nature of adaptation, typical for sports activities, depending on the initial motor level.

Discussion

The results of the study showed an improvement in the indicators of physical fitness and functional state of the cardiovascular system in adolescent girls after an aerobic programme. The greatest changes were observed in the development of aerobic and muscular endurance, while coordination indicators underwent less pronounced shifts. The nature of adaptive changes differed depending on the initial level of motor activity: girls with high activity showed a greater increase in indicators and faster recovery after exercise compared to low-activity participants, which indicates a differentiated response of the body to the same training stimulus.

The improvement in physical fitness was manifested primarily in the increase in aerobic and muscular endurance: the result of six-minute running increased by +15.9% in the low-activity group and +25.6% in the high-activity group, and the indicator of squats in 30 seconds – by +33.3% and +45%, respectively. The dynamics of coordination abilities was lower: in the 4×9 m shuttle run, the reduction in execution time was 5.5% and 8.8%. This adaptation structure is consistent with the conclusions of P. Stricker *et al.* (2020), who emphasised that in children and adolescents, overall training load stimulates the development of aerobic and muscular endurance, while improving coordination abilities requires the use of specially organised motor tasks with increased sensory-motor complexity. This nature of adaptation was consistent with data by M. Bratic *et al.* (2022), where a regular aerobic programme in girls caused an increase in endurance and muscle performance due to repeated cyclic loads of moderate intensity, which confirms the effectiveness of such a training approach. The study showed slower changes in speed coordination tests, which correlates with lower training sensitivity of this component.

The results obtained were consistent with the data by T. Petrušič *et al.* (2022), where school intervention contributed to improved physical fitness in girls aged 12-14, with the greatest increase in endurance, confirming the importance of the aerobic component in shaping the training response. However, the researchers noted a higher increase in speed and strength indicators, which partially does not coincide with the identified patterns in this study and may be conditioned by the game format of classes. The growth ratio between the groups was consistent with observations of D.D. Cohen *et al.* (2021), where a higher initial level of activity was associated with more intense training progress, confirming the role of initial motor status in the development of adaptive mechanisms. C. Romero *et al.* (2021) showed that the development of speed, strength, and coordination indicators in adolescents requires specific stimuli, which explains the minimal dynamics of shuttle running in this study.

Functional status indicators showed positive changes: resting heart rate decreased by 7.3% in the low-activity group and 11.4% in the high-activity group, HRR1 increased by 44.4% and 54.5%, respectively, while the Ruffier-Dixon Index improved by 21.6% and 29.7%. The decrease in peak heart rate after exercise was more pronounced in girls with high activity – 16 bpm versus 12 bpm, which reflects an increase in cardiac activity and an increase in recovery efficiency. The consistency of these changes can be traced with the data by E.S. Cowley *et al.* (2021), which showed that regular motor activity in adolescents contributes to a better physiological response to exercise. The researchers emphasised the role of psychosocial factors, which may partly explain the stable differences between groups. I. Csecs *et al.* (2020) indicated that systematic training contributes to the improvement of structural and functional parameters of the cardiac apparatus in adolescents. The researchers' observation of the gradual development of cardiac adaptations differs from the faster functional changes recorded in the current study.

According to the conclusions of T. Harju (2025), aerobic programmes enhance vagal effects on heart rate in adolescent girls, which is consistent with a more pronounced increase in HRR1 in the high motor activity group recorded in the present study. This mechanism may explain the higher rate of post-exercise recovery characteristic of participants with better initial fitness levels. The analysis by S.K. Hunter *et al.* (2023) confirmed that autonomous regulation of cardiac activity in girls is characterised by high plasticity in response to exercise. The researchers emphasised sex-specific mechanisms of heart rate control, which is consistent with the resulting HRR1 dynamics. Results of the study by M.M.R. Iñigo-Vollmer & M. Fernández-del-Valle (2023) demonstrated that regular aerobic exercise in girls provides a systemic improvement in the mechanisms of cardiovascular performance. The researchers emphasised the importance of adequate training intensity, which corresponds to a more effective improvement in the Ruffier-Dixon Index in the high activity group.

The established correlations showed a relationship between the level of motor activity and the scale of adaptive changes: the strongest associations were observed between PAQ-A and endurance gain ($r = 0.68$; $p < 0.01$) and HRR1 ($r = 0.70$; $p < 0.01$), while a decrease in resting heart rate correlated at $r = -0.72$ ($p < 0.01$). The correlation with the Ruffier-Dixon Index ($r = -0.65$; $p < 0.05$) reflected the integral nature of the response. The results were consistent with data by H.W. Landgraff *et al.* (2021), who showed that adolescents with a higher training background show a greater increase in maximum oxygen consumption, which supports the found association of PAQ-A with aerobic endurance. The researchers noted broad variability between individuals, which coincides with the heterogeneity of changes in the low-activity group. L.D. McGarrigal *et al.* (2025) stated that the development of motor function in girls depended on the initial level of motor activity involvement, which coincides with the established association between PAQ-A and increased muscle endurance. However, the researchers emphasised the age-related features of maturation, which had minimal impact due to the narrow age range in the study.

Observations of E. Papaevangelou *et al.* (2023) confirmed that female athletes with higher training load showed a more pronounced improvement in cardiorespiratory function during the season, which is consistent with the identified HRR1 correlations. However, researchers pointed out the role of the specificity of the sport, which was not relevant for the school contingent. The effectiveness of personalised programmes is determined by participants' individual activity levels, which is consistent with the identified association between PAQ-A and recovery rates reported by P. Petrovics *et al.* (2025). The researchers noted that motivational factors change the response to stress, which can also affect the resulting correlations. The data obtained by L. Plavsic *et al.* (2020) showed that systematic training leads to improved aerobic function in girls with different baseline fitness levels, but faster changes occur in those with higher baseline activity, which is fully consistent with the results obtained for PAQ-A.

