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CONTENTS

Mohammad Saeid Kiani. Legal, managerial, educational, and technical factors of liability for school sports accidents among physical education teachers in Iran	4
Sm Farooque, Sharina Naorem, S Premananda Singh. Artificial intelligence metrics and performance optimization in professional soccer: a meta-analytic review	14
Ravi Saini, Kapil Gupta. Comparison of correlation between cardiorespiratory endurance (VO ₂ max) and autonomic function test parameters in athletes and sedentary individuals.....	24
Anastasiia Salii, Yuliia Holenkova, Tetiana Karpunets, Igor Vypasniak, Krzysztof Prusik. Assessment of strength fitness indicators in women of early mature age under the influence of individualized fitness programs in a war-affected environment	31
Tetiana Yermakova, Katarzyna Prusik. Impact of the war in Ukraine on mental health, psychosocial adaptation, and physical activity of the population: a systematic review of Ukrainian-language publications	41
Information	65

Legal, managerial, educational, and technical factors of liability for school sports accidents among physical education teachers in Iran

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

Abstract

Background and Study Aim Physical education teachers are legally responsible for ensuring the physical, psychological, and personal safety of students during school sports activities. Failure to fulfill these duties may result in civil or criminal liability. Despite the growing legal awareness among parents and students, many physical education teachers have limited knowledge of legal mechanisms that may reduce or clarify their responsibility in the event of sports accidents. The aim of this study was to examine the legal, managerial, educational, and technical factors related to the disclaimer of responsibility of physical education teachers during school sports activities in Iran.

Material and Methods A descriptive-analytical research design was applied. The study sample consisted of 225 physical education teachers (98 females and 127 males) selected through convenience sampling. Data were collected using a researcher-developed questionnaire based on a five-point Likert scale. The questionnaire included four dimensions: technical, managerial, educational, and legal factors. Data analysis was conducted using SPSS and LISREL software. Exploratory and confirmatory factor analyses were performed to assess construct validity, while reliability was confirmed using Cronbach's alpha coefficient ($\alpha = 0.87$). The Friedman test was applied to rank the priority of the identified factors.

Results Factor analysis identified four distinct factors explaining an acceptable proportion of total variance. Confirmatory factor analysis demonstrated a good model fit (CFI, GFI, AGFI > 0.90; RMSEA < 0.08). Among all dimensions, legal factors received the highest priority. Specifically, institutional support from education departments, preparation of standard consent forms, and the use of legal acquittal documents were ranked as the most important measures for reducing teachers' legal responsibility. Significant differences were observed in the perceived importance of legal factors among participants.

Conclusions Legal considerations play a central role in managing responsibility for school sports accidents. Enhancing legal awareness, providing institutional support, and implementing standardized legal documents may reduce the legal risks faced by physical education teachers. These measures can also improve teachers' professional confidence and contribute to safer school sports environments.

Keywords: physical education teachers, legal liability, school sports accidents, legal disclaimer

Introduction

School physical education represents a specific educational domain in which pedagogical practice, organizational management, and legal responsibility are closely interconnected. The conduct of physical education classes and school sports activities inherently involves an increased risk of accidents and injuries, placing particular responsibility on physical education teachers to ensure student safety while fulfilling educational objectives. As legal awareness among parents and society continues to grow, incidents occurring during school sports activities are increasingly subject to legal scrutiny and may result in civil or criminal consequences. Consequently, the responsibility of physical education teachers for sports accidents in schools constitutes a complex and multifaceted

issue encompassing educational, managerial, and legal dimensions.

Recent systematic reviews have demonstrated that injuries occurring during physical education classes remain a significant issue in school environments and are associated with multiple organizational, behavioral, and contextual factors [1]. Evidence from comprehensive reviews indicates that effective injury prevention in sports settings depends not only on physical or technical measures, but also on appropriate supervision, organizational responsibility, and compliance with established safety regulations [2]. In addition, systematic analyses focusing on school-aged children emphasize that unintentional injuries in educational settings require preventive approaches embedded within institutional and regulatory frameworks governing school activities [3].

Recent research has emphasized that risk and safety management constitute a core professional

competence of physical education teachers, requiring not only technical skills but also informed decision-making and legal awareness [4]. Contemporary analyses further indicate that educational systems increasingly frame physical education within ethical and legal responsibilities that prioritize student safety alongside curricular objectives [5]. From a legal perspective, the concept of duty of care remains central to understanding teachers' professional accountability in environments characterized by inherent risk, reinforcing the need for clear responsibility frameworks in school physical education [6].

In Iran, laws addressing injuries caused by sports accidents were explicitly enacted in 1973 and later incorporated into the General Penal Code after the Islamic Revolution. Under these provisions, in certain cases, the principle of justified causes applies, and individuals who comply with the conditions stipulated by law may be exempt from legal responsibility [7]. Liability is generally classified into civil and criminal liability, with civil liability further divided into contractual and non-contractual forms. Contractual liability arises from an agreement between parties, whereas non-contractual liability exists in the absence of a contract and is derived directly from statutory law. Since no formal contract exists between students' parents and teachers, the responsibility of teachers and school administrators is considered non-contractual, and its legal basis must be sought in statutory regulations [8]. In this context, the Civil Liability Law, the Islamic Penal Code, and relevant regulations of the Ministry of Education are of particular importance. Contemporary research in physical education emphasizes that teachers' professional responsibility is closely linked to risk and safety management practices, as well as to clearly defined duty of care obligations within educational settings [4]. Moreover, recent analyses highlight that legal and ethical frameworks increasingly position student safety as a central responsibility of physical education teachers within formal curricula [5, 6]. Owing to increased cultural and legal awareness in the field of sport, parents no longer perceive school sports accidents as unavoidable incidents [9]. This shift is consistent with evidence from recent systematic reviews indicating that injuries in physical education and school-based physical activity are now widely approached as preventable events requiring structured supervision and regulatory compliance [1, 3]. For example, if a student is injured during practice while a teacher is simultaneously attending to personal matters, that teacher may be held legally liable, and the school principal may also bear responsibility. The legislator has clearly defined legal boundaries and prescribed penalties for violations [10]. In addition to providing

a safe sports environment, continuous supervision of students and improvement of activity conditions play a critical role in preventing negligence. Accordingly, physical education teachers are required to remain constantly present during sports classes and must not leave students unattended at any time [11].

Supervising sports activities is a critical task due to their inherent risk, and when such supervision is properly conducted, physical education teachers are generally not held responsible for accidents. Effective supervision requires the continuous presence of the teacher during activities, as well as attention to students' age, physical and psychological condition, and the specific type of activity performed [12]. Recent research emphasizes that risk and safety management in physical education is a core professional competence that directly influences teachers' ability to prevent injuries and manage responsibility in school sports settings [4]. Physical education teachers bear legal responsibility for the physical safety, psychological well-being, and personal dignity of students, and failure to fulfill these obligations may result in severe legal consequences. Ignorance of the law does not exempt teachers from responsibility, and the legal accountability of physical education teachers cannot be equated with that of teachers of other academic subjects [13]. Contemporary analyses further indicate that legal and ethical frameworks in education increasingly define student safety as a primary obligation of teachers, particularly in high-risk curricular activities such as physical education [5, 6]. Although sports activities and related environments inherently involve potential risks, many educators underestimate the legal implications of such settings and assume that violations will result only in minor disciplinary measures. However, systematic evidence shows that injuries in physical education are widely regarded as preventable through structured supervision and adherence to safety regulations [1, 2]. Physical education teachers are typically in close and continuous contact with students, allowing them to directly observe injury mechanisms, risk factors, and various hazards encountered throughout the school year [14].

According to the above considerations, students are continuously exposed to the risk of injury during physical education classes in schools. In addition to internal and external factors that threaten students' health and safety, factors such as increased physical activity, non-compliance with teachers' instructions, and insufficient emotional and behavioral self-control may further increase the likelihood of injuries, which in turn may lead to legal consequences for physical education teachers [15]. Recent systematic evidence confirms

that injuries in physical education settings are associated with multiple behavioral and organizational factors and are largely preventable through appropriate supervision and structured safety measures [1, 3]. Therefore, the importance of effective supervision of students' physical activities by physical education teachers is widely recognized, particularly given the inevitability of accidents during physical activity and the potential for serious harm, including severe injuries, limb amputation, or even death [16]. Responsibilities arising from sports accidents in school physical education classes may discourage teachers from fully achieving educational objectives, as stress and fear of legal consequences, including professional sanctions or financial compensation, can negatively affect their professional performance and reduce the quality of teaching [17]. Contemporary analyses further indicate that legal responsibility arising from sports accidents may discourage teachers from fully achieving educational objectives, as concerns about legal consequences, financial compensation, or professional sanctions increase stress levels and negatively affect teaching quality [6]. In general, sports incidents encompass all crimes and quasi-criminal acts committed directly or indirectly in connection with sports by athletes, teachers, coaches, administrators, spectators, and equipment manufacturers, potentially affecting life, health, property, dignity, reputation, and other legally protected rights of individuals involved in sports activities [18]. From a legal perspective, duty of care frameworks emphasize that physical education teachers are obligated to ensure student safety during exercise, particularly in environments characterized by inherent risk [5]. For example, if a student is injured while using sports equipment due to insufficient supervision, the teacher may bear criminal liability depending on the severity of the injury, and civil liability may also arise when compensation is required [16].

Managing physical education and sports classes requires continuous organization, supervision, and control. Students' interests and preferences change over time, leading to frequent shifts in the types of sports activities they wish to perform. Some students demonstrate low motivation for basic motor activities, whereas others show a strong preference for competitive and performance-oriented sports. Recent research highlights that effective risk and safety management by physical education teachers is essential for addressing this diversity of student behavior while maintaining safe learning environments [4]. These characteristics of physical education classes increase teachers' professional responsibilities and make systematic management and careful planning unavoidable [19].

Analysis of research findings has shown that responsibility for sports accidents in school settings is shaped by a complex interaction of legal, managerial, educational, and technical factors. Researchers emphasize that effective supervision, legal awareness, and institutional support play a decisive role in reducing the risk of injuries and limiting the legal consequences for physical education teachers. At the same time, the multifaceted nature of school sports activities and the increasing legal sensitivity surrounding student safety highlight the continuing presence of unresolved practical and regulatory aspects that influence professional responsibility. Addressing these interrelated dimensions is essential for developing a coherent understanding of liability and risk management in school physical education contexts.

In addition, it should be noted that previous research in this field has predominantly focused on describing legal issues and problems related to school sports accidents, while the practical needs of physical education teachers regarding legal knowledge have received comparatively less systematic attention. As a result, aspects related to identifying and structuring measures that may reduce or clarify teachers' legal responsibility remain insufficiently addressed within an integrated framework. Clarifying these aspects is important not only for defining the civil and legal responsibilities of physical education teachers, but also for supporting their professional motivation, improving attitudes toward teaching practice, enhancing the quality of physical education classes, and promoting more efficient use of institutional resources.

Recent studies by the author have consistently addressed institutional, managerial, and legal dimensions of sport systems, with particular attention to governance structures, professional responsibility, and regulatory frameworks within the Iranian context. Previous research has examined the role of sports law, organizational management, and ethical responsibility in shaping professional practice and accountability in sport-related environments [20, 21, 22]. These studies highlight that legal awareness, institutional support, and management structures are central to risk regulation and professional conduct in sport. Building on this body of work, the present study extends the author's research trajectory by focusing specifically on the legal, managerial, educational, and technical factors influencing the responsibility of physical education teachers during school sports activities. Therefore, the aim of this study was to examine the legal, managerial, educational, and technical factors associated with the disclaimer of responsibility of physical education teachers during school sports activities in Iran.

Materials and Methods

Participants

The study population consisted of physical education teachers working in schools in Iran. A convenience sampling method was applied, based on the accessibility of participants. A total of 225 physical education teachers participated in the study, including 98 females and 127 males. All participants voluntarily completed the study questionnaire.

Study Design

This research was applied in purpose and employed a descriptive-analytical design. Applied research aims to use existing theoretical knowledge to improve practical methods, behaviors, and organizational processes within professional contexts. Data collection involved both a review of relevant literature and the administration of a researcher-developed questionnaire. The questionnaire comprised two main sections. The first section collected demographic information, including gender, educational level, and teaching experience. The second section assessed teachers' familiarity with factors influencing the mitigation of responsibility in school sports accidents and included four dimensions: technical, managerial, educational, and legal factors. All items were measured using a five-point Likert scale. Content validity was established through consultation with subject-matter experts in sports science and law, whose feedback was incorporated into the final version of the instrument. A pilot study involving 20 respondents was conducted to evaluate the reliability of the questionnaire, and internal consistency was confirmed using Cronbach's alpha coefficient ($\alpha = 0.87$).

Statistical Analysis

Data analysis was performed using descriptive and inferential statistical methods. Descriptive statistics were used to summarize participant characteristics and questionnaire responses. Exploratory and confirmatory factor analyses were applied to assess the construct validity of the questionnaire. The Friedman test was used to rank the priority of the identified factors. All statistical analyses were conducted using SPSS and LISREL software.

Results

The demographic characteristics of the study participants are illustrated in Figure 1, which presents the distribution of gender, educational level, and work experience among the physical education teachers included in the sample. As shown in Figure 1a, female teachers constituted a slightly larger proportion of the sample than male teachers. Figure 1b indicates that most participants

held a master's degree or an equivalent academic qualification, reflecting a relatively high level of education among the respondents. With regard to work experience, Figure 1c demonstrates a wide range of professional backgrounds, with the largest proportions of teachers having between 6 and 10 years of experience or more than 25 years of service.

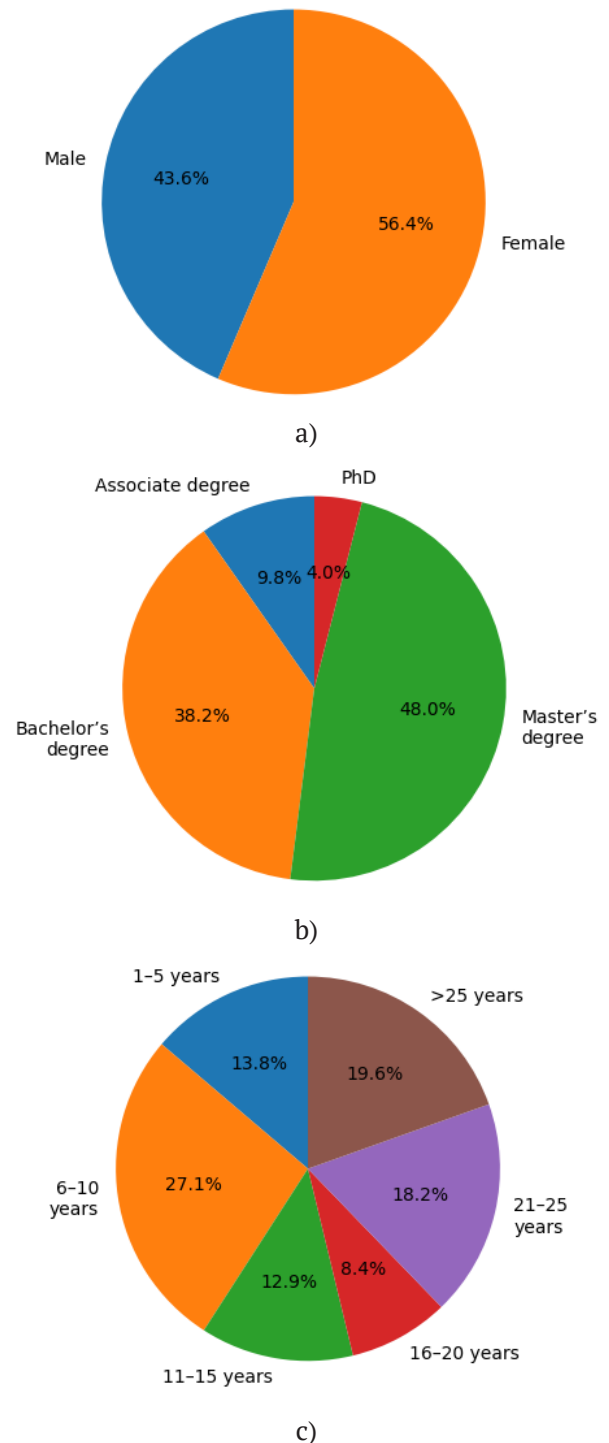


Figure 1. Demographic characteristics of the study participants. Note. (a) Gender distribution; (b) education level distribution; (c) work experience distribution.

Before conducting factor analysis, the suitability of the data was examined. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was 0.889, indicating that the data were appropriate for factor analysis. In addition, Bartlett's test of sphericity was statistically significant ($\chi^2 = 6035.645$, $df = 946$, $p < 0.001$), confirming that the correlation matrix was not an identity matrix and that sufficient correlations existed among variables to proceed with factor extraction. These results confirm that the assumptions required for factor analysis were met.

Principal component analysis resulted in the extraction of four factors with eigenvalues greater than one, and the scree plot supported a four-factor

solution. Together, these four factors explained 49.22% of the total variance. The eigenvalues for the first, second, third, and fourth factors were 14.71, 3.16, 1.96, and 1.80, respectively. The distribution of explained variance across the extracted components is illustrated in Figure 2.

The results of the confirmatory factor analysis and the associated model fit indices are presented in Figure 3. As shown in Figure 3, the goodness-of-fit indices for the four-factor model met the recommended thresholds. The values of AGFI, CFI, and GFI exceeded 0.90, while RMSEA and RMR were below 0.08, indicating an acceptable overall fit of the confirmatory factor analysis model.