The results show adaptive changes characteristic of adolescence to systematic aerobic exercise, which are used in physical education and sports practice, in particular, improving cardiorespiratory regulation and increasing the training response in physically active girls. According to Y.S. Rajpoot *et al.* (2025), in young female athletes, the recovery rate and sensitivity of autonomous heart rate regulation increase with increasing training intensity, which is consistent with higher HRR1 values in physically active girls. The researchers also demonstrated that cardiorespiratory responses in female athletes are more economical under conditions of repeated loads – a similar trend was observed in girls with high PAQ-A.

Additionally, R.S. Oliveira *et al.* (2018) found that higher levels of motor activity in adolescents are associated with more effective autonomous regulation of cardiac activity and favourable indicators of cardiorespiratory functioning, which may explain a more expressive training response in the high-activity group. The study by

A.Z. Skouras *et al*. (2023) proved that aerobic and resistive loads were shown to cause systemic changes in cardiovascular reactivity, which is consistent with an improvement in the Ruffier-Dixon Index and a decrease in heart rate in the study groups. The researchers noted that the effect of regular training is manifested in increasing the effectiveness of recovery mechanisms – a similar effect was recorded in the group of high activity. The increase in endurance and motor performance in physically active girls was consistent with the results obtained by Z. Wang *et al*. (2024), who showed that a combination of functional strength and aerobic training provides improvements in aerobic endurance and overall motor form in adolescents.

According to V.M.R. Weber *et al*. (2024), girls' regular participation in sports and wellness programmes is associated with increased cardiorespiratory fitness, which is consistent with higher results of high activity in HRR1 and resting heart rate. The researchers noted that systemic training stimuli contributed to the development of stable physiological adaptations, which correlated with the differentiated training response obtained in the study. Discussion of the results showed that the established adaptive changes in physical fitness and functional indicators of the cardiovascular system are consistent with data from other scientific studies that describe the positive effects of aerobic exercise on endurance, heart rate, and recovery rate in adolescent girls. The revealed relationship between the level of motor activity and the amount of training shifts corresponds to the models of differentiated training sensitivity described in sports science.

Conclusions

Analysis of the dynamics of physical fitness showed that the aerobic programme caused a gradual increase in endurance, strength, and coordination capabilities, but the rate of changes was differentiated depending on the initial motor status. In girls with high activity, the increase in the distance of six-minute running reached +25.6% compared to +15.9% for low activity, and the number of squats increased by +45% against +33.3%. Instead, the improvement in shuttle running time remained moderate (-8.8% and -5.5%, respectively), reflecting a lower specific sensitivity of coordination abilities to an aerobic training stimulus. The totality of results showed that the initial level of activity determines the scale and rate of positive morphofunctional changes in a single programme. The functional response of CVS also demonstrated a gradual nature of adaptation: although both groups had positive changes, their magnitude was higher in physically active girls. The decrease in resting heart rate was -11.4% in high activity versus -7.3% in low activity, while the increase in HRR1 reached +54.5% compared to +44.4%. The Ruffier-Dixon Index improved by +29.7% and +21.6%, respectively, reflecting more efficient integration of cardiovascular regulation mechanisms, faster recovery, and lower physiological stress under standard exercise. Thus, training adaptation was not only quantitative, but also qualitative in nature, increasing with increasing initial activity.

Correlation analysis deepened the results obtained, confirming that the level of motor activity is a predictor of training effectiveness. The strongest associations were found between PAQ-A and endurance gain in six-minute running ($r = 0.68$; $p < 0.01$) and HRR1 ($r = 0.70$; $p < 0.01$), while a negative correlation with changes in resting heart rate ($r = -0.72$; $p < 0.01$) and the Ruffier-Dixon Index ($r = -0.65$; $p < 0.05$) reflected economisation of cardiac activity in more active girls. The consistency of these connections indicates the systemic influence of the initial motor mode on the scale and course of adaptive processes, which confirms the concept of training sensitivity of adolescents. The combination of quantitative changes in physical fitness, functional responses and established correlations confirms that the aerobic programme contributed to the development of differentiated adaptive shifts, the scale and direction of which were determined by the initial level of motor activity

The prospects for further research are to specify the solution of the problem by including a control group to correctly determine the training effect depending on age and individual variability, and to expand the sample by gender, age and type of educational institutions, which will increase the significance of the results obtained. Further research should focus on comparing the effectiveness of different aerobic, strength, and combined programmes, and analysing how baseline physical activity levels modify training responses in adolescents in different socio-educational contexts.

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Conflict of Interest

None.

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Аеробні навантаження як чинник адаптаційних змін у фізичному та функціональному станах дівчат підліткового віку

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Анотація. Мета дослідження – комплексна характеристика зміни показників фізичної підготовленості та функціональних можливостей дівчат підліткового віку залежно від рівня рухової активності під впливом аеробних навантажень. Дослідження проводилося на базі Переяславської гімназії № 3 (Київська область) упродовж 17 березня – 25 травня 2025 року та включало аеробну програму з двома етапами вимірювання, що дозволило проаналізувати динаміку фізичної підготовленості й функціональних показників серцево-судинної системи дівчат-підлітків із різним рівнем рухової активності. Було з'ясовано, що у групі високої активності дистанція шестихвилинного бігу зросла з 900 ± 100 м до 1 130 ± 90 м (+25,6 %), тоді як у низької активності – з 820 ± 95 м до 950 ± 85 м (+15,9 %). Кількість присідань за 30 с збільшилася на +45 % (із 20 ± 4 до 29 ± 3) проти +33,3 % (із 18 ± 4 до 24 ± 3). Показники човникового бігу 4×9 м покращилися помірно: -1,1 с у високої активності та -0,7 с у низької. Функціональні зміни серцево-судинної системи проявилися зниженням частоти серцевих скорочень у спокої на -11,4 % та -7,3 % відповідно, приростом відновлення за першу хвилину на +54,5 % проти +44,4 %, а також зниженням індексу Руф'є-Діксона на 29,7 % і 21,6 %, що відображає покращення функціонального стану. Кореляційний аналіз підтвердив, що рівень рухової активності статистично пов'язувався із масштабом адаптаційних змін ($r = 0{,}68 - 0{,}72$; $p < 0{,}01$). Таким чином, вихідний руховий статус визначав тренувальну чутливість дівчат-підлітків і впливав на характер змін фізичної підготовленості та функціональних показників. Отримані дані можуть бути використані вчителями фізичної культури, тренерами та фахівцями оздоровчих програм для диференціації навантаження з урахуванням вихідного рівня рухової активності дівчат