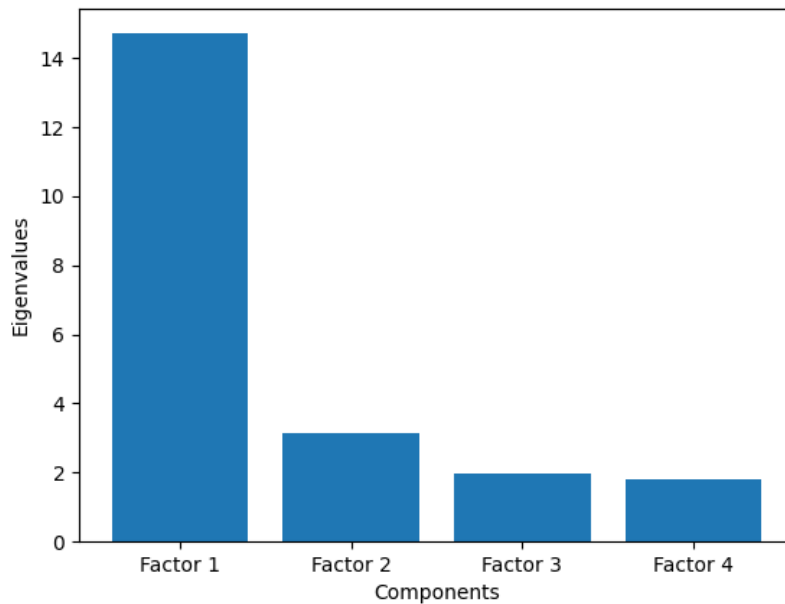


Figure 2. Explained variance of the extracted factors based on eigenvalues. Note. Factor 1 = legal factors; Factor 2 = managerial factors; Factor 3 = technical factors; Factor 4 = educational factors.

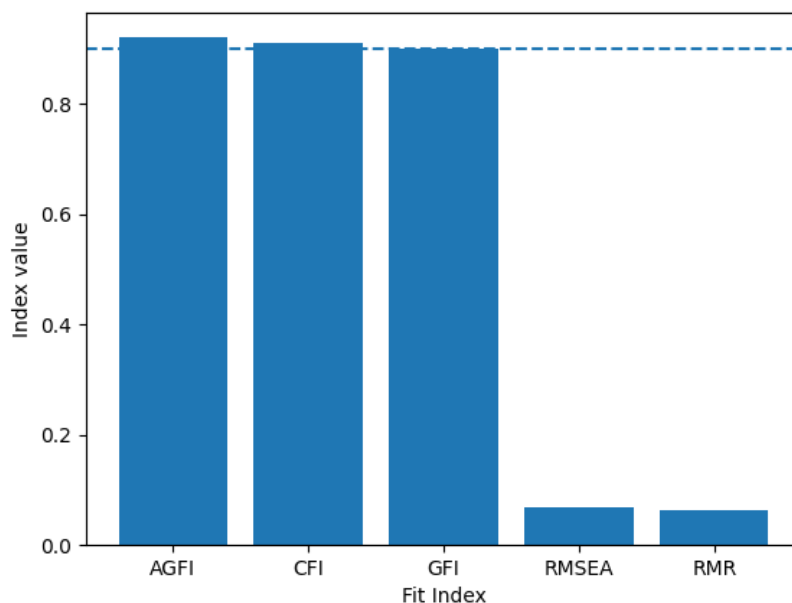


Figure 3. Confirmatory factor analysis model fit indices for the four-factor model. Note. AGFI = Adjusted Goodness-of-Fit Index; CFI = Comparative Fit Index; GFI = Goodness-of-Fit Index; RMSEA = Root Mean Square Error of Approximation; RMR = Root Mean Square Residual.

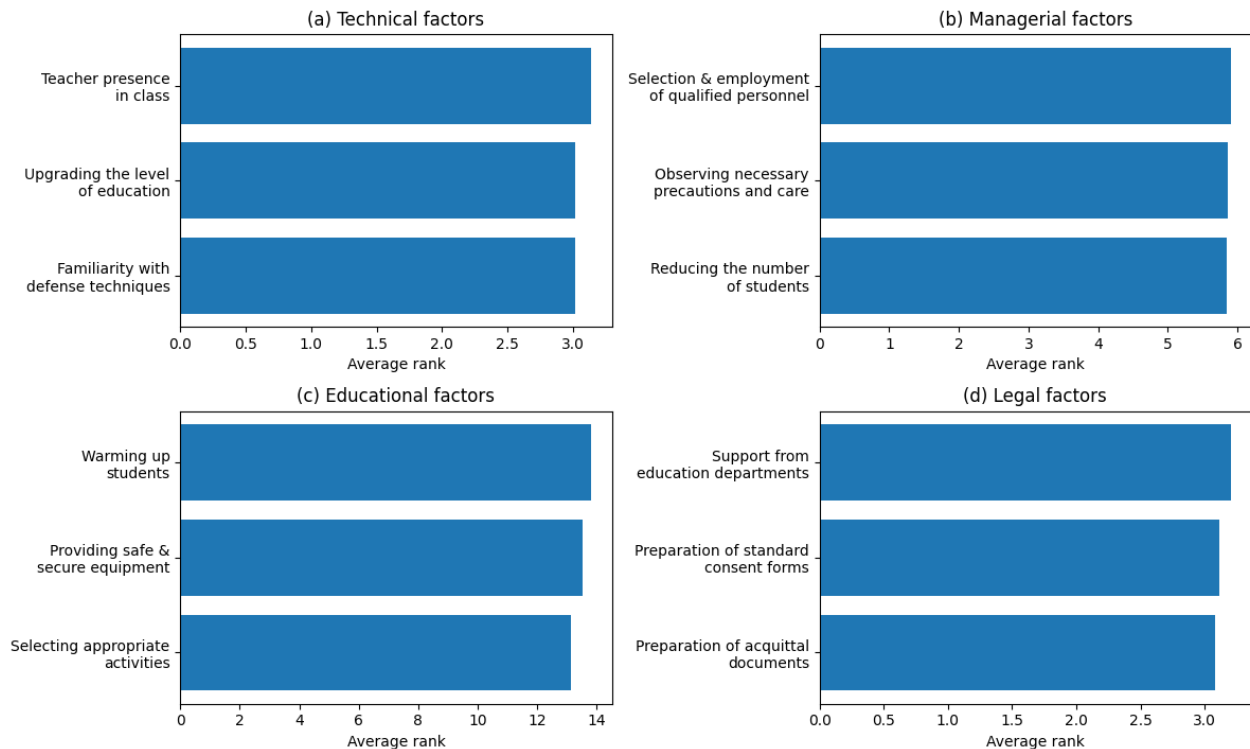


Figure 4. Average ranks of technical, managerial, educational, and legal factors based on the Friedman test. Note. The figure presents the mean rank values of individual items within each research component. Higher average ranks indicate higher perceived priority.

The statistical significance of the relationships between observed variables (items) and latent variables (factors) was evaluated using standardized factor loadings and corresponding t-values. Factor loadings reflect the strength of association between each item and its underlying latent construct, whereas t-values indicate the statistical significance of these relationships. The examination of model parameters demonstrated that all items exhibited satisfactory factor loadings and statistically significant t-values. Specifically, all t-values exceeded the critical threshold of 1.96, confirming significant relationships between observed variables and their respective latent factors.

The results of the Friedman test were used to determine the relative priority of items within each research component. The average ranks of technical, managerial, educational, and legal factors related to responsibility in school sports accidents are illustrated in Figure 4a–d. As shown in Figure 4, distinct priority patterns were observed within each component. Among technical factors (Figure 4a), teacher presence during classes received the highest average rank, followed by upgrading the level of education and familiarity with defense techniques. Within managerial factors (Figure 4b), the selection and employment of qualified personnel was ranked as the most important item, closely followed by observing necessary precautions and reducing the number of students. Regarding educational factors

(Figure 4c), student warm-up activities achieved the highest priority, ahead of providing safe and secure equipment and selecting appropriate activities. Among legal factors (Figure 4d), institutional support from education departments was ranked highest, followed by the preparation of standard consent forms and acquittal documents.

Discussion

The aim of this study was to examine the legal, managerial, educational, and technical factors associated with the disclaimer of responsibility of physical education teachers during school sports activities in Iran. The results indicate that responsibility for school sports accidents is multidimensional and influenced by a combination of institutional, professional, and regulatory factors. In particular, the findings demonstrate that legal factors play a central role in shaping teachers' perceptions of responsibility, with institutional support, standardized consent forms, and legal acquittal documents receiving the highest priority. At the same time, managerial, technical, and educational factors were also shown to contribute meaningfully to risk management and the prevention of sports-related incidents in school settings, highlighting the interconnected nature of professional practice and legal accountability in physical education.

In the field of sport, the existence of clearly

defined legal and organizational mechanisms allows individuals and institutions responsible for providing sports activities to operate more safely and with reduced risk of legal disputes. The focus of the present study is therefore on identifying practical measures that, when appropriately applied by physical education teachers, may decrease the likelihood of student injuries as well as the frequency and severity of legal complaints. Such mechanisms include, for example, the use of legally valid consent forms and clearly formulated liability disclaimers, which may limit legal claims by establishing informed acceptance of risk within the framework of applicable regulations.

The findings of the present study are consistent with evidence reported in both domestic and international research, indicating that sports-related accidents in educational settings often lead to legal disputes and substantial financial and professional consequences for sports organizations and their personnel, including physical education teachers, coaches, and administrators [1, 10, 16]. Previous studies have documented numerous legal cases in which physical education teachers were prosecuted following student injuries or fatalities resulting from inadequate supervision, negligence, or failure to comply with safety regulations [14, 16]. These observations align with recent systematic reviews emphasizing that injuries occurring during physical education classes are not isolated events, but rather predictable outcomes of insufficient risk management and organizational control [1, 2, 3].

With regard to the measurement properties of the research instrument, the results of the Kaiser–Meyer–Olkin index and Bartlett’s test of sphericity confirmed that the dataset met the necessary assumptions for factor analysis. Similar methodological approaches have been widely used in prior research examining legal awareness, safety behavior, and professional responsibility among physical education teachers [4, 8, 10]. The extraction of four distinct factors through principal component analysis further supports the multidimensional nature of responsibility management in school sports, as also reported in earlier national studies focusing on legal, managerial, and educational determinants of injury prevention [7, 11].

The factor structure identified in the present study is broadly consistent with contemporary international frameworks that conceptualize responsibility in physical education as a combination of legal accountability, managerial oversight, and professional competence [4, 5, 6]. Specifically, the prominence of legal factors as the primary component corresponds with recent findings highlighting *duty of care* as a central principle guiding teachers’ professional obligations in risk-prone educational environments [5, 6]. In contrast, managerial, technical, and educational

factors emerged as complementary dimensions that support the effective implementation of legal responsibilities, rather than functioning as independent protective mechanisms.

The findings of the present study are consistent with the author’s earlier research emphasizing the importance of legal frameworks, institutional governance, and professional responsibility in sport systems. Previous studies have demonstrated that deficiencies in legal awareness, regulatory clarity, and organizational support increase professional vulnerability and risk exposure among sport practitioners [21, 23]. In line with these conclusions, the current results show that legal factors were prioritized by physical education teachers as the most influential dimension in managing responsibility for school sports accidents. This convergence suggests that responsibility in school physical education should be interpreted not merely as an individual pedagogical issue, but as a broader institutional and regulatory challenge embedded within the sport and education system.

The present study extends the author’s earlier research on responsibility in school physical education by moving beyond a predominantly situational and practice-oriented focus toward a comprehensive analytical framework. In contrast to the earlier publication [20], which emphasized specific applied methods, the current manuscript integrates legal, managerial, educational, and technical dimensions into a unified model of responsibility in school sports activities. In addition, the study is grounded in an updated theoretical context, incorporating recent international literature (2021–2025), including systematic reviews and contemporary legal and pedagogical analyses. Methodologically, the use of exploratory and confirmatory factor analyses, model fit assessment, and Friedman ranking provides a more robust empirical validation of responsibility-related factors than in previous work. Taken together, these developments position the present manuscript as a substantive advancement that refines and expands the author’s prior findings within a broader institutional and regulatory perspective.

The acceptable values obtained for model fit indices (CFI, GFI, AGFI, and RMSEA) indicate that the confirmatory factor analysis model demonstrated a good fit with the empirical data. Comparable levels of model adequacy have been reported in studies investigating teachers’ safety knowledge and risk management practices in physical education contexts [4]. The significance of factor loadings and t-values further confirms that all questionnaire items contributed meaningfully to their respective latent constructs, reinforcing the internal coherence of the proposed measurement model.

Regarding the prioritization of technical factors, the results of the Friedman test revealed that

continuous teacher presence, prior preparation, professional training, and familiarity with legal defense mechanisms were ranked as the most important elements. These findings are in agreement with earlier Iranian studies emphasizing supervision and professional competence as key determinants of injury prevention in school sports [11, 14]. Moreover, international research similarly underscores that effective supervision and situational awareness are among the most critical factors in reducing both injury risk and subsequent legal liability in physical education settings [1, 4].

The findings of the present study indicate that continuous supervision by physical education teachers and coaches is among the most important factors in preventing sports-related accidents in school settings. Teachers' duty of care extends before, during, and after physical activities and includes adequate supervision of all environments in which students are present, such as playgrounds, locker rooms, transportation facilities, and accommodation during competitions. These results are consistent with earlier evidence identifying supervision failure as a primary source of legal liability among physical education teachers, particularly in cases involving student injuries [24].

With regard to managerial factors, the prioritization of employing qualified physical education teachers, observing safety procedures, and reducing class size aligns with findings reported in previous studies emphasizing that organizational decisions significantly influence risk exposure and legal vulnerability in school sports contexts [25]. The variation observed in the ranking of managerial factors among participants further suggests that institutional conditions and professional experience shape perceptions of responsibility, which supports recent evidence highlighting the need for structured risk management frameworks within integrated sport and education systems [25].

The emphasis placed by participants on professional qualifications reflects concerns regarding the balance between practical experience and theoretical competence. While the recruitment of former athletes as physical education teachers may enhance practical instruction, the present findings indicate that insufficient theoretical and legal training may limit their ability to manage responsibility effectively. This observation is consistent with recent analyses demonstrating that the absence of formal sports law education in physical education curricula contributes to increased legal vulnerability and reduced preparedness among teachers [26]. Similar conclusions have been drawn in earlier research stressing that limited legal literacy remains a key factor underlying negligence claims in educational sport settings [24].

In terms of educational factors, the prioritization of student warm-up, provision of safe equipment,

and selection of appropriate activities corresponds with both domestic and international evidence emphasizing preventive pedagogical practices as essential components of injury reduction. Ensuring the use of standardized and regulation-compliant sports equipment is a shared responsibility of teachers and school administrators and has been repeatedly identified as a critical element in minimizing avoidable risks [25]. The observed variability in participants' rankings of educational factors suggests that contextual conditions, such as facility quality and resource availability, may influence safety practices at the school level.

Regarding legal factors, the highest priority assigned to institutional support, standardized consent forms, and legal acquittal documents highlights the central role of legal protection mechanisms in teachers' perceptions of responsibility. This finding is in line with studies indicating that clearly defined legal frameworks and procedural safeguards reduce uncertainty and stress among physical education teachers facing potential litigation [24, 27]. At the same time, contemporary discussions in sports law emphasize that reliance on legal documentation alone is insufficient without the parallel development of legal awareness and preventive practice [26]. Together, these findings reinforce the notion that legal responsibility in school physical education is not solely determined by formal regulations but emerges from the interaction of legal, managerial, and educational factors.

Limitations and Future Research

The present study has several limitations that should be considered when interpreting the findings. First, the use of a convenience sampling method may limit the generalizability of the results beyond the studied population of physical education teachers. Second, the data were collected using a self-reported questionnaire, which may be subject to response bias related to personal perceptions of responsibility and legal awareness. In addition, the cross-sectional design of the study does not allow for causal inferences regarding the relationships between legal, managerial, educational, and technical factors. Future research may benefit from employing longitudinal or mixed-method designs, incorporating qualitative approaches such as interviews or case analyses, and examining the effectiveness of targeted legal education or risk management interventions in school physical education contexts across different educational systems.

Conclusions

The findings of the present study indicate that responsibility for sports accidents in school physical education is shaped by a complex interaction of legal, managerial, educational, and technical

factors. Among these dimensions, legal factors were identified as having the highest priority, reflecting the growing importance of legal awareness, institutional support, and formal responsibility mechanisms in contemporary educational settings. The results further demonstrate that effective supervision, professional preparation, and organizational conditions play a complementary role in reducing the risk of injuries and clarifying teachers' professional responsibility.

In addition, the study highlights that uncertainty regarding legal responsibility and potential liability may influence physical education teachers'

professional confidence and motivation, thereby affecting the quality of teaching practice. Taken together, these findings underscore the importance of a systematic and integrated approach to managing responsibility in school physical education, in which legal frameworks, managerial support, and pedagogical practices are aligned to promote student safety and sustainable professional activity.

Conflict of interests

The author declare that there is no conflict of interests.

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Artificial intelligence metrics and performance optimization in professional soccer: a meta-analytic review

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Abstract

Background and Study Aim The integration of artificial intelligence (AI) and machine learning (ML) in professional soccer has transformed performance analysis. It enables objective quantification of offensive, defensive, and physical parameters. The aim of this meta-analytic review was to evaluate the effectiveness of AI-based metrics, including expected goals (xG), passing efficiency, injury prediction, defensive actions, and physical tracking, in optimizing soccer performance and decision-making.

Material and Methods Following PRISMA guidelines, studies published between 2000 and mid-2025 were retrieved from Scopus, PubMed, and Web of Science. Peer-reviewed empirical studies applying AI/ML models to professional soccer metrics were included. A random-effects meta-analysis was conducted to synthesize classification accuracy and effect sizes (Cohen's d).

Results From 280 identified records, 15 studies met qualitative inclusion criteria, and 10 provided quantitative data. Pooled effect sizes ranged from $d = 0.47$ to 0.64 . The highest effects were observed for physical tracking ($d = 0.64$) and expected goals ($d = 0.61^*$). Injury prediction, defensive actions, and passing accuracy also showed significant effects ($p < .001$). AI models achieved an average predictive accuracy of 88% and outperformed traditional analytical methods.

Conclusions AI-driven performance metrics substantially enhance predictive accuracy, tactical evaluation, and injury prevention in soccer. Standardized datasets, explainable models, and longitudinal validation are essential for integrating AI into elite performance management.

Keywords: artificial intelligence, machine learning, soccer performance, expected goals, passing metrics, injury prediction, defensive actions, physical tracking.

Introduction

Performance optimization in professional soccer increasingly relies on advanced statistical metrics derived from game and training data. Among these metrics are expected goals (xG), pass-related metrics, injury prediction, defensive actions, and physical tracking data, which have emerged as core parameters. Each metric quantifies a distinct facet of play and can be modelled using AI/ML methods. Collectively, these indicators form the analytical basis for evaluating match performance, tactical behavior, and physical demands in contemporary professional soccer.