Ключові слова: рухова активність; тренувальний вплив; м'язова витривалість; швидкість відновлення; серцево-судинна система; дівчата 13-15 років; фітнес-програми

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Proteins: Mechanism of action, physical exercise and athlete's hypocaloric state based on literature review

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Abstract. Athletes and physically active people take nutritional supplements to improve their health, maintain their physical qualities and optimise the recovery process. At the same time, the specifics of their use and the mechanism of action in acute energy deficiency have not yet been definitively investigated, which makes the study of the effect of proteins and amino acids in the hypocaloric state of a person an urgent problem. The purpose of the study was to clarify the role and mechanism of the plastic and regulatory effect of proteins and amino acids with a branched chain on the body of athletes in hypocaloric conditions. The analysis of the literature was carried out using the methods of analysis, synthesis, systematisation and generalisation according to the method of using keywords in the electronic databases PubMed and SPORTDiscus. The peculiarities of the athlete's hypoenergetic condition and dietary protein supplements to preserve the athlete's muscle mass in the conditions of long-term physical tests have been clarified. It was found that with a limited level of calories and a low supply of fat, the need for protein increases almost twice. Taking protein within 2 hours after training or before going to bed stimulates a significant acceleration of muscle protein biosynthesis. The amino acid lysine in the composition of proteins activates the central regulator of anabolism of skeletal muscles – the intracellular multimolecular signalling target of rapamycin complex. Its regulatory signals are propagated by the cyclase system. As a result of the action of the appropriate protein kinase, reactions of phosphorylation of chromatin proteins, participants in processing, splicing, etc. occur. It is assumed that in this way lysine stimulates the rate of synthesis of various regulators and factors of anabolism, remodelling and growth. A hypothetical mechanism of the influence of leucine on the anabolic processes of muscle tissue is proposed in a graphic version. The study will be useful for specialists in biochemistry, sports nutrition, sports and wellness industries

Keywords: protein; lysine; training; target of rapamycin; energy deficit

Introduction

Long-term hypocaloric diets have certain disadvantages because they cause loss of fat and lean mass. A negative balance between them leads to muscle exhaustion, reduces the effectiveness of physical exercises and increases the risk of injuries. At the same time, low body weight is an important success factor in many sports, including gymnastics, martial arts, and figure skating. Athletes can use effective nutritional strategies to reduce body weight, which contribute to the preservation of muscle mass and athletic performance. In this context, increased protein intake prevents muscle

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wasting and supports physical performance during periods of energy restriction. Production and sales of sports nutrition and supplements are growing in the European Union. Athletes may sometimes consume them indiscriminately or choose products that have not been evaluated and approved by scientific evidence. In this sense, information about the interaction of the body, physical activity and nutrition contributes to making informed decisions about sports nutrition.

The International Society of Sports Nutrition presented its position paper on the effects of essential amino acid supplementation on skeletal muscle maintenance and performance. This position was published in the work of A.A. Ferrando *et al.* (2023). Several key provisions are highlighted from the published findings. Essential amino acids play the main role in stimulating the synthesis of muscle protein. Protein is critical for replacing degraded or damaged muscle proteins and increasing functional performance. With age and with energy deficiency, the proportion of leucine must be increased to overcome reduced muscle sensitivity. In the study of M. Holeček (2021) the emphasis is on skeletal muscles, which play a dominant role in the catabolism of branched-chain amino acids (BCAAs; valine, leucine, and isoleucine). The main role of skeletal muscles in the catabolism of these amino acids, according to the author, is determined by their mass and high activity of BCAA-aminotransferase, which is absent in the liver. A decrease in the level of amino acids in liver cirrhosis and an increase in their concentration in diabetes have been shown. The authors of this study considered it expedient to clarify the role of changes in BCAA metabolism in other pathologies. C. Tinline-Goodfellow *et al.* (2023) presented a concise description of the mechanisms underlying the target of rapamycin 1 complex (mTOR) mediated activation of muscle protein synthesis. It is recommended that future research be directed to further study mTORC1 activation at the periphery of skeletal muscle fibres. A group of researchers S. Allard *et al.* (2024) have shown that in mammals, mTORC1 controls cellular metabolism in response to energy availability. Transmitting mTORC1 signalling affects the regulation of energy intake, storage, and utilisation. In the authors' opinion, elucidating the mechanism of transmission of mTORC1 signals from one cell and organ to another can be a key factor for the development of safe methods of using proteins in sports practice and medicine.

V.V. Kuibida *et al.* (2022a; 2022b) considered the role of heat shock proteins in adaptation to physical load and growth of bone tissue, which is important for creating optimal methods of the training process and recovery. Viewing metabolism through the prism of the biology of physical activity has proven to be an accessible and practical strategy for gaining new insights into local and systemic regulation of metabolism. Recent methodological developments of J.A.B. Smith *et al.* (2023) improved understanding of the central role of skeletal muscle and nutrition in promoting health. Studying the signalling role of proteins and some amino acids is a new and promising direction of scientific research. The scientific literature is dominated by works devoted to some biochemical, physiological, medical and sports problems of the use of proteins in sports practice. However, it is quite rare to find works in which the mentioned aspects are comprehensively combined with the mechanisms of adaptation of the body in conditions of energy deficiency. This direction of research is relevant and can bring significant results in the theoretical and practical plane. Therefore, the purpose of the article was to find out the plastic and regulatory features of the action of proteins and amino acids under conditions of physical exertion and energy deficit and the methods of their use.

The purpose was achieved through the consistent use of traditional scientific theoretical methods: analysis, synthesis, systematisation and generalisation of data from special literature and Internet sources within the framework of the selected problem. The literature search was carried out on the basis of the above keywords in the PubMed and SPORTDiscus electronic databases. Using the analysis method, the research object, in particular: proteins, branched-chain amino acids, lysine, physical activity, target of rapamycin, energy deficit of the body, mechanism of action, was analysed and broken down into separate component parts. These components were studied in detail, without taking into account their interrelationships. The above-mentioned abstract elements are combined in concrete integrity and interaction by the method of synthesis. As a result of the conducted analysis and synthesis of essential properties, characteristics, features of sports dietary practice and metabolic reactions, the prerequisites for applying the method of systematisation were created. Consequently, this review material is presented in the form of two components or subdivisions: the role of proteins and methods of their use in the nutrition of athletes and physically active people; and the athlete's hypocaloric state and the mechanism of action of branched-chain amino acids. By the final method of generalisation, general signs, properties, trends are recorded and the transition from facts to certain regularities and conclusions is made.

Proteins in the Nutrition of Athletes and Physically Active People

The effectiveness of sports activities depends on the effectiveness of the training process and nutrition strategies, which form the basis of the multi-vector process of adaptation to physical activity. The building and regulatory function of amino acids with a branched chain, primarily leucine, is one of the aspects of the mechanism of adaptation to physical exertion. Current evidence suggests that dietary protein intake is necessary to support metabolic adaptation, repair, remodelling, and protein turnover. In traditional methodological approaches, a protein dose of 1.2 to 2.0 g/kg/day is recommended. Use of a higher dose may be recommended for short periods during intense exercise or when energy intake is reduced.

A significant number of athletes in various sports receive at least one musculoskeletal injury during their sports career. Most often, injuries are recorded during competition periods. A balanced protein diet is of great importance for the recovery and rehabilitation of athletes and physically active people. Eating for recovery after sports injuries has a lot in common with sports nutrition. However, there are differences regarding prevention of the risk or presence of sarcopenia, hypotrophy, or dysphagia. Increased protein consumption with an even distribution of food throughout the day helps to minimise the loss of muscle and strength during immobilisation. Dietary supplement strategies can be helpful in addressing issues related to appropriate caloric intake, timing, and decreased appetite. Rehabilitation nutrition, combined with training, leads to an improvement in the physical condition and acceleration of the return of athletes to the training process after surgery or injury.

The post-traumatic recovery of an athlete often leads to a long period of muscle shutdown, which leads to a loss of muscle mass. As a result of the lack of physical activity, the metabolic health and functional capacity of the athlete deteriorates. The most intense loss of muscle mass occurs during the first two weeks of not using the muscles. The degree of loss of post-traumatic muscle mass determines the level and duration of the necessary rehabilitation. Atrophy of muscle failure is associated with a decrease in the basal rate of protein synthesis and the development of anabolic resistance to food consumption. In this situation, the protein content of the food is crucial for stimulating the rate of its synthesis in the muscles. Increasing your daily intake of protein/amino acids of a specific type at specific times can limit the loss of muscle mass and strength.

Skeletal muscle mass is one of the indicators of human longevity and health. Human muscle mass is determined by the balance of two cellular processes – the synthesis of muscle protein and its breakdown. The balance between the processes of anabolism and catabolism is sensitive to the characteristics of physical activity and protein nutrition. Understanding the molecular mechanisms underlying this process shortens the way to the informed use of nutritional technology in sports and in overcoming age-related anabolic resistance of skeletal muscle. Knowledge of the molecular mechanisms of protein and amino acid effects facilitates the delineation of recommendations for future research directions that may advance knowledge in this field.

In 2023, the use of nutritional supplements by athletes was among the most significant problems. A group of researchers led by C.C. Carey *et al.* (2023) found that among 405 participants in the experiment, 52% take nutritional supplements to improve health, and 35% to maintain their physical qualities or recovery. A ranking of the processes and qualities of athletes and active people, which are significantly dependent on sports nutrition, has been compiled: more effective muscle recovery; increasing endurance; increasing strength and power. Except for performance in the peak power range, a protein intake of 1.6 g/kg/day appears to be sufficient to maximise gains in lean mass, muscle strength, performance, and aerobic capacity as when consuming 1.6 or 3.2 g/kg/day for 16 weeks. This daily amount of protein is effective and safely tolerated by young, healthy adults. R. Bagheri *et al.* (2023) recommended daily protein intake in excess of recommended doses to maximise metabolic adaptation to exercise.

In the study of E.R. Goldstein *et al.* (2023) after training, master class athletes consumed one of three beverages during a 2-hour recovery period: placebo (electrolytes and water), carbohydrates (1.2 g/kg), or a mixture of carbohydrates and proteins (0.8 g/kg + 0.4 g/kg). It has been established that the use of carbohydrates and a carbohydrate-protein mixture is equally effective in enhancing glycogen resynthesis during the 2-hour recovery period. Water and electrolytes alone were not effective in restoring endurance during the second bout of strenuous exercise. J. Zhang *et al.* (2023) studied 427 young people (217 women) aged 21 to 35 years who did 240 min of aerobic and resistance training per week. Strength training was found to be positively associated with intake of protein, vitamins B2, B3, B5, B6, and B12, and percent of total calories from protein, and negatively associated with percent of total calories from carbohydrate. Time spent in aerobic exercise was positively associated with fibre, pectin, and vitamin B6 intake and negatively associated with percentage of total calories from protein. It is assumed that it is worth paying attention to the negative relationship between physical exercises and carbohydrate consumption.