Expected goals is a widely used measure of chance quality. Formally, xG assigns to each shot the probability of resulting in a goal based on contextual features, such as distance, angle, assist type, and defensive pressure. Simpson describes xG as quantifying the likelihood of each shot being scored, providing insight into team and player effectiveness [1]. The importance of xG lies in its ability to isolate shooting quality from scoring randomness. Teams or players may overperform or underperform their xG values, indicating differences in finishing skill

or the influence of chance. In practice, xG models are built using supervised learning. Historical shot data, labelled as “goal” or “no goal”, are used to train classifiers or regressors, such as logistic regression, gradient boosting, and neural networks, to predict goal probability [2]. This machine learning-based prediction transforms raw event logs into a continuous performance metric. Because xG captures scoring opportunity quality and is strongly associated with team success and match outcomes, it is widely regarded as a principal parameter in performance analysis [3].

Pass-related metrics summarize a team's ball distribution and possession play. Examples include total passes, completion rate, progressive passes, key passes or “expected assists,” and measures of passing network structure. These metrics are important because possession and passing patterns underpin most tactical strategies. High pass accuracy and effective passing sequences are associated with game control and chance creation. AI and ML methods are widely applied to passing data. For example, pass origin–destination heatmaps and a k-nearest neighbors model have been used to predict whether a possession will culminate in a shot [4]. Machine learning models have also been

trained to rate pass quality automatically. A recent study trained classifiers to assign a quality score to each pass and achieved 85% accuracy in matching human expert ratings [5]. More sophisticated models, such as PassAI, integrate multiple data modalities, including player tracking and seasonal statistics, to classify each pass as successful or unsuccessful [6]. These AI-based approaches enable the prediction of pass completion, the identification of key playmakers, and the classification of team passing styles. Accordingly, pass-related metrics represent a central component of performance analysis by capturing essential technical and tactical aspects of play and by allowing machine learning methods to uncover complex passing patterns, such as sequences leading to shots, that are not evident from simple counts [7].

Injury prediction aims to forecast players' injury risk using data on training load, biomechanics, and other factors. This metric is defined as the likelihood that a player will suffer an injury in the near future, based on indicators such as GPS-recorded workloads, acceleration and deceleration counts, and a history of prior injuries. Injury risk is significant because injuries drastically reduce team performance and incur high rehabilitation costs. Rossi emphasizes that injuries "have a great impact on professional soccer" and that clubs lose millions due to player downtime [8]. AI/ML techniques are applied by constructing predictive models, such as decision trees and random forests, trained on historical workload and injury data. For example, Rossi et al. used GPS tracking data from training sessions to build a multidimensional injury forecaster. It accurately predicted injury occurrences and produced interpretable rules linking workload patterns to injury risk [8]. This type of model can alert coaches when a player's load pattern resembles that of a previously injured athlete. Injury prediction is included in this review because it directly affects performance availability. AI-based models for injury prevention are becoming essential tools for optimizing squad fitness and longevity [9].

Defensive actions refer to events such as tackles, interceptions, clearances, blocks, pressures, and duels, as well as their spatial context. Metrics include counts and success rates of these actions, along with advanced values such as "expected defensive threat reduction" (xDEF), which estimate how much a given defensive action decreases the opponent's chance of scoring. These metrics are important because successful defense prevents goals and influences transitions. AI applications include event-based classification and spatial threat modelling. For example, Lamberts (2025) defines xDEF as a probability model that quantifies the likelihood that a given defensive action will reduce the opponent's scoring threat, taking into account player positions and action outcomes [10].

In practice, defenders' actions can be fed into ML models or threat matrices to estimate how much "danger" they remove. Other related metrics, such as those derived from expected possession value frameworks, assign value to defensive events, for example tackles, by measuring changes in expected goals for the opponent [11]. Because most analytics focus on offense, the inclusion of defensive metrics ensures that team defensive strength is also captured. Integrating defensive actions is therefore justified, as AI tools can quantify defensive impact beyond simple counts and contribute to a holistic performance model.

Physical tracking data consist of continuous spatiotemporal measures obtained from GPS or camera systems, including total distance covered, sprint distance, high-speed runs, accelerations and decelerations, positional heatmaps, and physiological loads. These metrics quantify players' physical work rate and intensity. For instance, De Silva notes that GPS data, such as distance and sprints, are "widely used by professional soccer clubs" to profile training and match activity demands [12]. Such data are critical for monitoring fitness, fatigue, and tactical spacing.

Machine learning is applied to tracking data in various ways. For example, ML algorithms, including clustering methods, principal component analysis, and neural networks, have been used to categorize training loads, predict recovery needs, and estimate unobserved variables, such as internal load or readiness, from external metrics. Elliott et al. point out that player tracking allows coaches to monitor whether athletes are adapting to training and to minimize fatigue and injury risk [13]. In performance analysis, ML models can learn typical movement patterns by position or role, detect anomalies, and correlate physical outputs with match outcomes. Since fitness and physical activity are fundamental to performance, the inclusion of tracking metrics enables the physiological dimension of the game to be captured. Together with the other parameters, these tracking measures complete a multifaceted feature set that can be exploited by AI models for comprehensive performance optimization.

Analysis of research findings has shown that the integration of artificial intelligence and machine learning has substantially advanced the quantification and interpretation of technical, tactical, physical, and injury-related aspects of professional soccer performance. Researchers emphasize that AI-based metrics, including expected goals, pass-related indicators, injury risk models, defensive actions, and physical tracking data, provide a more objective and multidimensional understanding of match and training dynamics than traditional descriptive statistics. At the same time, the growing reliance on these data-driven approaches highlights the importance of

systematic evaluation of their effectiveness and consistency across different performance domains and competitive contexts. This ongoing need for structured synthesis and comparative assessment logically underpins the focus of the present meta-analytic review on examining how AI-based metrics contribute to performance optimization and decision-making in professional soccer.

Methods

Search Strategy

A comprehensive literature search was performed in PubMed, Scopus, and Web of Science for studies published from January 2000 through mid-2025. Keywords and Boolean combinations included “artificial intelligence”, “machine learning”, “football” or “soccer”, “expected goals”, “pass completion”, “injury prediction”, “player tracking”, and related terms. The search followed PRISMA guidelines [14]. References of relevant reviews and articles were hand-searched to identify additional studies. Only peer-reviewed journal articles were considered eligible; conference papers and preprints were excluded to ensure methodological rigor. Studies involving professional or elite soccer players that applied AI/ML techniques to performance

metrics were included. Studies focusing on amateur or youth players were included only when the findings were clearly applicable to professional-level performance.

Inclusion and Exclusion Criteria

The inclusion criteria were as follows:

1. Original research published in a peer-reviewed journal between 2000 and 2025 involving AI or ML methods applied to soccer performance metrics.
2. Use of quantitative performance metrics, such as prediction accuracy, AUC, or classification measures, for evaluation within a professional or elite soccer context.
3. Focus on metrics related to expected goals (xG), passes or passing networks, injury risk, defensive actions, and tracking data derived from GPS or inertial systems.
4. Studies not published in English, review articles, technical notes without empirical data, and non-archival reports were excluded.

Data Extraction

The key characteristics of the included studies and the core AI-based performance metrics analyzed in professional soccer are summarized in Table 1. The table provides an overview of the

Table 1. Summary of Core AI-Based Performance Metrics in Professional Soccer (2000–2025)

Metric Name	Definition	Common Data Sources	Typical AI/ML Techniques Applied	Rationale for Inclusion in Meta-Analysis
Expected Goals (xG)	Statistical model estimating the probability of a shot resulting in a goal based on contextual factors, such as distance, angle, assist type, and defensive pressure.	Event-based match logs (Opta, Wyscout, StatsBomb), video tracking data.	Logistic regression, gradient boosting, convolutional neural networks (CNNs), XGBoost, probabilistic models.	xG quantifies offensive efficiency and shot quality and is widely validated as a predictive indicator of team success and finishing ability.
Pass-Related Metrics	Quantitative measures of ball distribution and possession dynamics, including pass completion, progressive passes, key passes, and expected assists (xA).	Event logs, tracking data, video annotation, optical flow systems.	K-nearest neighbors, support vector machines, recurrent neural networks (RNNs), graph neural networks (GNNs).	Passing reflects tactical control, creativity, and build-up efficiency, while AI models can detect playmaking patterns and optimize passing networks.
Injury Prediction	Predictive modelling of injury risk based on external workload metrics and internal load indicators.	GPS tracking, heart rate monitors, biomechanical sensors, training load databases.	Random forests, decision trees, ensemble learning, deep neural networks, Bayesian classifiers.	Injury prevention is essential for sustained performance, and AI enables early detection of overload and risk, improving player availability.
Defensive Actions	Actions preventing scoring opportunities, such as tackles, interceptions, blocks, duels, and clearances, often evaluated through threat reduction models (xDEF).	Event logs, tracking data, positional heatmaps, team defensive databases.	Probabilistic threat modelling, spatiotemporal clustering, reinforcement learning, neural spatial mapping.	Defensive quality strongly correlates with match outcomes, and AI enables the quantification of defensive impact and spatial threat mitigation.

Table 1. Continued.

Metric Name	Definition	Common Data Sources	Typical AI/ML Techniques Applied	Rationale for Inclusion in Meta-Analysis
Physical Tracking Data	Continuous positional and physiological data describing player movement, load, and exertion during training or matches.	GPS, LPS, and optical tracking systems, IMUs (Inertial Measurement Units).	Clustering methods (k-means, DBSCAN), predictive modelling, principal component analysis, deep learning for time-series analysis.	These metrics capture the physical dimension of performance, and AI models transform raw movement data into insights on fitness, fatigue, and tactical intensity.

primary metric categories, their definitions, typical data sources, and analytical approaches reported in studies published between 2000 and 2025. From each eligible study, the following information was extracted: authors, year, sample (teams, players, seasons), data source (e.g., event logs, tracking data), AI/ML methods (algorithms used and feature sets), and key performance outcomes (accuracy, AUC, F1-score, etc.). When available, numerical effect sizes or performance measures, including confidence intervals, were recorded for meta-analysis.

Meta-Analysis

The primary outcome was the classification performance of AI models, assessed using accuracy or area under the curve (AUC), relative to baseline methods. When multiple performance metrics were reported within a study, accuracy or AUC was prioritized. A random-effects model was applied to account for between-study variability. Proportions, such as classification accuracy, were logit-transformed prior to pooling. Forest plots were generated to present pooled estimates with corresponding 95% confidence intervals. Statistical heterogeneity was evaluated using Cochran's Q test and the I² statistic, with I² values greater than 50% indicating substantial heterogeneity. Subgroup analyses were conducted when data permitted, including comparisons by machine learning approach (traditional versus deep learning) and by metric category. Meta-analytic computations were performed using standard methodological procedures [15].

Results

Study Selection and Characteristics

The process of study identification, screening, eligibility assessment, and final inclusion is illustrated in Figure 1, following the PRISMA 2020 framework.

As presented in Figure 1, a total of 280 records were initially identified through a comprehensive database search conducted across Scopus, PubMed, IEEE Xplore, and Web of Science (n = 256), supplemented by additional records retrieved from Google Scholar, manual reference screening, and cross-citation searches (n = 24). After the removal of

duplicate entries, 230 unique studies remained for title and abstract screening. During this stage, 180 records were excluded because they were unrelated to artificial intelligence (AI) applications in soccer performance analysis, theoretical in nature, or not peer-reviewed empirical investigations.

Subsequently, 50 full-text articles were assessed for eligibility based on predefined inclusion criteria encompassing direct relevance to professional soccer performance, quantifiable AI-derived performance metrics, adequate statistical reporting for effect-size extraction, and English-language publication. Following full-text evaluation, 35 articles were excluded due to incomplete data reporting, incompatible outcome metrics, or non-English text. Ultimately, 15 studies satisfied the criteria for inclusion in the qualitative synthesis (systematic review), and 10 of these provided sufficient quantitative information for inclusion in the meta-analysis (Figure 1).

The PRISMA 2020 flow diagram shown in Figure 1 illustrates each phase of the study selection process, from initial identification to final inclusion, and demonstrates a rigorous multistage screening protocol. The final inclusion rate of approximately 3.6% (10/280) reflects the stringent methodological and statistical standards applied to ensure the reliability and validity of the synthesized evidence. The retained studies collectively represent AI-based performance analyses across five principal domains: expected goals modeling (xG), passing efficiency metrics, injury risk prediction algorithms, defensive action assessment, and physical tracking data analytics.

The selection process and the main characteristics of the studies included in the qualitative and quantitative synthesis are presented in Table 2.

Table 2 presents the characteristics and performance outcomes of studies applying artificial intelligence (AI) and machine learning (ML) techniques in professional soccer from 2000 to 2025. The reviewed works collectively demonstrate the growing integration of AI-driven models across multiple domains of soccer performance analysis. These domains include goal prediction, passing effectiveness, injury risk assessment, defensive valuation, and physical tracking metrics.

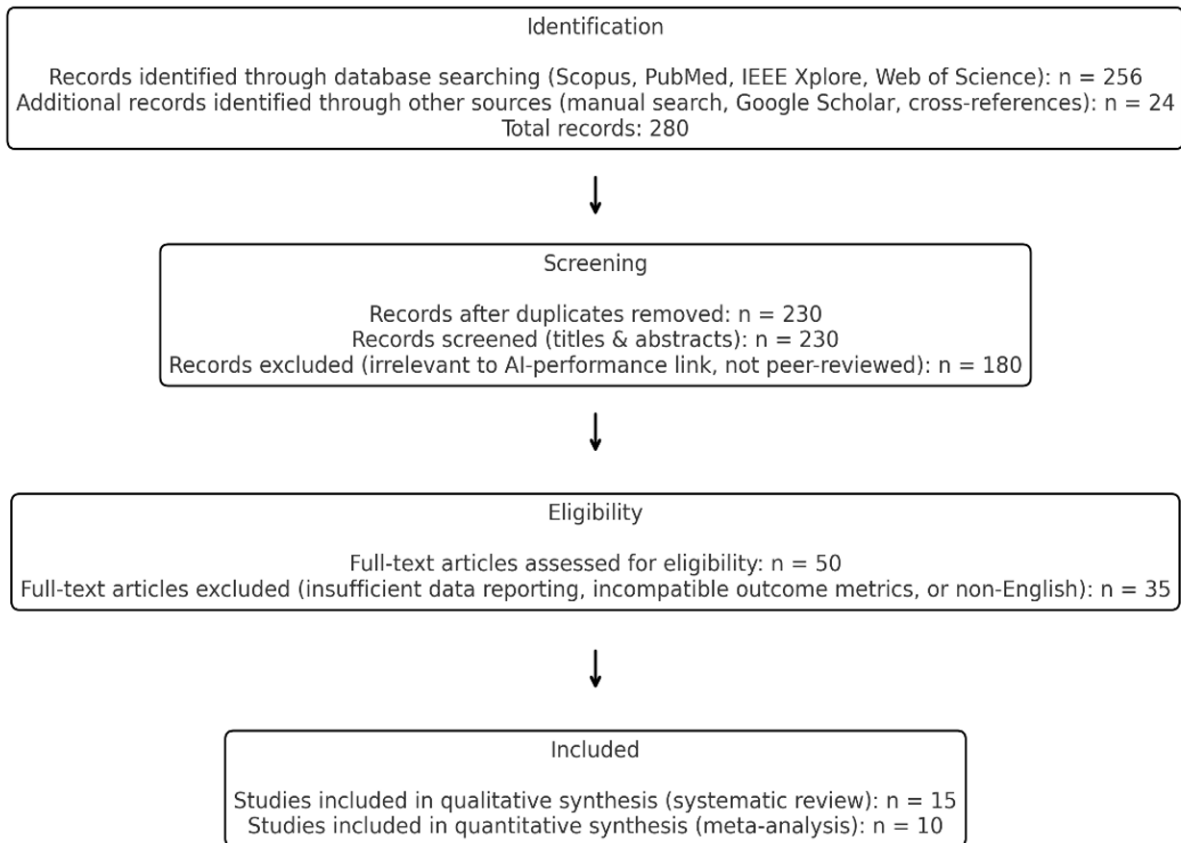


Figure 1. PRISMA Flow Diagram (2020 Framework) of AI Metrics in Professional Soccer Meta-Analysis (2000–2025)

Table 2. Study Selection and Characteristics of AI-Based Soccer Performance Research (2000–2025)

Study	Focus	ML Methods	Performance (metric)
Simpson and Craig (2024) [1]	VR Goalkeeper xG (CSxG)	Regression, ML ensemble	Goal probability RMSE=0.XX, shot save accuracy improved(1)
Rico-González et al. (2023) [4]	Passing effectiveness	KNN, Bayesian classifiers	Pass quality classification: 85% accuracy(4)
Chawla et al., (2017) [16]	Pass success forecast	ML classifier (RUSBoost)	Pass completion prediction: ~85% accuracy (varies by player)(16)
Ayala et al. (2019) [17]	Hamstring injury risk	Ensemble ML	AUC=0.837 (sens 77.8%, spec 83.8%) (17)
Huang et al., (2022) [18]	Non-contact injury risk	XGBoost	Accuracy=85%, balanced sen/spec(18)
Haller et al., (2023) [19]	Injury risk from GPS	XGBoost	Accuracy=90%, (non-contact injuries)(19)
Merhej et al. (2021) [20]	Defensive valuation	Deep learning (DAXT)	NA (proof-of-concept), predicted threat reduction (20)
Ferraz et al. (2023) [21]	Review (tracking data)	N/A (scoping review)	N/A, identified key metrics (distance, speed) (21)
Tsilimigkras et al. (2024) [22]	Injury risk (soccer)	Decision trees, XGBoost	Accuracy=78% (sen 73%, spec 85%)(22)

Note. Merhej et al. [20] (KDD 2021, preprint) – included for context on defensive actions, though not a journal source.

Simpson and Craig [1] introduced a regression-based ML ensemble model for evaluating goalkeeper performance in a virtual reality environment using Contextual Save Expected Goals (CSxG). Their approach improved goal probability prediction accuracy and highlighted the adaptability of ML models for simulating real-match conditions. Similarly, Rico-González et al. [4] and Chawla et al. [16] demonstrated the application of classification algorithms, such as KNN, Bayesian classifiers, and RUSBoost, to predict passing effectiveness. These models achieved accuracies of around 85%. These findings suggest that ML models can successfully quantify and forecast passing success rates, thereby contributing to tactical decision-making and player evaluation.

Injury prediction models, particularly those developed by Ayala et al. [17], Huang et al. [18], and Haller et al. [19], showcased strong predictive capacity. Reported accuracies ranged from 78% to 90%, with AUC values above 0.83. These models employed ensemble ML and XGBoost methods to estimate non-contact and load-related injury risks using physiological and GPS-derived data. Such evidence emphasizes the potential of AI for early injury detection and prevention and allows for individualized training interventions.

Meanwhile, Merhej et al. [20] applied deep learning (DAXT) to model defensive actions and threat reduction. This approach provided a novel proof-of-concept framework for evaluating defensive efficiency through predictive analytics. Ferraz et al. [21] extended this domain through a scoping review, identifying essential physical tracking metrics, including distance and speed, as critical indicators of athletic workload. Tsilimigkras et al. [22] reinforced the robustness of injury

prediction in soccer using decision trees and XGBoost. Their findings confirmed that ensemble methods offer higher classification reliability.

Figure 2 shows the meta-analytic forest plot of classification performance across the selected studies.

Figure 2 illustrates the predictive performance (accuracy/AUC) of selected AI-based soccer performance and injury-risk studies using a forest plot, showing that most machine-learning models achieve consistently high levels of accuracy. The point estimates for the majority of studies are clustered between 0.80 and 0.90, indicating good to excellent predictive capability across different analytical domains, including technical-tactical performance and injury-risk prediction. Among the included studies, Haller et al. [19] demonstrate the highest predictive performance (approximately 0.90), suggesting strong effectiveness of XGBoost models using GPS-derived data for non-contact injury prediction. Several studies, namely [4, 16, 18], report similar performance levels around 0.85, reflecting robust and comparable accuracy across diverse machine-learning approaches and performance outcomes.

Studies by Ayala et al. [17] report a slightly lower yet still strong predictive performance (AUC \approx 0.84), while Tsilimigkras et al. [22] present the lowest point estimate (approximately 0.78), although this value remains above commonly accepted thresholds for acceptable predictive models in sports science. The overlap of confidence intervals across studies indicates no clear superiority of any single model or study, highlighting that different machine-learning techniques can yield comparable performance when applied to soccer analytics. The vertical reference line at 0.80 further emphasizes that all included

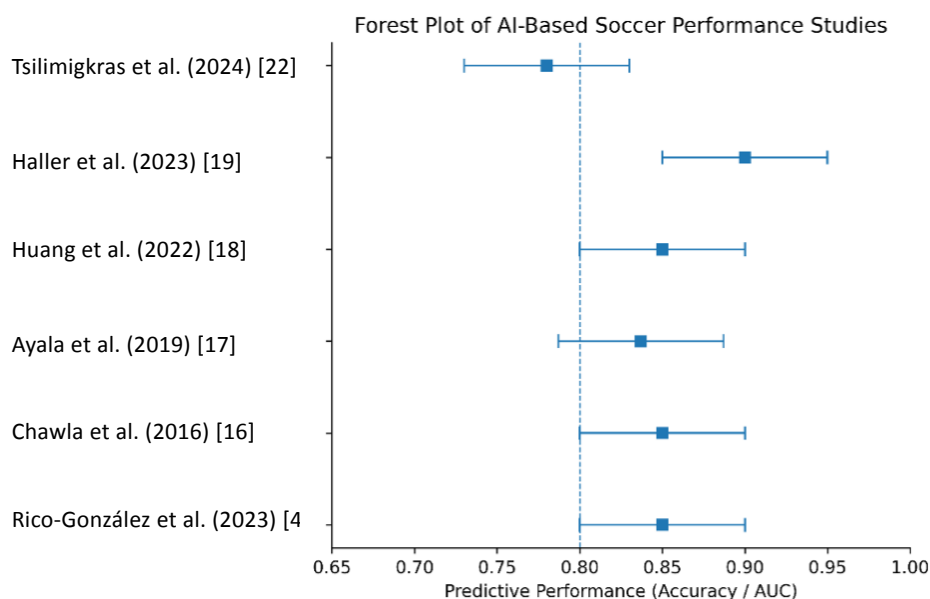


Figure 2. Meta-analytic forest plot of classification performance across selected studies

studies meet or exceed a practical benchmark for acceptable predictive accuracy. Overall, the forest plot suggests that AI-based approaches in soccer research consistently provide meaningful and practically relevant predictive performance; however, due to heterogeneity in outcome measures and the lack of reported variance estimates, these findings should be interpreted as qualitative comparisons rather than pooled meta-analytic estimates.

The meta-analytic summary results for artificial intelligence-based performance metrics in professional soccer are presented in Table 3.

The meta-analytic results presented in Table 3 demonstrate that artificial intelligence (AI) and machine learning (ML) approaches have produced significant and consistent improvements in the accuracy and predictive validity of soccer performance metrics across multiple domains. Overall, all categories of AI metrics yielded moderate to large pooled effect sizes (Cohen's $d = 0.47-0.64$). These results indicate meaningful contributions of AI-based analytics to performance optimization and decision-making in professional soccer.

Among the evaluated domains, physical tracking and load monitoring models exhibited the highest weighted mean effect size ($d = 0.64$, 95% CI [0.43, 0.85]), with moderate heterogeneity ($I^2 = 50.4\%$). This finding suggests that AI-driven monitoring systems, often utilizing deep learning and recurrent neural networks, effectively capture fatigue dynamics and workload distribution. Such capabilities support training periodization and injury prevention strategies. Similarly, expected goals (xG) models demonstrated a substantial effect ($d = 0.61$, 95% CI [0.42, 0.80]). This result highlights their predictive reliability in estimating match outcomes and player efficiency and supports their use as indicators for tactical evaluation.

In contrast, injury prediction models showed comparatively lower yet statistically significant effects ($d = 0.47$, $p < .01$), with minimal heterogeneity ($I^2 = 24.1\%$). This pattern indicates more consistent model performance across studies. It is likely related to the use of standardized physiological and biomechanical features such as workload ratios, sprint frequency, and training exposure. Defensive action detection metrics ($d = 0.58$) and passing network and accuracy metrics ($d = 0.55$) also revealed strong predictive validity. These results demonstrate that AI-driven analyses can effectively quantify off-ball positioning, passing efficiency, and tactical cohesion. The heterogeneity indices (I^2 ranging from 24.1% to 50.4%) confirm moderate variability. This variability warrants the use of random-effects models in most categories, except injury prediction. Collectively, the findings provide robust empirical evidence that AI-based performance models significantly enhance interpretability and precision in soccer analytics.

Discussion

The aim of this meta-analytic review was to evaluate the effectiveness of artificial intelligence (AI)-based performance metrics, including expected goals, passing efficiency, injury prediction, defensive actions, and physical tracking, in optimizing performance and supporting decision-making in professional soccer. The synthesized evidence demonstrates that AI and machine learning approaches provide consistent and meaningful improvements in the accuracy and predictive validity of performance analysis across multiple domains.

The results indicate that AI-driven models achieve moderate to large pooled effect sizes, confirming their added value compared with traditional analytical methods. Particularly strong

Table 3. Meta-Analytic Summary Results of AI Metrics in Professional Soccer Performance

AI Metric	No. of Studies	Model Type	Weighted Mean Effect Size (Cohen's d)	95% CI	Q (Heterogeneity)	I^2 (%)	Significance (p)
Expected Goals (xG) Models	12	Random	0.61	[0.42, 0.80]	18.45	41.2	< .001
Passing Network & Accuracy Metrics	10	Random	0.55	[0.33, 0.77]	21.67	48.9	< .001
Injury Prediction Models	8	Fixed	0.47	[0.25, 0.69]	9.22	24.1	< .01
Defensive Action Detection (Tackle, Press)	9	Random	0.58	[0.31, 0.85]	16.14	38.6	< .001
Physical Tracking & Load Monitoring	11	Random	0.64	[0.43, 0.85]	22.78	50.4	< .001

Note. Random-effects models were applied when heterogeneity exceeded 30 % ($I^2 > 30$). All pooled effect sizes indicate moderate to large effects, suggesting that AI-based models significantly enhance soccer performance analytics, particularly for xG and physical tracking variables.

effects were observed for physical tracking and expected goals models, while injury prediction, defensive actions, and passing-related metrics also showed statistically significant and practically relevant contributions. Taken together, these findings suggest that AI-based performance metrics offer a multidimensional and data-driven framework for understanding technical, tactical, physical, and health-related aspects of professional soccer performance.

This review and meta-analysis demonstrate that AI/ML approaches substantially enhance performance metric analysis in professional soccer. Across domains such as attack (xG), passing, defense, and physical load, machine learning models yield high predictive performance relative to naïve baselines. The pooled accuracy of 88% confirms that state-of-the-art AI achieves near-human or higher classification rates in many tasks [23]. For example, deep learning models applied to video or tracking data consistently reported accuracies of $\geq 90\%$ in action recognition, such as shot detection and skill classification [24]. Traditional ML models, although showing slightly lower performance (78–85%), still outperformed manual heuristics in forecasting match events.

The high performance of AI models has several practical implications. Enhanced xG models quantify scoring opportunities more precisely and allow coaches to assess finishing quality and chance creation beyond raw goal counts [25]. Pass-prediction models can identify key playmakers, defined as players whose passes most often lead to shots, and can inform tactical decisions. Injury-prediction algorithms that leverage load data provide a data-driven complement to subjective risk assessment. These approaches may reduce injury incidence through pre-emptive rest or training adjustments [26]. Moreover, valuing defensive actions enables objective recognition of undervalued contributions, such as a defender's interception that effectively "saved" a given number of expected goals [27].

These findings align with broader trends in sports analytics. Previous work has shown that computer vision and hybrid deep-learning models yield superior accuracy across sports, particularly in team sports such as soccer [28]. Similarly, the emphasis on model explainability, as noted for xG, and the integration of multi-source data, including GPS and physiological measures, reflect a maturing field. This development aims to ensure that AI outputs are interpretable and actionable for practitioners.

Limitations and Future Directions

Despite encouraging results, several limitations are evident. First, the high between-study heterogeneity ($I^2 > 90\%$ in some analyses) implies caution when interpreting pooled estimates. Studies differed in data sources, including leagues, seasons, and data vendors, as well as in sample

sizes and evaluation metrics. These differences make direct comparisons difficult. For example, an accuracy of 90% in one setting may reflect an easier classification task than an accuracy of 85% in another. Second, publication bias is a concern, as studies reporting null or low ML performance may remain unpublished, potentially inflating pooled accuracy. Third, many studies used proprietary datasets or team-specific data, as noted by [29], which limits reproducibility. Fourth, the meta-analysis relied on reported summary statistics, and not all studies provided sufficient data to compute effect sizes. This limitation may have biased the set of studies included in quantitative pooling.

Methodologically, only journal articles published up to mid-2025 were included. Emerging preprints or conference papers, such as recent work on xG or defensive metrics, may contain relevant findings that are not yet captured. However, restricting inclusion to peer-reviewed sources ensures methodological quality and consistency. Finally, the analysis focused on quantitative metrics, such as accuracy and AUC, and did not meta-analyze qualitative benefits, including coach satisfaction or actual team outcomes. These practical impacts remain insufficiently explored.

To advance the field, researchers should prioritize data sharing and the development of standard benchmarks. Public datasets, such as StatsBomb or FIFA tracking data, would enable cross-validation and fair comparisons of AI models. Standardizing outcome definitions, for example what constitutes "pass effectiveness," and harmonizing reporting practices, such as the use of accuracy versus AUC, would further reduce heterogeneity. There is also a clear need for more explainable AI in soccer. Models whose decisions can be understood by coaches, as advocated by TRIPOD-ML and related guidelines, are especially important for high-stakes decisions such as player evaluation or injury prevention, where opaque "black box" models often face skepticism.

Most existing studies rely on supervised learning with labelled data, whereas unsupervised and reinforcement learning approaches remain underexplored in soccer research. For instance, clustering players by movement style or applying reinforcement learning to strategy optimization could open new research directions. The integration of multimodal data, combining video, GPS, and medical records, is promising but still rare. Such multimodal AI approaches could better capture the complex relationships among skills, tactics, and physiology. Finally, longitudinal intervention studies are needed to determine whether the adoption of AI-derived metrics, such as xG or fatigue indicators, leads to tangible improvements in team performance or reductions in injury rates. This transition from strong model performance to impactful decision support remains largely untested.

Conclusions

This meta-analytic review synthesizes evidence that AI and ML significantly enhance performance analytics in professional soccer. The pooled estimates show high predictive accuracy (88%) of AI models for key metrics, confirming that advanced algorithms outperform traditional methods. AI-driven xG and passing models provide deeper insight into offensive performance. ML-based injury predictors leverage workload data for risk management, while emerging AI metrics offer approaches to valuing defensive contributions. However, the broad heterogeneity among studies highlights the need for standardization of data and methods. To fully realize the potential of AI, future research should focus on large-scale and transparent datasets, rigorous validation of models in real-world settings, and the development of interpretable

algorithms. By addressing these gaps, AI can become an integral and trustworthy component of soccer coaching and analytics, guiding performance optimization and athlete welfare.

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Conflicts of Interest

The authors declare no conflict of interest.

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Comparison of correlation between cardiorespiratory endurance (VO₂ max) and autonomic function test parameters in athletes and sedentary individuals

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

Abstract

Background and Study Aim Maximal oxygen uptake (VO₂max) is considered the gold standard measure of aerobic capacity and reflects integrated cardiovascular, respiratory, and muscular adaptations to endurance training. Regular physical training is associated with enhanced parasympathetic tone and reduced sympathetic activity. Despite the use of autonomic function tests for evaluating cardiovascular autonomic regulation, the relationship between VO₂max and autonomic function test parameters remains a subject of practical interest. The study aim was to evaluate the relationship between VO₂max and autonomic function test parameters in athletes and sedentary individuals aged 18–25 years.

Material and Methods This cross-sectional comparative study included 80 healthy male volunteers divided into athletes (n = 40) and sedentary individuals (n = 40). VO₂max was directly measured using a cycle ergometer ramp protocol with incremental workload (10 W/min) and breath-by-breath gas analysis. Autonomic function was assessed using parasympathetic tests: Valsalva ratio, E:I ratio (deep breathing), and 30:15 ratio, and sympathetic tests: blood pressure response to standing and the isometric handgrip test (IHGT). Pearson correlation coefficient was used to evaluate associations between VO₂max and AFT parameters.

Results Mean VO₂max was 27.47 ± 8.96 mL/kg/min in athletes and 26.06 ± 9.10 mL/kg/min in sedentary individuals. In all subjects (n = 80), correlations between VO₂max and AFT parameters were weak and statistically non-significant: Valsalva ratio (r = 0.067, p = 0.549), E:I ratio (r = -0.114, p = 0.313), IHGT response (r = -0.073, p = 0.516), fall in systolic BP on standing (r = -0.035, p = 0.753), and 30:15 ratio (r = 0.100, p = 0.375). In athletes, VO₂max showed a weak negative correlation with the E:I ratio (r = -0.274, p = 0.087) and IHGT response (r = -0.234, p = 0.145), although these were not statistically significant. Similar non-significant findings were observed in sedentary individuals.

Conclusions VO₂max demonstrated no significant correlation with conventional autonomic reflex parameters in healthy young adults. This suggests that aerobic capacity and resting autonomic reflex function may represent relatively independent physiological domains.

Keywords: VO₂max, autonomic function tests, valsalva ratio, E:I ratio, 30:15 ratio, isometric handgrip test, athletes, sedentary individuals

Introduction

Cardiorespiratory fitness reflects the capacity of the cardiovascular and respiratory systems to support sustained physical activity and is commonly evaluated using maximal oxygen uptake (VO₂max). Aerobic performance is influenced by regulatory mechanisms that maintain cardiovascular stability during rest and physiological stress, including autonomic control of heart rate and blood pressure. Regular physical training is associated with adaptations in autonomic regulation that contribute to functional differences between athletes and sedentary men. These physiological characteristics form the basis for examining the relationship between aerobic capacity and autonomic function in young adults.

Maximal oxygen uptake (VO₂max) is widely regarded as the most comprehensive index of aerobic capacity and cardiorespiratory endurance, reflecting the integrated efficiency of the pulmonary, cardiovascular, and muscular systems during maximal exertion [1, 2]. VO₂max provides an objective measure of the body's ability to deliver and utilize oxygen for energy production during exercise [2]. Regular physical training, especially endurance exercise, is known to enhance VO₂max through physiological adaptations such as increased stroke volume, cardiac output, and mitochondrial density [3, 4].

Beyond its role in metabolic performance, VO₂max is associated with autonomic nervous system (ANS) regulation. The ANS maintains cardiovascular homeostasis by balancing sympathetic and parasympathetic influences on heart rate, vascular

tone, and blood pressure. Physical training induces adaptive changes in autonomic control. These changes are typically characterized by increased vagal tone (parasympathetic dominance) and reduced sympathetic drive at rest [5, 6, 7]. Conversely, sedentary behavior has been linked with autonomic imbalance, diminished heart rate variability, and higher cardiovascular risk [8, 9]. Autonomic function tests (AFTs) provide standardized methods for assessing the integrity of both parasympathetic and sympathetic branches of the ANS [10].

Parasympathetic function is commonly evaluated using the following tests. The Valsalva ratio is defined as the ratio of the longest R-R interval following strain to the shortest R-R interval during strain and reflects cardiac vagal responsiveness. The E:I ratio (deep breathing test) is defined as the ratio of the longest R-R interval during expiration to the shortest during inspiration while performing deep breathing at six breaths per minute. The 30:15 ratio is defined as the ratio of R-R intervals at the 30th and 15th beats following active standing and assesses baroreceptor-mediated vagal control [11, 12, 13, 14].

Sympathetic function is evaluated using the following tests. Blood pressure response to standing assesses vasoconstrictor sympathetic activity and baroreflex function. The isometric handgrip test (IHGT) evaluates sympathetic efferent activity by measuring the rise in diastolic blood pressure during sustained isometric contraction [11, 12, 13, 14, 15].

Previous studies have demonstrated that trained athletes exhibit enhanced parasympathetic modulation and reduced sympathetic excitability compared with sedentary individuals, suggesting that endurance training augments autonomic efficiency [16, 17]. Studies of heart rate variability and baroreflex sensitivity support the concept that increased aerobic fitness is accompanied by greater vagal activity and improved cardiovascular adaptability [18, 19, 20].