Milk proteins contain essential amino acids (with a sufficient amount of leucine), 80% casein and 20% whey protein. Whey protein belongs to the "fast" proteins, and casein – to the "slow" proteins. In an 8-week experiment by H. Yapici *et al.* (2023), 8 exercises/training were performed with a volume of 3 sets of 8 repetitions and a rest interval between them of 120 s. Two experimental groups participated in the experiment: first group performed combined strength training + consumption of 500 ml of chocolate milk (30 g of protein), second group – strength training without consumption of chocolate milk. The participants of the first group had higher indicators of muscle thickness, lean body mass, maximum strength, length of the jump against the movement, and peak power than the representatives of the second group. The authors concluded that chocolate milk should be considered as a promising post-workout nutritional supplement. M. Ummels *et al.* (2023) evaluated the nutritional value and absorption kinetics of processed barley/rice proteins extracted from brewer's waste grain and compared them with pea proteins. F. Li *et al.* (2021) reported that isolated soy protein supplementation (40 g/day, 5 days per week, 8 weeks) combined with aerobic exercise (8 weeks at an intensity of 40-65% heart rate reserve) improved body composition, anthropometric characteristics, and cardiovascular pulmonary endurance in women.

The traditional dietary intake of protein for adults is 0.8-0.9 g/kg/day body weight. These guidelines differ from the authoritative recommendations of the Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine of 1.2-2.0 g/kg/day. Athletes training for endurance and strength are recommended to consume 1.2-1.7 g/kg/day. Population protein requirements are still based on nitrogen balance. However, this approach is quite debatable. Achieving a balanced intake and excretion of nitrogen is not essential for athletes, for whom the main goal is the successful performance of physical exercises. Nutritional strategies are necessary, for example, for people with type 1 diabetes to control glycemia after exercise. F.R. Muntis *et al.* (2023) monitored glucose levels in 112 adolescents aged 14.5 years and 36.6% overweight or obese. Intensive insulin therapy led to an increase in body weight. Adolescents were recommended to participate in 60 min/day of physical activity of medium and intense power.

C. Ruiz-Castellano *et al.* (2021) provided recommendations for diet, nutrition, and nutritional supplementation for the weight loss phase of strength-trained athletes. Protein intake (2.2-3.0 g/kg/day) should be spread throughout the day (3-6 meals) to ensure sufficient protein in each meal (0.40-0.55 g/kg body weight/food) and eat within 2-3 hours before and after training. Military personnel experience long periods of energy deficits during combat and training, making them susceptible to harmful weight loss. Research results of R.E. Anderson *et al.* (2023) support the recommendation that more than 0.8 g/kg/day is needed to moderate the effect of energy deficit on lean body mass reduction, whereas intakes of up to 1.6 g/kg/day may be better. However, precise recommendations cannot be made because the severity and duration of energy deficits varies between studies. Longer and larger studies are needed to elucidate the role of protein during energy deficits in the military.

Consumption of compounds rich in amino acids improves collagen content in tendons and their biomechanical properties. N.W.C. Campbell *et al.* (2023) found: if an oral bolus of essential amino acids is not combined with exercise, it leads to only a moderate increase in the concentration of amino acids in the peritendinous Achilles tendon; in combination with exercise with a gap in the consumption of essential amino acids resulted in a higher concentration of amino acids in the tendons compared to no exercise.

D. Mercer *et al.* (2020) calculated the average need for protein consumption for female athletes in the period before menopause. It is close to the needs of those who train in the mode of aerobic endurance (1.28-1.63 g/kg/day), engage in resistance exercises (1.49 g/kg/day) and periodic physical exertion (1.41 g/kg/day) lasting ~60-90 min. Pre- and post-workout protein intake of 0.32-0.38 g/kg has been shown to be beneficial for female athletes performing resistance exercise and periodic exercise. However, in further studies, researchers need to identify the influence of the phase of the menstrual cycle or the use of hormonal contraceptives on the need for protein.

Nutrition has a significant impact on injury prevention and recovery due to its impact on the athlete's overall physical and psychological well-being and improved tissue healing. In particular, amino acid and protein intake, antioxidants, creatine, and omega-3 have been studied for their role in preventing muscle loss and anabolic resistance and healing injuries. An adequate nutritional strategy plays an important role in recovery and rehabilitation after injury, and nutritional interventions should become part of standard practice in post-injury care (Smith-Ryan *et al.*, 2020).

A group of researchers led by P. Rodriguez-Lopez *et al.* (2022) analysed and screened commercial protein supplements for sports practice and identified the types of tested protein products. Among them, whey (milk) is a protein of high biological value with a high concentration of branched amino acids, including leucine. There are three types of protein: concentrated (with 70-80% protein and a small amount of carbohydrates and fats); isolated (with 90% protein and a minimum amount of carbohydrates and fats); hydrolysed (a protein in which long polypeptide chains are broken into short peptides, due to which their absorption occurs faster). Casein (milk) is a protein of high biological value, which makes up 80% of milk protein. Due to the acidic environment of the stomach, it forms blood clots that slow down its absorption. Egg albumin is a protein of high biological value without fat or carbohydrates. Soy protein has a high biological value, its digestion is fast. It is usually low in leucine unless it is additionally fortified. Other plant proteins have lower biological value unless multiple sources are mixed or fortified.

Protein supplements have certain features and characteristics, in particular, a sufficient amount of branched chain amino acids (BCAA – leucine, isoleucine, valine) and high biological value, digestibility and bioavailability. They correspond to the classification of the Australian Institute of Sport as isolated protein supplements from a certain source: whey, casein, egg albumin, plant sources (soy, hemp, peas, chickpeas, rice, etc.). There are no special regulations for protein supplements that regulate the production and marketing of this type of sports nutrition. Supplement usage patterns for different purposes, dosages, and regimens do not always align with the protein that works best. In addition, supplements may contain substances that are classified as doping according to World Anti-Doping Agency. They contain substances that are not prohibited, but reduce their quality. In particular, this is furosine, which appears in whey proteins during their preparation at high temperatures due to the Maillard reaction. R.J. Maughan *et al.* (2018) and P. Rodriguez-Lopez *et al.* (2022) noted that in some places supplements may contain enzyme and allergen impurities and ingredients that lead to absorption or doping problems. The content of BCAA in the blood plasma can signal certain diseases. Significant changes in the content of combinations of amino acids leucine/isoleucine/valine, etc. were revealed in blood plasma of patients with coronary heart disease with atrial fibrillation.