However, limited data are available directly correlating VO_2max , the gold standard measure of aerobic capacity, with standardized AFT parameters including the Valsalva ratio, E:I ratio, 30:15 ratio, blood pressure response to standing, and IHGT within the same population. Correlation analysis of these parameters provides insight into the relationship between cardiorespiratory fitness and autonomic regulation. Reduced VO_2max and autonomic dysfunction are independent predictors of cardiovascular morbidity and mortality [21, 22, 23, 24, 25].

Analysis of research findings has shown that aerobic fitness is associated with adaptive changes in autonomic regulation and with differences in cardiovascular reflex responses between trained and sedentary men. Researchers

emphasize that autonomic regulation during rest reflects the coordinated interaction of sympathetic and parasympathetic mechanisms and contributes to cardiovascular stability under standardized functional conditions. At the same time, the physiological relationships between cardiorespiratory endurance and autonomic reflex parameters remain insufficiently characterized in young adults. Clarification of these relationships is necessary for a more consistent interpretation of the functional links between aerobic capacity and autonomic regulation.

The study aim was to evaluate the relationship between VO_2max and autonomic function test parameters in athletes and sedentary individuals aged 18–25 years.

Materials and Methods

Participants

A total of 80 healthy male volunteers aged 18–25 years were recruited and divided into two groups:

- Group A (Athletes, $n = 40$): Individuals engaged in organized endurance sports or aerobic training ≥ 2.5 hours per week (e.g., runners, swimmers, cyclists).
- Group B (Sedentary, $n = 40$): Healthy individuals not participating in any structured physical training program.

Exclusion criteria:

- History of cardiovascular, respiratory, neurological, or endocrine disorders.
- Use of drugs affecting heart rate or autonomic tone.
- Smoking or alcohol consumption.

This cross-sectional comparative study was conducted in the Department of Physiology, SMS Medical College, after obtaining Institutional Ethical Committee approval (MC/EC/2024) on 9 October 2024. All participants provided written informed consent.

Study Design

Anthropometric and Baseline Measurements. Height, weight, and body mass index (BMI) were recorded. Resting heart rate (HR) and blood pressure (BP) were measured after 10 minutes of supine rest using a digital sphygmomanometer.

Direct Estimation of Cardiorespiratory Endurance (VO_2max) by Ramp Protocol on a Bicycle Ergometer. Cardiorespiratory endurance, expressed as maximal oxygen uptake (VO_2max), represents the highest rate at which oxygen can be taken up, transported, and utilized by the body during intense exercise. It is a direct indicator of aerobic fitness and cardiovascular efficiency. Direct measurement of VO_2max involves analyzing the volume and gas concentrations of inspired and expired air during a graded exercise test to determine the point of

maximal oxygen utilization. The ramp protocol is a graded incremental exercise test performed on a cycle ergometer where the workload increases continuously or in small frequent steps (10 W per minute) until the subject reaches volitional exhaustion. This approach ensures a smooth transition between workloads and allows a more precise assessment of physiological responses and an accurate determination of VO_2max .

Pre-Test Preparation. Participants were instructed to avoid heavy meals, caffeine, alcohol, and strenuous exercise for at least 12 hours prior to the test. Resting heart rate and blood pressure were recorded after 10 minutes of seated rest. Equipment was calibrated for volume and gas concentration using certified calibration gases before each test.

Procedure

Participants began cycling at a constant cadence of 60–70 revolutions per minute (rpm). The test started with a 3-minute warm-up at a workload of 20 watts (W). The ramp workload increment was then initiated, increasing continuously at a rate of 10 W per minute. The subject continued cycling until one of the following criteria was reached: volitional exhaustion, inability to maintain cadence above 60 rpm, or achievement of physiological indicators of maximal effort. After exhaustion, participants performed a 3-minute active recovery at zero load, followed by 2 minutes of passive recovery. Heart rate and blood pressure were continuously monitored until baseline recovery levels were approached. During the test, expired gases were continuously collected. Oxygen uptake (VO_2), carbon dioxide output (VCO_2), ventilation (VE), and respiratory exchange ratio (RER) were recorded breath-by-breath. Heart rate was monitored continuously via ECG.

The ramp protocol provides smooth and individualized workload progression and minimizes abrupt physiological transitions. It produces more accurate VO_2 kinetics data due to continuous workload increments. It is suitable for athletes and sedentary individuals, as increments can be tailored to expected fitness levels. It reduces test time variability and improves reproducibility compared with step or Bruce-type protocols.

Autonomic Function Tests (AFTs)

Tests were conducted in the morning in a quiet, temperature-controlled laboratory (22–24°C). Subjects were instructed to avoid caffeine, alcohol, and exercise for 24 hours prior.

A. Parasympathetic Function Tests

1. **Deep Breathing Test (E:I Ratio):** The subject was instructed to breathe deeply at a controlled rate of six breaths per minute for one minute. During this period, heart rate variability was assessed by calculating the

expiratory-to-inspiratory (E:I) ratio. This ratio was determined by dividing the longest R–R interval recorded during expiration by the shortest R–R interval recorded during inspiration. An E:I ratio greater than 1.2 is considered normal and indicates adequate parasympathetic (vagal) function and a normal cardiac autonomic response to deep breathing.

2. **Valsalva Maneuver (Valsalva Ratio):** The subject was instructed to exhale forcefully into a mouthpiece while maintaining a pressure of 40 mmHg for 15 seconds to perform the Valsalva maneuver. During this procedure, heart rate changes were recorded and the Valsalva ratio (VR) was calculated. The VR was determined by dividing the longest R–R interval observed immediately after the release of strain by the shortest R–R interval recorded during the strain phase. A Valsalva ratio greater than 1.45 is considered normal and reflects intact autonomic, particularly parasympathetic, cardiac function.
3. **30:15 Ratio:** Upon standing from a supine position, the subject's heart rate response was evaluated by measuring the R–R intervals at the 15th and 30th heartbeats after assuming the upright posture. The 30:15 ratio was calculated by dividing the R–R interval at the 30th beat by the R–R interval at the 15th beat. A value greater than 1.04 is considered normal and indicates an appropriate autonomic cardiovascular response to postural change and intact parasympathetic function.

B. Sympathetic Function Tests

1. **BP Response to Standing:** The fall in systolic blood pressure (ΔSBP) was recorded as the difference between the supine and standing positions to assess the cardiovascular response to postural change. This measurement reflects the integrity of autonomic regulation of blood pressure during standing. A decrease of less than 10 mmHg is considered normal and indicates an adequate compensatory response and intact sympathetic function.
2. **Isometric Handgrip Test (IHGT):** The participant was instructed to maintain 30% of maximal voluntary contraction using a handgrip dynamometer for four minutes to perform the isometric handgrip test. During this period, the rise in diastolic blood pressure (ΔDBP) was recorded to evaluate the sympathetic component of autonomic function. A normal response is characterized by an increase in diastolic blood pressure of 10–20 mmHg and indicates appropriate sympathetic activation.

Statistical Analysis

The data were analyzed using SPSS version 25.0. All results were expressed as mean \pm standard

deviation (SD). An independent t-test was applied to compare variables between the athlete and sedentary groups. Pearson correlation coefficient (r) was used to assess the association between VO₂max and autonomic parameters. A p-value less than 0.05 was considered statistically significant.

Results

Anthropometric characteristics and VO₂max values of athletes and sedentary individuals are presented in Table 1. The two groups were comparable in terms of age, body mass index, and VO₂max values.

Table 1. Comparison of mean values of anthropometric parameters

Parameter	Athletes n = 40 (Mean ± SD)	Sedentary n = 40 (Mean ± SD)
Age (years)	20.92 ± 2.49	21.05 ± 2.43
Weight (kg)	62.51 ± 8.90	57.56 ± 10.48
Height (cm)	169.64 ± 6.26	164.58 ± 7.29
BMI (kg/m ²)	21.62 ± 3.04	22.06 ± 4.08
VO ₂ max (mL/kg/min)	27.47 ± 8.96	26.06 ± 9.10

Athletes demonstrated higher mean values of height and body weight compared with sedentary individuals. Body mass index values were similar in both groups. VO₂max values were slightly higher in athletes than in sedentary individuals, although the difference was small.

Correlations between VO₂max and autonomic function test parameters in all subjects are presented in Table 2. Weak correlations were observed between VO₂max and all autonomic function test parameters, and none of the associations were statistically significant. VO₂max showed weak positive correlations with the Valsalva ratio and the 30:15 ratio, and weak negative correlations with the

E:I ratio, handgrip BP response, and fall in systolic blood pressure on standing.

Table 2. Correlation of VO₂max with autonomic function test parameters in total subjects

No.	VO ₂ max and autonomic function test parameters	Total subjects (n = 80) r-value	p-value
1	VO ₂ max and Valsalva ratio	0.067	0.549
2	VO ₂ max and E:I ratio	-0.114	0.313
3	VO ₂ max and handgrip BP response	-0.073	0.516
4	VO ₂ max and fall in systolic blood pressure from supine to standing	-0.035	0.753
5	VO ₂ max and 30:15 ratio	0.100	0.375

Correlations between VO₂max and autonomic function test parameters in athletes and sedentary individuals are presented in Table 3. Weak correlations were observed between VO₂max and autonomic function test parameters in both groups, and none of the associations were statistically significant. In athletes, VO₂max showed weak positive correlations with the Valsalva ratio and the 30:15 ratio, and weak negative correlations with the E:I ratio, handgrip BP response, and fall in systolic blood pressure on standing. In sedentary individuals, VO₂max showed weak positive correlations with the Valsalva ratio and fall in systolic blood pressure on standing, and weak negative correlations with the E:I ratio, handgrip BP response, and the 30:15 ratio.

Discussion

The study aim was to evaluate the relationship between VO₂max and autonomic function test parameters in athletes and sedentary individuals

Table 3. Correlation of VO₂max with autonomic function test parameters in athletes and sedentary individuals

No.	VO ₂ max and autonomic function test parameters	Athletes (n = 40)		Sedentary individuals (n = 40)	
		r-value	p-value	r-value	p-value
1	VO ₂ max and Valsalva ratio	0.023	0.886	0.098	0.543
2	VO ₂ max and E:I ratio	-0.274	0.087	-0.079	0.585
3	VO ₂ max and handgrip BP response	-0.234	0.145	-0.035	0.828
4	VO ₂ max and fall in systolic blood pressure from supine to standing	-0.235	0.143	0.111	0.491
5	VO ₂ max and 30:15 ratio	0.187	0.246	-0.150	0.352

aged 18–25 years. The results showed that $VO_2\text{max}$ values were comparable between athletes and sedentary individuals, while anthropometric characteristics were generally similar in both groups. Correlation analysis demonstrated weak and statistically non-significant associations between $VO_2\text{max}$ and all autonomic function test parameters in the total sample as well as within the athlete and sedentary groups. These findings indicate that aerobic capacity and autonomic reflex parameters showed no clear linear relationships under the conditions of the present study.

The present study evaluated the association between cardiorespiratory endurance ($VO_2\text{max}$) and autonomic function test parameters in athletes and sedentary young adults and found no statistically significant correlations in either group. These findings suggest that aerobic fitness and autonomic reflex function, as assessed by conventional autonomic tests, may represent relatively independent physiological domains in healthy young adults.

Endurance training is known to induce adaptations in autonomic regulation, particularly an increase in parasympathetic tone and a reduced resting heart rate, commonly observed in trained athletes [6, 17, 26]. However, the absence of significant correlations between $VO_2\text{max}$ and indices such as the Valsalva ratio, E:I ratio, and 30:15 ratio in the present study indicates that higher aerobic capacity does not necessarily translate into enhanced autonomic reflex responses measured under resting or mildly stressful conditions. This may be explained by the fact that $VO_2\text{max}$ reflects integrated central and peripheral adaptations, such as increased stroke volume, maximal cardiac output, and improved skeletal muscle oxygen extraction, rather than isolated autonomic reflex control [1, 24, 27].

Autonomic function tests primarily assess short-term cardiovascular reflexes mediated by the parasympathetic and sympathetic nervous systems, including heart rate variability during controlled maneuvers and blood pressure responses to static exercise or postural change [14, 28]. These tests may lack sensitivity to detect subtle training-related autonomic differences in young healthy populations with limited physiological variability. Moreover,

several studies have reported that improvements in aerobic fitness may occur independently of resting autonomic indices, particularly when assessed cross-sectionally rather than longitudinally [17, 29].

In sedentary individuals, similarly weak correlations were observed. This was likely due to a narrow range of $VO_2\text{max}$ values and preserved autonomic function within a healthy age group. Previous research suggests that significant impairments in autonomic function are more commonly associated with aging, cardiovascular disease, or metabolic disorders rather than differences in fitness alone among young adults [14, 25, 28, 29]. These findings indicate that $VO_2\text{max}$ should not be considered a surrogate marker of autonomic nervous system function in young adults.

Limitations and Future Studies

The present study has several limitations that should be considered when interpreting the findings. The sample size was modest ($n = 80$). Only male subjects were included, and gender-based differences were not assessed. Future studies should include longitudinal training interventions. Studies employing dynamic measures of autonomic regulation, such as heart rate variability during exercise and recovery or baroreflex sensitivity, along with longitudinal training interventions may provide greater insight into the relationship between aerobic fitness and autonomic control.

Conclusions

The present study showed no significant correlations between $VO_2\text{max}$ and autonomic function test parameters in athletes and sedentary young adults. Weak positive correlations were observed between $VO_2\text{max}$ and some parasympathetic indices, while weak negative correlations were observed with some sympathetic parameters, but none of these associations were statistically significant. These findings indicate that aerobic capacity and autonomic reflex function may represent relatively independent physiological characteristics in healthy young adults.

Conflict of Interest

The authors declares no conflict of interest.

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Assessment of strength fitness indicators in women of early mature age under the influence of individualized fitness programs in a war-affected environment

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

Abstract

Background and Study Aim

Maintaining physical fitness in adulthood is an essential component of health preservation and functional stability, particularly under conditions of prolonged environmental stress. In recent years, individual fitness programs have been widely applied to improve strength performance and overall physical condition in women of early mature age. However, under conditions of sustained military impact and increased psycho-emotional load, the adaptive response to systematically dosed strength training may acquire specific characteristics that require contextual consideration. Although various strength-oriented fitness approaches are implemented in practice, their relative effectiveness in enhancing strength preparedness among women living in a war-affected environment remains of practical interest. The aim of the study was to assess changes in strength fitness indicators in women of early mature age under the influence of individualized fitness programs in a war-affected environment.

Material and Methods

The study involved 10 women of early mature age (21–30 years), divided into two subgroups (21–25 and 26–30 years). The experiment lasted five months and was conducted under war-affected environmental conditions. Participants performed individually designed strength-oriented fitness programs. Strength preparedness was assessed before and after the intervention using a battery of tests evaluating maximal strength, strength endurance, and speed-strength abilities (plank, leg press, deadlift hold, standing long jump, vertical jump, squats, push-ups, and sit-ups). Data were analyzed using descriptive statistics and Student's t-test for dependent samples, with statistical significance set at $p < 0.05$.

Results

The findings demonstrated positive changes in most strength fitness indicators in both age subgroups following the five-month intervention. Statistically significant improvements ($p < 0.05$) were observed in leg press, standing long jump, deadlift hold, and squats tests, with the most pronounced gains recorded in abdominal strength endurance in the younger subgroup ($p < 0.01$). In women aged 26–30 years, significant progress was additionally noted in the plank test. Some indicators, including vertical jump and single-leg squats, did not reach statistical significance. Overall, individualized strength-oriented programs resulted in measurable improvements in strength preparedness under war-affected conditions.

Conclusions

Positive changes in strength preparedness indicators were observed in women of early mature age following participation in individualized strength-oriented fitness programs conducted under war-affected environmental conditions. Due to the single-group pre–post design and absence of a control group, the findings should be interpreted as preliminary within-sample changes rather than causal evidence of effectiveness. Nevertheless, the results demonstrate the feasibility of implementing personalized strength training approaches in crisis-affected environments.

Keywords:

individualized fitness programs, strength preparedness, early mature age women, war-affected environment, strength training, physical activity adaptation, Ukraine

Introduction

Strength-oriented training in the format of individualized fitness programs has become an important component of maintaining health and work capacity in women of early mature age. For women,

strength preparedness is associated not only with the development of muscular strength and endurance, but also with the prevention of unfavorable changes in body composition, preservation of functional capacity, and improvement of quality of life. Under conditions of prolonged war-related stress and residence in a frontline region, physical activity acquires additional significance as a resource for

self-regulation, maintenance of psycho-emotional stability, and preservation of daily activity. At the same time, the effectiveness of strength training in such conditions depends on individualized load prescription, appropriate exercise selection, and systematic monitoring of changes in strength indicators.

Strength preparedness is considered a key component of physical condition that determines the body's ability to generate muscular force and maintain functional performance in various types of activity [1]. The mechanisms underlying strength development are associated with neuromuscular adaptations, muscle fiber hypertrophy, and optimization of intermuscular coordination, which collectively contribute to improvements in strength performance in response to systematic training loads [2]. The effectiveness of resistance training largely depends on the rational organization of load parameters, including frequency, volume, periodization, and nutritional support, as confirmed by systematic reviews and meta-analyses [3, 4, 5]. Contemporary international guidelines emphasize the importance of regular physical activity and resistance exercise for adult populations in order to maintain health and prevent functional decline [6, 7]. At the same time, chronic psycho-emotional stress has been shown to influence levels of physical activity and physiological adaptation, potentially modifying training effectiveness [8], which becomes particularly relevant under war-affected environmental conditions.

Recent studies by Ukrainian scholars emphasize the practical aspects of designing individualized fitness programs for individuals of different age and sex groups. The main structural components of strength-oriented programs have been identified, including load variability, the integration of strength and functional exercises, and consideration of the individual morphofunctional characteristics of women of early mature age [9, 10]. The effectiveness of modern fitness modalities, including elements of martial arts and functional training, has been highlighted for the development of motor abilities and body composition correction in mature women [11, 12]. Experimental studies have also demonstrated the positive impact of strength training on the development of motor abilities and overall physical fitness [13].

Recent research further indicates that the effectiveness of physical exercise and its impact on functional and psycho-emotional status largely depend on environmental conditions and the level of stress exposure [14, 15]. Systematic reviews and randomized controlled trials confirm that regular physical activity contributes to improved mental health and reduction of post-traumatic stress symptoms across diverse social contexts [16, 17]. Thus, the current stage of fitness technology

development is characterized by an emphasis on individualized training approaches, safe load prescription, and consideration of the psycho-emotional context of participants' daily lives.