Hypocaloric State of the Athlete and the Mechanism of Action of Amino Acids with a Branched Chain

It is advisable to consider in more detail the hypocaloric condition and the mechanism of action of amino acids. In cases of energy restriction or sudden inactivity resulting from injury, there is a need for increased protein intake to 2.0 g/kg/day or higher (Burke *et al.*, 2023). T.J. O'Leary *et al.* (2023) found that short periods of severe energy deprivation and heavy exercise (in the form of 36-hour military field exercises) can suppress bone formation for at least 96 hours. Inhibition of bone formation in men and women did not differ. Protein feeding did not compensate for decreased bone formation during severe energy deficits.

In the studies of C. Hiroux *et al.* (2023) exogenous ketosis did not affect body composition but was effective in weight control, maintained declines in physical capacity, and improved general stress parameters. Protein requirements increased when athletes became calorie restricted or low fat. In 2014, the team led by E.R. Helms *et al.* (2014) studied the effect of dietary protein on the body composition of energy-restricted athletes subjected to strength training. It was concluded that the need for protein for them is 2.3-3.1 g/kg, taking into account the limitation of caloric content and leanness.

Targeted weight loss in obese older adults is a risk factor for accelerated muscle loss. In the experiment A.M. Verreijen *et al.* (2017) were involved 100 overweight and obese adults aged 55-80. The effect of a high-protein diet and/or physical exercise on the preservation of fat-free mass during weight loss was studied. During the 10-week weight loss programme, all subjects followed a hypocaloric diet and performed strength exercises 3 times a week: the first group consumed food with a high (1.3 g/kg) and the second with a normal (0.8 g/kg) protein content. It was concluded that in the group with the combined use of a high-protein diet and strength exercises, the index of fat-free body mass increased significantly more.

Consuming high doses of protein during energy deficits combined with intense exercise results in effective muscle gain and fat loss. In the experiment of T.M. Longland *et al.* (2016) used hypoenergetic diets (~ 40% of requirement) that provided 33 ± 1 kcal/kg. Young men of group I consumed a small amount (1.2 g/kg/day), and men of group II consumed an increased amount (2.4 g/kg/day) of protein. All participants of the experiment performed resistance exercises in combination with high-intensity interval training for 4 weeks 6 times a week. It was concluded that during marked energy deficit, intake of 2.4 g protein kg/day was more effective than intake of 1.2 g protein kg/day in lean body mass gain and fat loss in combination with high volume resistance and anaerobic exercises.

Energy deficiency leads to a decrease in the formation of bone tissue, increased resorption, or a combination of them. Physiological adaptation to low energy availability includes changes in the concentration of regulatory hormones: a decrease in triiodothyronine (T3), insulin-like growth factor-1, leptin, and testosterone. M. Papageorgiou *et al.* (2017) recorded changes in the ovulatory cycles of women due to inhibition of gonadotropin-releasing hormone, reduction of pulsation of luteinising hormone and concentration of estrogens. The effect of a short-term low energy deficit at 15 kcal/kg on bone metabolism in women and men was studied. It has been established that with a lack of energy, the process of bone formation slows down and the resorption of bone tissue increases only in women. These metabolic changes are accompanied by a decrease in the response to insulin and leptin.

The results of studies by J. Kwon *et al.* (2023) expanded the understanding of the role and mechanism of action of leucine. It has been shown that dietary protein is necessary for the body's recovery process and its adaptation after training. Previous reports suggest that many athletes meet their total daily protein requirement at dinner. In contrast, an even distribution of protein doses ≥0.24 g/kg body weight consumed throughout the day provides rapid rates of anabolism in skeletal muscle compared to a skewed intake pattern. Leucine is considered the main driver of the anabolic reaction after eating, and its content determines the quality of the protein. Adaptation to speed-force load occurs by stimulating the activity of the protein synthetic mechanism. Increasing the biosynthesis of muscle proteins is an adaptive response to an increase in the concentration of leucine and exogenous amino acids. The above-mentioned amino acid is not synthesised in the human body. It participates in the process of building and restoring muscle mass. It is part of a complex of three amino acids (leucine, isoleucine, valine) for sports nutrition and is designated as BCAA (branched-chain amino acids). The most leucine is in meat, dairy products, fish, soybeans, beans and other legumes. With a lack of amino acids in the body, growth slows down, muscle tissue breaks down, and body weight decreases. The main part of food amino acids is metabolised in the liver. At the same time, according to the research of Y. Huang *et al.* (2011) amino acids with branched side chains undergo catabolic transformations in skeletal muscle, heart, neurons, adipose tissue, and kidney. They ensure the stability of the tertiary structure of proteins.

Leucine, isoleucine and valine are amino acids with hydrophobic properties. Hydrophobic repulsion during interaction with hydrogen and ionic bonds and Van der Waals forces ensure the processes of formation and stabilisation of the tertiary structure of the protein. Leucine is involved in the stabilisation of the tertiary structure of proteins, the binding of O_2 to myoglobin and haemoglobin, and the interaction of enzymes with substrates. It accelerates anabolic reactions, leads to increased muscle mass and strengthens bones, ligaments and tendons. The above-mentioned amino acid accelerates the process of wound healing and recovery after injuries. Leucine provides backup energy in the event of a lack of glucose and leads to an increase in endurance and strength. Before use, it is diluted in a bottle with drinking water in the amount of 2.5-5 g and used before, during or after training and washed down with water. Leucine regulates the rate of muscle protein synthesis by activating the mTOR complex (mammalian target of rapamycin) and possibly other proteins of this regulatory pathway.

The dose of leucine that is inside the protein (the leucine threshold hypothesis) and its subsequent variables in the plasma (the leucine trigger hypothesis; peak magnitude, rate of rise, and total availability) determine the magnitude of the response of muscle protein synthesis after exercise and eating. K. Wilkinson *et al.* (2023) found a pronounced correlation between the dose of leucine and muscle protein synthesis after exercise in the elderly. On the other hand, the correlation was less expressed in young people.