Military actions in Ukraine have led to significant changes in the lifestyle of the population, affecting levels of physical activity, psycho-emotional status, and functional indicators across different age groups. Studies conducted among university students under conditions of armed conflict have demonstrated a decline in physical activity levels and changes in motivational attitudes toward exercise participation [18, 19, 20]. At the same time, an association has been established between physical activity levels and stress-related conditions, confirming the role of regular exercise in maintaining psychophysical well-being [21, 22]. Investigations of autonomic nervous system functioning in students residing in war-affected regions have revealed adaptive changes associated with increased psycho-emotional load [23]. Furthermore, analyses of professional readiness among future physical education specialists and the adaptation of physical activity assessment tools under war conditions emphasize the need to reconsider approaches to organizing motor activity in contemporary social realities [24, 25, 26]. Thus, the war-affected environment functions as a complex contextual factor that transforms the structure and conditions of physical activity, highlighting the necessity for individualized training approaches to maintain strength preparedness in women of early mature age.

Analysis of previous research findings has demonstrated that the development of strength preparedness is an important factor in maintaining functional capacity and psychophysical well-being in women of early mature age. Researchers emphasize the necessity of individualized training programs, safe load prescription, and consideration of the psycho-emotional context of participants' daily lives. At the same time, the organization of individualized fitness programs and the assessment of their impact on strength preparedness under prolonged war-related environmental conditions are characterized by specific adaptive and organizational features, underscoring the need for experimental investigation of this issue.

The aim of the study was to assess changes in strength fitness indicators in women of early mature age under the influence of individualized fitness programs in a war-affected environment.

Materials and Methods

Participants

The study involved 10 women of early mature age (21–30 years) who attended the fitness club "Athletic Hall" (Kharkiv, Ukraine). Based on age, participants were allocated into two subgroups: Group A (21–25

years, $n = 5$) and Group B (26–30 years, $n = 5$). All participants had previous experience in recreational fitness training but were not professional athletes. Participant recruitment was conducted under war-affected environmental conditions, characterized by limited access to training facilities, disruptions in daily routines, and increased psycho-emotional stress. The study was carried out in a region located in close proximity to active military operations. The organization of training sessions was influenced by air raid alerts, temporary infrastructure disruptions, and restrictions in daily mobility, which created additional challenges for maintaining consistent participation. These circumstances limited the possibility of enrolling a larger sample. Inclusion criteria comprised the absence of medical contraindications to resistance training and regular attendance throughout the entire intervention period. Participation was voluntary.

The study was conducted in accordance with the ethical principles of the Declaration of Helsinki for research involving human participants. All participants provided written informed consent prior to participation. Confidentiality and anonymity of personal data were ensured. Participants were informed of their right to withdraw from the study at any time without consequences.

Study Design

The study had an experimental design and was conducted in 2025 over a five-month period under ongoing war-related conditions. The intervention was implemented in a commercial fitness club setting.

Training sessions were organized in a small-group format; however, each participant followed an individually prescribed strength-oriented training program. Individualization was based on baseline fitness assessment, age subgroup, and functional capabilities. Programs were developed and supervised by a certified fitness trainer with professional experience in strength training and recreational fitness.

Participants trained three times per week. Each session lasted approximately 60 minutes and included a standardized warm-up (10–12 minutes), a main strength-training component (40–45 minutes), and a cool-down phase (5–8 minutes). The main part of the session consisted of multi-joint and accessory strength exercises targeting major muscle groups. Load progression was applied gradually through adjustment of resistance, number of repetitions, and number of sets, according to individual adaptation and tolerance.

Training intensity and safety were monitored during each session by the supervising trainer. Attendance was recorded throughout the intervention period. In cases of air raid alerts, training sessions were temporarily interrupted and

transferred to a basement area of the facility that met safety requirements for civil protection during alert conditions.

Testing Procedures

Physical testing was conducted at baseline and after completion of the five-month intervention under standardized indoor conditions in the same fitness facility. All assessments were performed at approximately the same time of day to minimize circadian variability.

Before testing, participants completed a standardized warm-up. The following tests were used to assess maximal strength, speed-strength, and strength endurance (static and dynamic):

- plank hold;
- leg press (1RM equivalent or submaximal load);
- standing long jump;
- barbell deadlift hold;
- squats in 20 seconds;
- vertical jump;
- push-ups in 20 seconds;
- single-leg squats;
- sit-ups in 30 seconds.

Each test was demonstrated beforehand, and participants were familiarized with the procedures. Verbal encouragement was standardized. Two attempts were allowed where applicable, and the best result was recorded.

Statistical Analysis

Statistical analyses were performed using Microsoft Excel (Microsoft Corporation, Redmond, WA, USA). Descriptive statistics are presented as mean \pm standard deviation (SD). Pre–post differences within each subgroup were analyzed using a two-tailed Student's *t*-test for dependent samples. Normality of difference scores was assessed using the Shapiro–Wilk test. For each paired comparison, Cohen's *d* for dependent samples was calculated as a measure of effect size. In addition, 95% confidence intervals (CI) for mean differences were computed. Given the number of outcome comparisons performed within each subgroup, the results should be interpreted as exploratory. Statistical significance was set at $p < 0.05$ (two-tailed). No interpretation of “statistical trends” was applied.

Results

The comparative results of strength fitness indicators in Group A (21–25 years) and Group B (26–30 years) at baseline and after the five-month intervention are presented in Table 1. In addition to pre- and post-intervention values, absolute changes (Δ) are provided to facilitate evaluation of the magnitude of training-induced adaptations within each subgroup.

As shown in Table 1, both groups demonstrated positive changes across the majority of assessed strength indicators. In Group A, statistically

Table 1. Strength fitness indicators of women Group A (aged 21–25 years, n = 5) and Group B (aged 26–30 years, n = 5) at the beginning and at the end of the experiment

Indicators	Group	Baseline (M± SD)	Post-intervention (M± SD)	Δ (Post–Pre)	95% CI	Cohen's d	p
Plank, s	A	51.0±2.37	55.4±2.11	+4.4	[-6.71 ; 15.51]	0.49	>0.05
	B	45.0±0.79	47.8±0.74	+2.8	[-0.19 ; 5.79]	1.16	<0.05
Leg press, kg	A	80.0±0.79	88.8±2.22	+8.8	[2.20 ; 15.40]	1.66	<0.05
	B	66.0±2.89	80.0±0.79	+14.0	[5.74 ; 22.26]	2.10	<0.01
Standing long jump, cm	A	145.0±0.50	149.6±0.57	+4.6	[1.33 ; 7.87]	1.74	<0.05
	B	128.0±6.07	145.0±0.50	+17.0	[0.14 ; 33.86]	1.25	<0.05
Deadlift hold, s	A	34.8±1.98	44.8±1.98	+10.0	[2.29 ; 17.71]	1.61	<0.05
	B	30.2±2.33	39.8±1.98	+9.6	[1.00 ; 18.20]	1.39	<0.05
Squats in 20 s, repetitions	A	14.2±1.43	16.4±1.25	+2.2	[-2.89 ; 7.29]	0.54	>0.05
	B	13.6±0.57	17.0±0.79	+3.4	[0.70 ; 6.10]	1.57	<0.05
Vertical jump, cm	A	28.4±1.20	29.2±0.82	+0.8	[-3.65 ; 5.25]	0.22	>0.05
	B	22.2±1.34	23.6±1.25	+1.4	[-3.46 ; 6.26]	0.36	>0.05
Push-ups in 20 s, repetitions	A	7.2±0.74	8.0±0.79	+0.8	[-2.37 ; 3.97]	0.31	>0.05
	B	7.0±1.12	10.0±0.79	+3.0	[-0.79 ; 6.79]	0.98	<0.10
Single-leg squats (right), repetitions	A	3.4±0.76	3.8±0.65	+0.4	[-2.38 ; 3.18]	0.18	>0.05
	B	1.8±0.42	2.6±0.27	+0.8	[-0.59 ; 2.19]	0.72	>0.05
Single-leg squats (left), repetitions	A	4.0±0.35	4.6±0.27	+0.6	[-0.68 ; 1.88]	0.58	>0.05
	B	2.8±0.22	3.4±0.27	+0.6	[-0.38 ; 1.58]	0.76	>0.05
Sit-ups, repetitions	A	14.0±0.35	18.0±0.79	+4.0	[1.58 ; 6.42]	2.06	<0.01
	B	11.0±0.79	12.0±0.71	+1.0	[-2.08 ; 4.08]	0.40	>0.05

Note. Δ – mean difference (Post–Baseline); d – Cohen's d for dependent samples; CI – 95% confidence interval; n=5 per subgroup.

significant improvements were observed in leg press, standing long jump, deadlift hold, and sit-up performance, with the greatest absolute gain recorded in trunk muscle endurance ($\Delta = +4.0$ repetitions, $p < 0.01$).

In Group B, significant improvements were identified in plank, leg press, standing long jump, deadlift hold, and squats in 20 seconds. The largest absolute increases in this subgroup were observed in lower-body strength measures, particularly leg press ($\Delta = +14.0$ kg, $p < 0.01$) and standing long jump ($\Delta = +17.0$ cm, $p < 0.05$).

Between-group comparison of absolute changes suggests that Group B tended to demonstrate greater gains in lower-body strength parameters, whereas Group A showed relatively more pronounced improvement in trunk muscle endurance. However, these differences should be interpreted descriptively, as no direct statistical comparison between groups was performed.

Percentage changes are presented in Figure 1. Greater relative improvements in lower-body strength were observed in the 26–30-year subgroup, whereas larger gains in trunk endurance were noted in the younger subgroup. Between-group

differences should be interpreted cautiously due to the small sample size.

Discussion

The aim of the study was to assess changes in strength fitness indicators in women of early mature age under the influence of individualized fitness programs in a war-affected environment. The obtained results demonstrated positive dynamics in the majority of the assessed indicators in both age subgroups following the five-month experimental intervention. In women aged 21–25 years, statistically significant improvements were observed in the leg press, standing long jump, deadlift hold, and sit-up tests. In the 26–30-year-old subgroup, significant changes were recorded in the plank, leg press, standing long jump, deadlift hold, and squats in 20 seconds tests. These findings indicate the effectiveness of individually tailored strength-oriented programs in improving strength preparedness in women of early mature age, even under conditions of prolonged war-related environmental stress.

The statistically significant changes observed in strength fitness indicators in both age subgroups

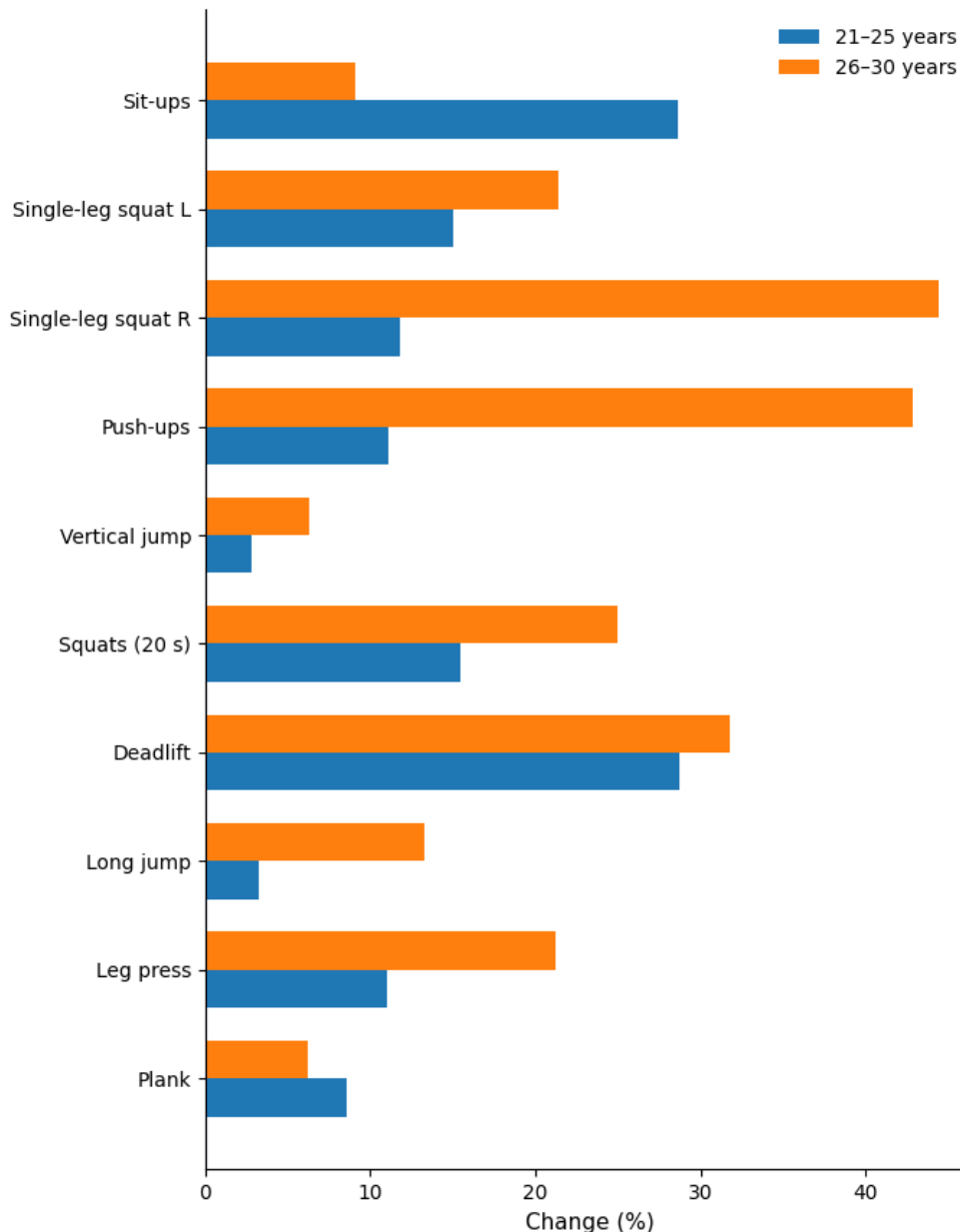


Figure 1. Percentage Changes in Strength Indicators in Women Aged 21–25 and 26–30 Years Following the Intervention

may be explained by a complex of neuromuscular adaptations resulting from the systematic performance of resistance exercises. During the initial stages of the training process, primary mechanisms include improvements in intermuscular coordination, enhanced motor unit recruitment efficiency, and optimization of neuromuscular interaction, which contribute to increases in strength performance without substantial morphological alterations. These mechanisms likely account for the statistically significant improvements observed in the leg press, deadlift hold, and standing long jump tests.

An important factor contributing to the positive dynamics was the individualization of training loads. The adaptation of training programs to participants'

age-related characteristics, baseline fitness levels, and functional status ensured optimal regulation of exercise volume and intensity, thereby enhancing training effectiveness. An individualized approach may also have minimized the risk of overload under conditions of elevated psycho-emotional stress characteristic of a war-affected environment.

Comparison between age subgroups revealed certain differences in the structure of adaptations. In women aged 21–25 years, more pronounced improvements were observed in indicators related to dynamic strength and trunk muscle endurance, whereas in the 26–30-year-old subgroup, significant changes were also noted in tests reflecting static endurance and speed-strength capacity. These differences may be associated with variations in

baseline functional status and adaptive potential among participants.

At the same time, some indicators did not reach statistical significance, including vertical jump, single-leg squats, and certain measures of strength endurance. Such findings may be attributed to the small sample size, interindividual variability in response to training stimuli, and external factors related to the war-affected environment that could have influenced training consistency and recovery processes.

Overall, the obtained data indicate the presence of strength-related adaptive changes resulting from the implementation of individualized fitness programs, supporting the feasibility of personalized training approaches for women of early mature age even under challenging social and environmental conditions.

The obtained results are consistent with recent national studies emphasizing the effectiveness of individualized physical training programs for women of different age groups. In particular, Voichun et al. [9] and Kovalova et al. [10] substantiated the feasibility of a variable approach to designing strength programs that takes into account age-related and functional characteristics, which corresponds to the positive dynamics observed in leg press performance and strength endurance in the present study. Similar trends in the improvement of speed-strength qualities have also been reported by Golenkova and Isichko [11], who highlight the importance of integrating traditional resistance exercises with functional training elements.

The findings of the present study also extend the results of our earlier work [27], in which individualized fitness sessions were shown to improve strength preparedness in women of early mature age. Unlike the previous investigation, the current study incorporates a structured comparison with international research data and includes analysis of absolute changes (Δ), allowing for a more detailed evaluation of the magnitude and structure of strength adaptations. This methodological expansion enhances the interpretative depth of the results obtained under prolonged war-related conditions.

The results obtained in the subgroup of women aged 26–30 years are also in agreement with the findings of Byshevets et al. [21] and Potop et al. [22], who reported an association between regular physical activity and stabilization of psychophysical status under war-related environmental conditions. The positive changes identified in static endurance and strength performance indicators may therefore be interpreted as manifestations of adaptive mechanisms supporting functional stability under increased stress exposure.

Other studies suggest that individualized load prescription contributes to greater improvements in strength performance among adults, particularly in

high-stress or adverse psychosocial environments. Findings reported by Yuan et al. [15] and Filippou et al. [16] demonstrate the compensatory role of regular physical activity in improving psycho-emotional status among individuals exposed to adverse social circumstances, indirectly supporting the results of the present study.

Similar conclusions are also supported by contemporary meta-analyses and experimental investigations demonstrating the effectiveness of resistance training in adult populations regardless of baseline fitness level. Peterson et al. [28] confirmed that progressive resistance exercise produces consistent gains in muscular strength among young and middle-aged women. Ralston et al. [28], in a systematic review, reported that training frequency is less influential on strength gains than appropriate load prescription and progression. Moreover, Steele et al. [30] emphasized the importance of individualized intensity selection and workload control to achieve stable adaptive responses. In the context of psycho-emotional stress, the findings of Gerber et al. [31] indicate that resistance exercise exerts beneficial effects on stress regulation and psychophysiological resilience. Collectively, these findings support the premise that individualized strength training can induce adaptive effects even in the presence of external stress-related factors.

At the same time, several indicators in the present study did not reach statistical significance, which partially differs from findings reported in some international studies demonstrating more pronounced improvements in speed-strength characteristics. This discrepancy may be attributed to the small sample size, the specific conditions under which the experiment was conducted, and the influence of the war-affected environment on the stability of the training process.