The manipulation of cellular signals is a powerful factor in the therapy of diseases and the implementation of a strategy of influence on the motor system. Amino acids with a branched chain enter the blood from the gastrointestinal tract faster than others. When the concentration of leucine and necessary hormones increases, the synthesis of proteins in the muscles is accelerated. Leucine activates a special anabolic receptor – mTOR, which signals a sufficient amount of building materials for the construction of new proteins. The function of the above protein receptor belongs to serine/threonine protein kinases (mechanistic target of rapamycin kinase). Due to the effects of phosphorylation, leucine stimulates the rate of synthesis of growth hormone, which strengthens the mechanostat of bone tissue, accelerates the formation of muscle mass, cartilage and other connective structures. The mTOR receptor is part of two multimeric protein complexes that differ in activators, targets, and sensitivity to rapamycin. The first complex – TORC1 (target of rapamycin complex 1) stimulates cell growth by accelerating ribosome biogenesis and translation, slowing protein degradation, and activating the uptake of nutrients from the environment. The rapamycin complex 1 (mTORC1) complex includes: anabolic receptor – mTOR and proteins raptor (regulatory-associated protein of TOR), mLST8 (mammalian lethal with Sec13 protein 8), or GβL and PRAS40 (proline-rich PKB (protein kinase B)/AKT substrate 40 kDa).

mTORC1 is considered to be the main regulator of muscle protein synthesis. The amino acid lysine activates the mTORC1 complex through the enzymes of the cyclic nucleotide system, in particular – GTPases (a type of G-proteins that belong to the Ras superfamily), which leads to the relocalisation of the complex. Upon activation of the mTORC1 complex, muscle protein biosynthesis is enhanced due to the phosphorylation of key regulators of mRNA translation p70 kinase of ribosomal protein S6 (S6K1). Instead, rapamycin inhibits mTORC1, blocks cell proliferation, and suppresses the immune response to transplanted organs. As a result of physical exertion, branched-chain amino acids or other anabolic stimuli, this complex moves to the periphery of the cell. Leucine has the greatest anabolic effect among amino acids due to its ability to independently modulate muscle protein synthesis. Phosphorylation of RPS6 Ser240/244 (phospho-S6 ribosomal protein) occurs in human muscle fibres, where mTOR is translocated after anabolic stimuli. Focal adhesion complexes (point contacts) are considered a potential site of mTORC1 regulation *in vivo*. There are two types of adhesive contacts: cell-to-cell and cell-to-matrix. Translocation and accumulation of receptors on the cell membrane leads to binding of the cell to the extracellular matrix through the actin cytoskeleton and anabolic effects (Hodson *et al*., 2022). Food components can cause epigenetic changes through DNA methylation, or through changes in the expression of some miRNAs. Carbohydrates, proteins, and fats are broken down during digestion into monomeric compositions, respectively, into monosaccharides, amino acids, and fatty acids (Sohel, 2020; Norouzi *et al*., 2023).

Pathways of regulation of metabolic processes may involve common signalling links, for example, mTORC1. S. Abou Sawan *et al.* (2020) stated that skeletal muscles are characterised by high plasticity. Muscle tissue is capable of remodelling in response to a number of physiological stimuli. Historically, the lysosome has been considered a catabolic organelle that facilitates autophagy, phagocytosis, and exo-/endocytosis. However, evidence has recently emerged for several anabolic roles of lysosomes in the maintenance of skeletal muscle mass. They have been implicated in the mechanistic target of mTORC1 intracellular signalling centre and EB/lysosomal biogenesis transcription factor signalling in the mTORC1-mediated regulation of protein synthesis. It has been suggested that the lysosome is an understudied organelle that has the potential to support the adaptive response of skeletal muscle to anabolic stimuli. Regulation of autophagy protein expression rate in response to chronic contractile activity in postmitotic cells depends on lysosomes. A. Parousis *et al.* (2018) found that chronic contractile activity enhances mitochondrial biogenesis, as well as the ability of lysosomes to improve mitochondrial turnover. The hypothetical mechanism of the effect of leucine on increasing muscle mass is presented in a graphic version (Fig. 1).

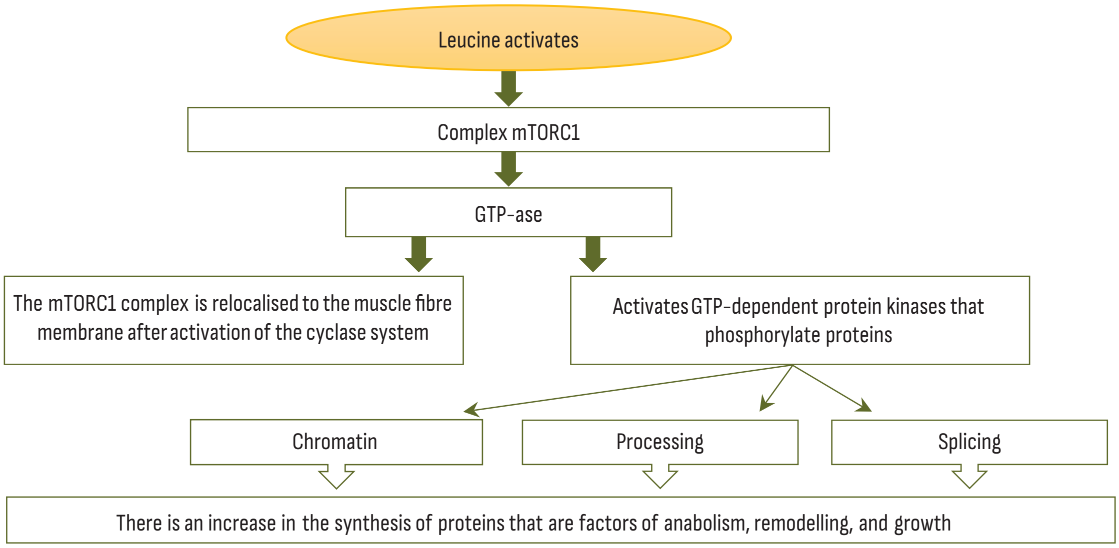

Figure 1. Hypothetical mechanism of action of leucine and anabolic processes of muscle tissue
Source: created by the authors