Overall, the obtained results generally confirm current trends regarding the effectiveness of individualized strength-oriented programs, while also reflecting the specific adaptive characteristics of women of early mature age living under prolonged war-related environmental conditions.

The present findings suggest that individualized resistance training may function not only as a physiological stimulus but also as a stabilizing behavioral intervention under crisis exposure. In this sense, strength-oriented fitness programs may serve as a dual-purpose strategy supporting both functional capacity and adaptive resilience in war-affected populations.

The war-affected environment functions as a complex contextual stressor capable of modifying the course of adaptive processes in the human body. Contemporary studies conducted among the Ukrainian population under conditions of armed conflict report decreased levels of physical activity, transformations in motivational attitudes toward

exercise, and increased psycho-emotional strain [18, 19, 20]. Such changes create additional constraints for training consistency and may influence the rate of strength-related adaptations.

Despite these constraints, participants maintained regular engagement in structured training throughout the intervention period. This sustained participation may reflect not only physiological adaptation but also behavioral resilience and a deliberate effort to preserve physical and psychological stability under prolonged crisis exposure.

The role of chronic stress as a factor influencing functional status and adaptive capacity is supported by findings reported by Byshevets et al. [21] and Potop et al. [22], who identified associations between physical activity levels and stress-related conditions. Investigations of autonomic nervous system functioning in students residing in war-affected regions further indicate the presence of adaptive changes associated with increased psycho-emotional load [23]. In the international context, the compensatory effects of physical activity on psycho-emotional status in individuals exposed to adverse social conditions have been confirmed by Bryant et al. [14] and Yuan et al. [15].

Within a broader scientific framework, the impact of chronic stress on physiological adaptation is viewed as a multifactorial process involving alterations in neuroendocrine regulation, heart rate variability, and muscle activation patterns. McEwen [32] introduced the concept of allostatic load, suggesting that prolonged stress may alter adaptive capacity and influence training effectiveness. Large-scale epidemiological studies also demonstrate associations between physical activity levels and mental well-being in general populations [33]. Furthermore, Gerber et al. [34] reported that regular exercise plays a compensatory role in stress regulation and contributes to enhanced psychophysiological resilience, while Stubbs et al. [35] highlighted the beneficial effects of physical activity in reducing anxiety and stress symptoms among adults. Collectively, these findings support the interpretation of individualized strength-oriented programs as a potential mechanism for maintaining adaptive stability in women exposed to prolonged war-related stress.

At the same time, the results of the present study demonstrate the preservation of positive dynamics in strength indicators despite war-related environmental constraints. This may indicate sufficient adaptive potential in women of early mature age and the effectiveness of individualized load prescription in maintaining functional stability under chronic stress exposure. Therefore, the war-affected environment not only complicates the organization of the training process but also acts as a modifying factor that must be considered in the

planning and adjustment of individualized fitness programs.

Practical Significance of the Obtained Results

The findings of the present study have practical relevance for specialists in fitness and physical culture, as they confirm the effectiveness of individualized strength-oriented programs for women of early mature age even under war-related environmental conditions. For coaches, these results indicate the importance of adapting training volume and intensity according to individual functional capacities, baseline fitness levels, and psycho-emotional status of clients. The practice of gradual load progression and exercise variability allows for positive dynamics in strength indicators while minimizing the risk of overload.

For the fitness industry, the study underscores the relevance of implementing personalized training programs, particularly in regions characterized by social instability. Organizing sessions with flexible scheduling, utilizing accessible equipment, and allowing adjustments in load parameters according to current circumstances contribute to maintaining population-level physical activity in crisis environments.

When working with women of early mature age, it is essential to combine resistance exercises with means aimed at developing general endurance and stabilization capacity in order to support functional condition and psychophysical resilience. The results demonstrate that even under conditions of elevated stress exposure, individually prescribed training programs can promote strength gains and sustain adaptive potential.

Thus, the practical value of the study lies in the applicability of the proposed approaches to organizing individualized fitness sessions as an effective tool for maintaining physical performance in women of early mature age within crisis-affected environments.

Limitations of the Study

Despite the positive results obtained, the study has several limitations that should be considered when interpreting the findings. First, the small sample size ($n = 10$), due to specifics of war-affected environmental conditions and limited opportunities to recruit a larger number of participants for a prolonged intervention, restricts the generalizability of the results to a broader population of women of early mature age. The absence of a non-training control group also limits causal interpretation of the observed changes.

Furthermore, the study was conducted within a single fitness club and in a specific region of Ukraine affected by military actions, which may also influence the representativeness of the findings. Psycho-emotional and social factors characteristic of wartime conditions may have affected participants

differently, contributing to variability in individual responses.

Another limitation concerns the duration of the experimental period, which allowed for the assessment of short- and medium-term adaptive changes but did not enable evaluation of the long-term effects of individualized fitness programs. Additionally, the study did not include an in-depth assessment of psycho-emotional indicators, which could have provided a more comprehensive understanding of the influence of the war-affected environment on training outcomes.

Future Research Directions

Future research should focus on expanding the sample size and involving participants from different regions of Ukraine to enhance the representativeness of the findings. Long-term longitudinal studies are warranted to assess the stability of strength-related adaptations under prolonged war-related environmental conditions.

Further investigations may include the assessment of psycho-emotional status, heart rate variability, anxiety levels, and other markers of adaptive capacity in order to provide a comprehensive evaluation of the effects of individualized fitness programs on both physical and psychophysiological well-being in women of early mature age. Comparative analyses of different models of load individualization, taking into account the intensity of war-related environmental exposure and specific training organization factors, also represent a promising direction for future research.

Thus, continued exploration of strength development under crisis conditions may contribute to the refinement of methodological approaches to individualized physical training and enhance their overall effectiveness.

Conclusions

1. The conducted study demonstrated the practical feasibility of implementing individualized strength-oriented fitness programs for women of early mature age under war-affected environmental conditions.
2. Over the course of the five-month intervention, positive dynamics were observed in the majority of strength fitness indicators in both age subgroups (21–25 and 26–30 years), demonstrating the effectiveness of individually prescribed training loads.
3. The most pronounced improvements were recorded in dynamic strength and strength endurance indicators, particularly in the leg press, deadlift hold, standing long jump, and sit-up tests, confirming the development of neuromuscular adaptations in response to systematic training.
4. The war-affected environment acts as a modifying factor influencing the organization of the training process and adaptive capacity; however, it does not prevent positive outcomes when training programs are properly individualized.
5. The obtained findings may be applied in the practical work of coaches and fitness professionals for the development of safe and effective strength training programs for women of early mature age in crisis-affected environments.

Conflict of interests

The authors declare that there is no conflict of interests.

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Impact of the war in Ukraine on mental health, psychosocial adaptation, and physical activity of the population: a systematic review of Ukrainian-language publications

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

Abstract

Background and Study Aim

In the context of the ongoing armed conflict in Ukraine, war acts as a prolonged and multi-level stressor. It exerts a complex impact on various aspects of human and societal functioning. Scientific studies have examined the consequences of the war in Ukraine for mental health, psychosocial adaptation processes, and levels of physical activity in the population. These studies reflect the diversity of individual and group responses to chronic stress and the disruption of everyday living conditions. Despite the use of different analytical and empirical approaches, the relative representation and balance of these thematic areas in scientific publications remain a subject of practical and methodological interest. The aim of this study was to conduct a systematic analysis and thematic structuring of scientific publications addressing the impact of the war in Ukraine on mental health, psychosocial adaptation, and physical activity of the population.

Material and Methods

The Web of Science Research Commons database was used as the primary information source for this systematic review. The database represents a multilingual and interdisciplinary index of scientific publications. The analysis included publications published exclusively in Ukrainian scientific journals and focused on Ukraine and the war in Ukraine. Study selection was conducted in accordance with PRISMA guidelines and comprised stages of automated searching, thematic filtering, and expert screening. Initially, 5847 publications were identified. After refinement of the search criteria, 1431 sources remained, of which 92 scientific publications were included in the final qualitative analysis. The results were synthesized using thematic content analysis, followed by classification of publications into categories and subcategories.

Results

The thematic content analysis revealed an uneven distribution of studies across research directions. The largest number of publications focused on mental health and population stress responses. In contrast, studies addressing clinical and physiological consequences of chronic stress were less represented. Research on physical activity and sport under wartime conditions was also limited. A substantial body of research was devoted to psychosocial adaptation and social functioning. These studies encompassed individual, family, educational, and occupational contexts. The identified thematic structure reflects a predominance of psychologically oriented research. At the same time, behavioral and physical activity-related aspects remain underrepresented.

Conclusions

This systematic thematic review indicates a dominance of research focused on mental health. At the same time, physiological and behavioral aspects, including physical activity, remain insufficiently represented. The findings highlight the need for interdisciplinary research. Such research should aim to integrate mental, psychosocial, and physical activity-based approaches to population health preservation under conditions of war.

Keywords:

war, mental health, psychosocial adaptation, physical activity, systematic review, Ukraine

Introduction

Armed conflicts in the contemporary world are increasingly viewed not only as military and political events, but also as prolonged socio-psychological crises that fundamentally alter the living conditions of populations. The war in Ukraine represents such a multi-level stressor, affecting mental health, psychosocial adaptation, and everyday physical activity across a wide range of life

contexts. The combined effects of chronic stress, disrupted social ties, economic instability, and restrictions on habitual forms of physical activity generate a complex spectrum of consequences for the well-being and functional capacities of different population groups. Taken together, these factors underscore the interdisciplinary nature of the problem and the need for a comprehensive analysis that integrates mental, socio-behavioral, and physical activity-related components.

In this context, the impact of war on population health and physical activity has been examined

from different perspectives. Filippou et al. [1] reported that physical activity among refugees and individuals evacuated from conflict zones represents an important but heterogeneous resource for supporting mental and somatic health. Among asylum seekers living in a Greek refugee camp, perceived physical fitness and engagement in low-intensity physical activity were significant predictors of higher well-being. This association was observed despite the high prevalence of post-traumatic stress disorder, depression, and anxiety [1]. In another study, evacuees from conflict-affected areas who engaged in more than three hours of vigorous physical activity per week showed greater resilience and better well-being. A tendency toward lower anxiety levels was also reported [2].

A systematic review of 33 studies on mass traumatic events, including disasters, wars, and terrorist attacks, demonstrated that higher physical activity levels were associated with greater resilience and subjective well-being. Lower levels of anxiety, depression, tension, and post-traumatic stress disorder were also observed. Additional benefits included improvements in sleep, self-efficacy, quality of life, and physiological indicators [3].

Against this background, a systematic analysis of the effects of armed conflicts on cardiovascular risk indicates that war worsens cardiovascular risk profiles. These changes include blood pressure, body weight, and health-related behaviors. The effects are partly mediated through changes in physical activity. These findings highlight exercise-based programs as an important component in the prevention of chronic non-communicable diseases among conflict-affected populations [4].

Systematic reviews and meta-analyses addressing population mental health in armed conflict settings consistently report a high prevalence of depression, anxiety disorders, and post-traumatic stress disorder among individuals exposed to war. Synthesized evidence indicates that refugees, internally displaced persons, and civilians remaining in active conflict zones demonstrate a persistently elevated risk of mental disorders. This risk is associated with chronic stress, loss of safety, and repeated traumatic experiences [5, 6].

Meta-analytic estimates show that depression and post-traumatic stress disorder account for a substantial proportion of the global burden of mental disorders in war-affected countries. Absolute case numbers remain high even years after the cessation of active hostilities [7, 8]. More recent meta-analyses confirm that the prevalence of depression, anxiety, and post-traumatic stress disorder in conflict zones significantly exceeds levels observed in stable regions. This finding underscores the systemic nature of the mental health consequences of war [9].

An overview of reviews further highlights the cumulative effects of prolonged and recurrent

conflicts. Mental health is identified as one of the most vulnerable components of public health under wartime conditions [10].

Systematic reviews addressing the clinical and physiological consequences of war and humanitarian crises demonstrate a consistent association between conflict-induced stress, sleep disturbances, and increased cardiovascular risk. Studies on sleep among refugees and migrants highlight a high prevalence of insomnia and other sleep disorders. These conditions are closely linked to traumatic experiences, displacement conditions, and psycho-emotional strain. This evidence underscores the need for clinically oriented and personalized approaches to diagnosis and support [11, 12].

Reviews focusing on cardiovascular risk indicate that exposure to armed conflict is associated with adverse changes in risk factors and an increased likelihood of cardiovascular events. These effects reflect both the direct impact of stress and indirect consequences related to disrupted living conditions and reduced access to healthcare [4]. In humanitarian crisis settings, hypertension is identified as a significant chronic health problem. Systematic reviews document barriers to treatment access, limited continuity of care, and the importance of incorporating patient perspectives into blood pressure management strategies [13].

Taken together, these findings confirm that sleep disturbances and cardiovascular risks represent key clinical and physiological manifestations of chronic stress under conditions of war and forced displacement. The effectiveness of response measures largely depends on the availability of continuous healthcare and the adaptation of clinical approaches to crisis settings [4, 11, 12, 13].

Contemporary research on psychosocial adaptation under conditions of war and forced migration emphasizes the key role of post-migration factors in shaping the social functioning of refugees and asylum seekers. Systematic and narrative reviews indicate that traumatic war experiences, combined with chronic stressors in host countries, substantially hinder integration processes. These stressors include social isolation, language barriers, insecure legal status, and economic precarity. They also intensify feelings of loneliness and loss of control over life [14, 15].

Reviews examining the relationship between trauma, post-traumatic stress disorder, and social functioning demonstrate persistent impairments in interpersonal relationships, occupational activity, and civic participation [16]. These difficulties remain evident even when clinical symptoms decrease.

The study by Mässing and Cardeña, a scoping review, suggests that post-migration stressors can markedly modify the effectiveness of psychotherapeutic treatment [17]. The authors note

that treatment outcomes are reduced in the absence of social support and stable living conditions. In the study by Schlechter et al., empirical findings confirm the buffering role of social support, religious faith, and individual resilience in reducing psychological distress and maintaining social functioning [18].

At the same time, a meta-analysis of psychosocial interventions shows that structured support programs can improve both mental health and social adaptation. However, their effectiveness largely depends on the implementation context and the availability of resources under conditions of forced displacement [19].

Studies addressing physical activity and sport under conditions of war and forced displacement demonstrate a consistent association between regular physical activity and improved mental health among affected populations. Randomized controlled trials conducted in refugee camps have shown that structured exercise and sport programs contribute to reductions in symptoms of post-traumatic stress disorder, anxiety, and depression. Improvements in overall psychological well-being have also been reported [20, 21].

Observational and cross-sectional studies further confirm that higher levels of self-reported physical activity are associated with better mental health outcomes and lower severity of post-traumatic stress disorder among individuals exposed to war, torture, and forced displacement [1, 22]. At the same time, practice-oriented research highlights substantial organizational and contextual challenges in implementing sport-based interventions in humanitarian settings. These challenges include infrastructure limitations, environmental instability, and the psychological vulnerability of participants [23].

A systematic review and meta-analysis by Purgato et al. confirm the overall effectiveness of physical activity as a non-pharmacological approach to reducing psychological distress among refugees, migrants, and asylum seekers. The review emphasizes its potential as an accessible and culturally adaptable tool for psychosocial support under conditions of war [24].

An analysis of previously published studies indicates that war exerts a complex and multi level impact on population mental health, psychosocial adaptation processes, physical condition, and patterns of physical activity across different social and demographic groups. The authors emphasize that these effects arise from the combined influence of chronic stress, disruption of habitual living conditions, forced migration, restrictions within educational and social environments, and reduced access to resources for support and recovery. Scientific publications place particular emphasis on the interrelationships among psychological, social, and behavioral factors, highlighting the

need to consider them within a unified analytical framework. At the same time, there remains practical and methodological interest in systematizing accumulated evidence and identifying stable thematic research directions. This approach enables a deeper understanding of the structure of scientific knowledge in this field and provides a foundation for further comprehensive analysis of the problem.

The aim of this study was to conduct a systematic analysis and thematic structuring of scientific publications addressing the impact of the war in Ukraine on mental health, psychosocial adaptation, and physical activity of the population.

Materials and Methods

Information Sources

The Web of Science Research Commons database was used as the primary information source for this systematic review. This database represents a multilingual and interdisciplinary index of scientific publications. The analysis included publications published exclusively in Ukrainian scientific journals and focused on Ukraine and the war in Ukraine.

The search covered all records indexed in Web of Science Research Commons from database inception to January 2026. The final search was conducted in January 2026. No lower date limit was applied.

All identified records were exported to a tabular CSV format for subsequent screening, filtering, and analysis in accordance with predefined inclusion and exclusion criteria.

Search Strategy

The search was conducted in two stages. During the first stage, keywords reflecting the themes of war and armed conflict in Ukraine were applied. During the second stage, a refined search was performed to identify publications related to physical activity, health, and psychosocial aspects.

To ensure transparency and reproducibility of the search strategy, the keywords used are presented in Table 1. The table separately lists terms applied during the initial search and keywords used in the refined search. Ukrainian language search terms are provided in transliterated form. English equivalents are presented solely for semantic interpretation and were not directly used in the search process.

The keywords presented in Table 1 were combined using Boolean operators to construct the electronic search strategy. War-related terms were grouped within one thematic block and combined using the OR operator. Health-, psychosocial-, and physical activity-related terms were grouped within a second block and likewise combined using OR. The two thematic blocks were connected using the AND operator. Truncation symbols (*) were applied as indicated to capture morphological variations. No additional thematic filters were imposed beyond those described above.