Leucine plays a plastic and signalling role in the body; it is considered the main driver of the anabolic reaction. The content of leucine and some amino acids with a branched chain and hydrophobic properties determine the nutritional value of the protein. The introduced hydrophobic repulsion of the amino acid complements the forming force of hydrogen bonds, ionic bonds and Van der Waals forces, which ensure the processes of formation and stabilisation of the tertiary structure of the protein. Lysine activates the central regulator of skeletal muscle anabolism – the mTORC1 complex, which consists of mTOR, Raptor, mLST8, PRAS40 and DEPTOR proteins. The regulatory signal is propagated with the participation of enzymes of the cyclic nucleotide system, in particular – GTPases. This complex is relocalised to the muscle fibre membrane. The protein receptor (mechanical target of rapamycin mTOR) belongs to serine/threonine protein kinases. As a result of the reaction of phosphorylation of chromatin proteins, participants in processing, splicing, etc., the amino acid stimulates the rate of synthesis of various regulators and factors of anabolism, remodelling, and growth. In particular, the production of growth hormone accelerates, which strengthens the mechanostat of bone tissue, accelerates the formation of muscle mass, cartilage and other connective structures.

In the course of the study, the following conclusions can be reached: the synthesis of muscle protein is maximally enhanced after the consumption of 10 g of essential amino acids in free form or in the form of a protein bolus in a dose of 20-40 g. The total daily rate of replenishment of the body with high-quality protein (~0.75-1.2 g/kg body weight) should be evenly divided into three portions (~ 0.25-0.40 g/kg body weight) and consumed every 3-4 hours during the day. The specified scheme of protein consumption is the most effective compared to other models of nutrition. Taking high-quality protein sources after exercise within 2 hours after exercise or consuming casein protein (~30-40 g) before bed stimulates a significant increase in muscle protein synthesis and does not affect lipolysis. If there is no physical exercise, then changing the frequency of meals has a rather limited effect on weight loss and body composition.

Conclusions

The need for protein increases when athletes are on a calorie-restricted or low-fat diet. For them, the need for protein can be 2.3-3.1 g/kg, taking into account the restriction of caloric content and leanness. Consuming high doses of protein during energy deficits combined with intense exercise results in effective muscle gain and body fat loss. Increased protein intake prevents muscle wasting and supports physical performance during periods of energy restriction. Pre- and/or post-exercise dietary interventions (carbohydrate + protein or protein alone) may act as an effective strategy to support strength gains and improve body composition. However, the size and timing of the pre-exercise meal can affect the degree of post-exercise protein requirement. Among commercial protein supplements for sports practice, some proven protein products of high biological value are selected: whey (milk), casein (milk), egg albumin, and soy protein. It is most effective to consume protein during the day by dividing it into 3 meals, which qualitatively affects the composition of the body compared to other types of food. Without exercise, changing the frequency of meals has little effect on body weight and composition. The use of protein after training or before casein at bedtime stimulates significant synthesis of muscle protein without affecting lipolysis.

Further research should examine the effect of combining an exercise programme with altered meal frequency on weight loss and body composition. It is worth making a comparative analysis between common regulatory blocks of the signalling mechanism of action of branched-chain amino acids and myokines, osteokines, hepatokines, adipokines, microRNAs during physical activity of different intensity, duration and during the recovery period. Useful information may be gained by the broader use of [^{14} C]-leucine and other labelled amino acids to investigate mTORC1-lysosomal repositioning and intracellular utilisation of dietary amino acids in response to anabolic stimuli. How lysosomal regulation may contribute to skeletal muscle anabolism needs to be elucidated.

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Conflict of Interest

None.

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Білки: механізм дії, фізичне навантаження та гіпокалорійний стан спортсмена за даними огляду літератури

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Анотація. Спортсмени та фізично активні люди приймають харчові добавки для покращення здоров'я, підтримки своїх фізичних якостей та оптимізації процесу відновлення. Водночас особливості їх використання та механізм дії при гострому дефіциті енергії і досі остаточно не досліджені, що робить вивчення впливу білків та амінокислот при гіпокалорійному стані людини актуальною проблемою. Метою дослідження було з'ясувати роль і механізм пластичного й регуляторного впливу білків та амінокислот із розгалуженим ланцюгом на організм спортсменів у гіпокалорійних умовах. Аналіз літератури здійснено за допомогою методів аналізу, синтезу, систематизації та узагальнення за методикою використання ключових слів в електронних базах даних «PubMed» та «SPORTDiscus». З'ясовано особливості гіпоенергетичного стану спортсмена та дієтичних білкових добавок для збереження м'язової маси спортсмена в умовах тривалих фізичних випробувань. Виявлено, що при обмеженому рівні калорій та низькому запасі жиру потреба в білку зростає майже вдвічі. Прийом протеїну впродовж 2 годин після тренування або перед сном стимулюють значне прискорення біосинтезу м'язового білка. Амінокислота лізин у складі протеїнів здійснює активацію центрального регулятора анаболізму скелетних м'язів – внутрішньоклітинного мультимолекулярного сигнального комплексу – мішені рапаміцину. Його регуляторні сигнали поширюються циклазною системою. Унаслідок дії відповідної протеїнкінази відбуваються реакції фосфорилювання білків хроматину, учасників процесингу, сплайсингу тощо. Зроблено припущення, що таким шляхом лізин стимулює швидкість синтезу різноманітних регуляторів та факторів анаболізму, ремодуляції та росту. Запропоновано гіпотетичний механізм впливу лейцину на анаболічні процеси м'язової тканини в графічному варіанті. Дослідження буде корисним фахівцям із біохімії, спортивної дієтології, спортивної та оздоровчої галузей

Ключові слова: протеїн; лізин; тренування; мішень рапаміцину; енергодефіцит

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