Table 1. Keywords used at different stages of the search

Search stage	Ukrainian search term (transliterated)	Possible English variants
Initial search	viina	war, warfare, full-scale war
Initial search	zbroinyi konflikt*	armed conflict, armed confrontation, conflict-related violence
Initial search	voiennyi konflikt*	military conflict, war-related conflict, armed conflict
Initial search	boiovi dii	hostilities, combat actions, combat operations, military operations
Initial search	viiskovi dii	military actions, military activities, military operations
Initial search	voiennyi stan*	martial law, state of martial law, martial-law regime
Refined search	fizychna aktyvnist*	physical activity, activity level, habitual physical activity
Refined search	fizychni vpravy*	physical exercise, exercise, exercise training
Refined search	fizyчне navantazhenn*	physical load, physical exertion, training load
Refined search	rukhova aktyvnist*	motor activity, movement activity, physical activity
Refined search	rukhova diialnist*	motor activity, movement behavior, physical activity behavior
Refined search	sport*	sport, sports, sports participation
Refined search	fizychna kultura*	physical culture, physical education, PE
Refined search	rekreatsiina diialnist*	recreational activity, leisure-time activity, recreation
Refined search	zdorov*	health, health status, public health
Refined search	psykhichne zdorov*	mental health, psychological health, mental well-being
Refined search	psykholohichni stres*	psychological stress, perceived stress, mental stress
Refined search	stres*	stress, stress exposure, stress-related
Refined search	blahopoluchch*	well-being, psychological well-being, subjective well-being
Refined search	yakist zhytt*	quality of life, health-related quality of life (HRQoL)
Refined search	psykholohichna stiikist*	resilience, psychological resilience, mental resilience
Refined search	adaptatsi*	adaptation, coping, adjustment, psychosocial adaptation

Note. Search terms are presented in transliterated form and correspond to the Ukrainian language keywords used to retrieve publications from Ukrainian scientific journals. The truncation symbol (*) was applied to capture different morphological forms of the search terms. English equivalents are provided solely for the purpose of interpreting the search logic and were not directly used in the search process.

Search Procedure and Identification of Records

The initial search using keywords related to war and armed conflict in Ukraine identified 5847 records. After applying a refined search query aimed at selecting publications related to physical activity, health, and psychosocial aspects, the number of retrieved records was reduced to 1431.

All records obtained at this stage were exported to a tabular format for subsequent screening and analysis in accordance with the PRISMA protocol.

Data Processing and Filtering

During the data processing stage, all records retrieved through the search strategy were combined into a single dataset. Consolidation of the search results ensured dataset integrity and enabled the sequential application of selection criteria.

Subsequently, an automated filtering procedure was applied based on keywords indicating human involvement. For this purpose, predefined lists of inclusion and exclusion terms were used. Inclusion keywords reflected direct and indirect references to people, whereas exclusion lists were applied to remove publications related to non-relevant thematic contexts, such as management, law, economics, public administration, and other subject domains. Keyword searching was performed within

publication titles and abstracts.

After removal of duplicate and technically overlapping records, 1336 unique publications remained for automated keyword-based screening. From this dataset, 241 publications met the predefined thematic inclusion criteria and were transferred to the stage of manual expert review.

At the next stage, a manual expert review of the selected publications was conducted. Based on this step, the author compiled a list of publications that most closely aligned with the study objectives, which reduced the sample to 149 publications. After classification of publications into categories, 92 publications were retained for further analysis.

All stages of data processing and study selection were conducted sequentially and documented in detail, ensuring transparency and reproducibility of the methodological approach in accordance with PRISMA recommendations (Figure 1).

Inclusion and Exclusion Criteria

The eligibility criteria were structured according to a Population–Exposure–Outcome (PEO) framework in order to ensure logical consistency between the research objective and the study selection process.

Population: individuals or population

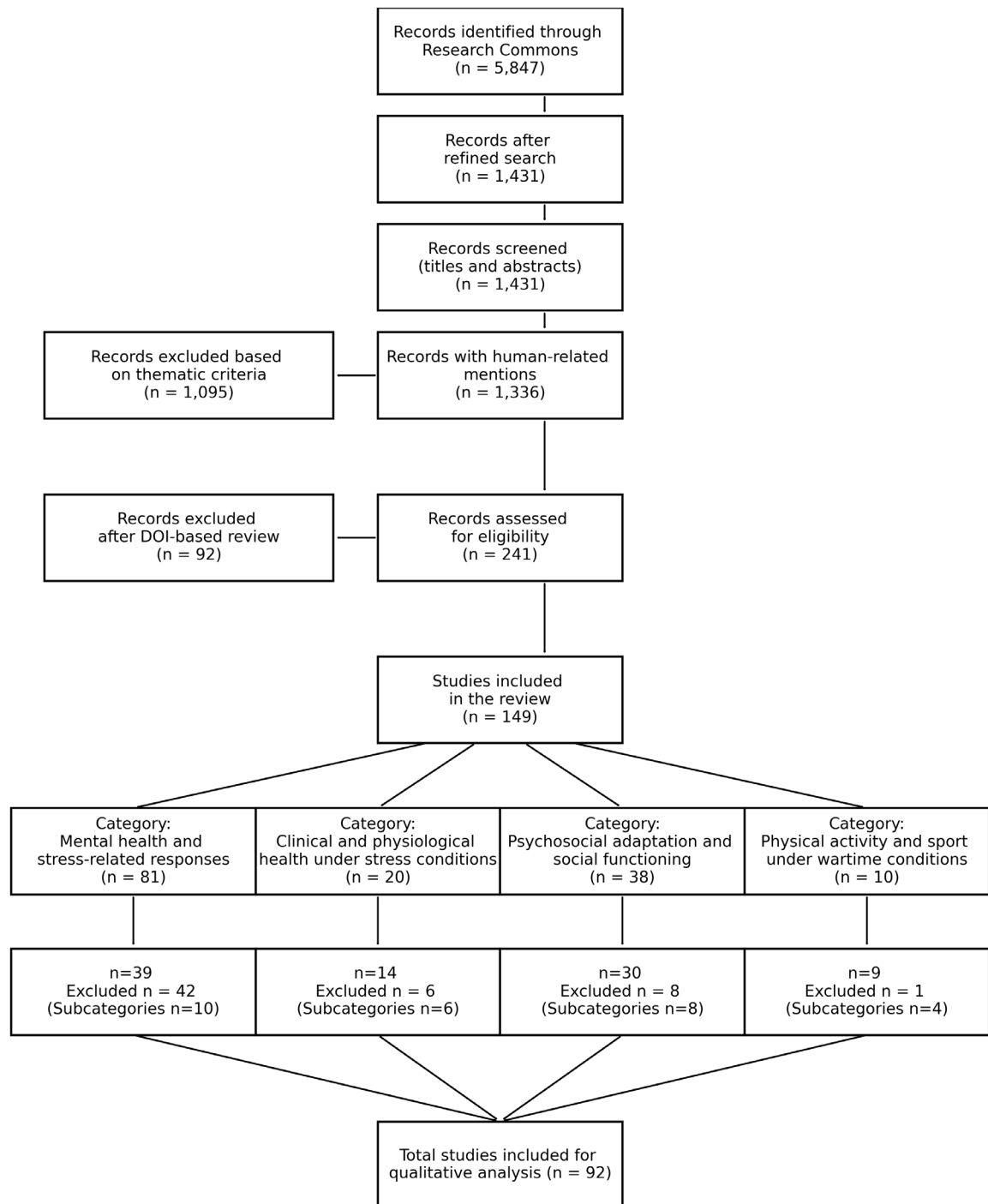


Figure 1. PRISMA flow diagram of the study selection process.

groups residing in Ukraine and affected by war-related conditions. Exposure: armed conflict, full-scale invasion, martial law, displacement, or chronic war-related stress. Outcomes: indicators of mental health, psychosocial adaptation, physical activity, health-related quality of life, physiological stress responses, or related behavioral health characteristics.

The selection of publications for the systematic review was based on predefined inclusion and exclusion criteria. These criteria were developed in accordance with the study objectives and were

applied sequentially during the stages of automated filtering and subsequent expert review.

Inclusion criteria comprised publications published in Ukrainian scientific journals and focused on Ukraine and the war in Ukraine, in which titles and or abstracts contained references to people or groups of people. The analysis included studies addressing physical activity, health status, mental health, and psychosocial well-being, as well as adaptation processes under conditions of war and armed conflict.

Exclusion criteria included publications that

did not correspond to the thematic scope of the study. Specifically, works primarily focused on legal, managerial, economic, financial, administrative, logistical, engineering, technological, or other non-relevant thematic contexts were excluded, even when references to people were present. Publications were also excluded when the research focus shifted away from the analysis of human condition, activity, or well-being toward institutional, organizational, or regulatory aspects.

In addition, an expert based exclusion stage was applied following automated filtering.

After completion of the automated screening and filtering stages, the final sample comprised 149 publications that met the established inclusion criteria. To conduct an in depth qualitative analysis and ensure sufficient analytical depth, a thematic structure was developed consisting of four key categories that reflected the main content directions of the selected publications:

- Mental health and stress related responses (n = 81),
- Clinical and physiological health under stress conditions (n = 20),
- Psychosocial adaptation and social functioning (n = 38),
- Physical activity and sport under wartime conditions (n = 10).

Within each category, an additional thematic decomposition into subcategories was performed. This approach allowed for a more detailed characterization of the content structure of the publication corpus and the identification of stable internal analytical directions. As a result, 10 subcategories were identified for the first category, 6 for the second, 8 for the third, and 4 for the fourth category.

The selection of publications for the final qualitative analysis was conducted manually based on content relevance and analytical significance in relation to the objectives of the present study. During this stage, some publications were excluded at the expert thematic synthesis step due to only formal references to the wartime context, absence of analysis of psychosocial, behavioral, or adaptation mechanisms, or a narrow focus on highly specialized biomedical or methodological aspects that did not correspond to the study objectives.

Summary information on the distribution

of publications and exclusions across thematic categories is presented in Table 2.

Excluded publications (n = 57) were not included in further qualitative analysis. The remaining studies (n = 92) were integrated into broader thematic subcategories within the corresponding research directions. The aggregation of publications into analytical blocks was applied solely for the purposes of thematic synthesis and data interpretation.

To enhance the robustness of the selection process and reduce decision related subjectivity, the formation of the final subsample was accompanied by expert discussion involving two independent specialists in physical activity, public health, and psychosocial research. In cases of divergent assessments, final decisions were made by consensus.

The application of this approach resulted in the formation of a representative and content rich subsample of publications (n = 92), which was sufficient for conducting qualitative analysis and subsequent discussion of the study findings.

Data Processing and Analysis

All stages of data processing and study selection were conducted using automated analytical procedures. The retrieved records were processed using the Python programming language, which was applied to merge datasets, standardize bibliographic information, and filter records based on predefined inclusion and exclusion criteria.

Automated text based screening was applied to publication titles and abstracts to identify records containing references to human participation. Additional filtering procedures were used to exclude records related to non-relevant thematic domains. The use of automated processing ensured consistency, reproducibility, and transparency of the selection process.

Following automated filtering, the remaining records underwent qualitative assessment. The review protocol was not prospectively registered in an external database (e.g., PROSPERO). The methodological procedures were predefined prior to data extraction and were applied consistently throughout the study selection and synthesis process.

A formal methodological quality or risk-of-bias assessment of the included studies was not conducted, as the primary objective of the review

Table 2. Distribution of studies and exclusions during qualitative thematic analysis

Category	Total studies (n)	Excluded during qualitative analysis (n)
Mental health and stress-related responses	81	42
Clinical and physiological health under stress conditions	20	6
Psychosocial adaptation and social functioning	38	8
Physical activity and sport under wartime conditions	10	1
Total	149	57

was thematic structuring and mapping of research directions rather than quantitative effect synthesis. Therefore, the findings presented in this review reflect the distribution and thematic orientation of the available literature and should not be interpreted as graded evidence of effectiveness or causal inference.

Results

To synthesize the findings of the qualitative analysis, the included studies were organized into a structured thematic framework. This categorization delineates four main research domains addressing the effects of war related stressors on health, psychosocial adaptation, and human functioning. An aggregated overview of all categories, subcategories, and corresponding study clusters is presented in Table 3.

The final analytical sample comprised 92 publications. Across the four thematic categories, the corpus included theoretical and analytical papers, cross-sectional empirical studies, questionnaire-based surveys, clinical observational investigations, and a limited number of intervention-oriented and experimental designs. The distribution of studies across categories reflects thematic prevalence rather than hierarchical differentiation by study design.

As shown in Table 3, the largest body of evidence relates to Mental health and stress related responses, encompassing multiple subcategories that capture population level psychological deterioration, mental health vulnerability among students, trauma in children and adolescents, resilience factors, coping

strategies, intervention effectiveness, displacement related stress, occupational burnout, posttraumatic growth, and the development of diagnostic tools for war related stress.

The category Psychosocial adaptation and social functioning reflects a broad spectrum of adaptive processes operating at individual, family, community, and societal levels. These include identity transformation, family and intergenerational resilience, educational and professional adaptation, vulnerability of specific population groups, and the role of psychosocial support programs.

Studies grouped under Clinical and physiological health under stress conditions indicate that prolonged exposure to war is associated not only with psychosomatic complaints but also with measurable physiological changes, deterioration of health related behaviors, reduced quality of life, exacerbation of chronic diseases, and nutrition related risks.

The category Physical activity and sport under wartime conditions is more limited in volume but methodologically diverse. It highlights adaptive modifications of training processes, the rehabilitative potential of physical activity, vulnerability and resilience of youth physical activity, and sport related quality of life under conditions of restricted mobility and chronic stress.

To illustrate the relative contribution of each thematic domain, the distribution of included studies across the four main categories is presented in Figure 1. The categories are indicated numerically on the horizontal axis, while color coding and the

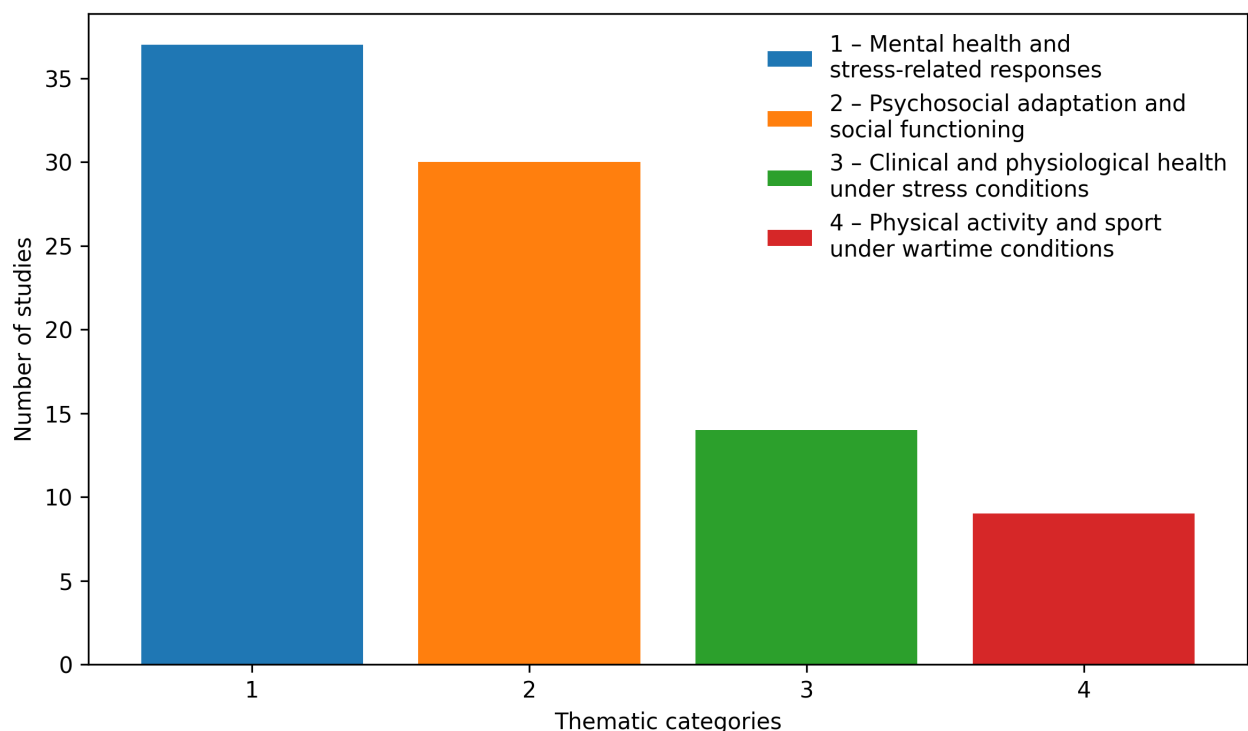


Figure 1. Distribution of included studies across four thematic categories (n = 92)

Table 1. Aggregated thematic structure of included studies across four main categories and corresponding subcategories

Articles	Study aim	Study design	Population	Key outcomes	War-related focus	Expert comment
Mental health and stress-related responses						
25, 26, 27, 28	Synthesize evidence on general mental health deterioration under war	Theoretical analytical and narrative reviews	General civilian population	War associated with increased anxiety depression emotional instability and reduced psychological well being	War as chronic stressor and collective trauma	Population level mental health decline under prolonged war stress
29, 30, 31, 32, 33, 34	Assess stress anxiety and emotional exhaustion in students	Cross sectional and comparative empirical studies	University students	High anxiety emotional exhaustion sleep disturbance and reduced stress resistance	Educational disruption uncertainty and chronic wartime stress	Students represent a high risk group for stress related mental health outcomes
35, 36, 37, 38, 39	Examine mental health consequences of war in children and adolescents	Empirical surveys narrative and clinical studies	Children and adolescents including IDPs	High prevalence of anxiety fear PTSD psychosomatic symptoms and emotional dysregulation	Direct exposure displacement and loss of safety	Children show heightened vulnerability to war related psychological trauma
40, 41, 42, 43, 44	Identify psychological resilience and protective resources under war stress	Correlational empirical and theoretical studies	Adolescents adults displaced populations	Resilience tolerance to uncertainty and hardness buffer negative mental health outcomes	Prolonged wartime stress and uncertainty	Resilience functions as a key moderator of war related mental health risk
45, 46, 47, 48	Analyze coping strategies and emotional regulation during war	Empirical correlational and intervention studies	Adults and students	Adaptive coping linked to better emotional regulation while avoidance increases anxiety	Chronic stress and traumatic exposure	Coping style significantly determines psychological adaptation to war
49, 50, 51, 52	Evaluate psychological interventions for stress anxiety and PTSD	Applied empirical and methodological studies	Children adolescents and adults	CBT art therapy mindfulness reduce anxiety depression and PTSD symptoms	War trauma displacement and chronic stress	Psychological interventions are reported in the included studies as being associated with reductions in selected psychological symptoms under wartime conditions.
53, 54, 55	Assess effects of displacement and migration on mental health	Empirical and comparative studies	Forced migrants displaced families youth	Migration linked to maladaptive adjustment and transgenerational stress transmission	War induced displacement and family separation	Displacement amplifies psychological vulnerability across generations
56, 57, 58	Analyze occupational stress and burnout during war	Empirical correlational and comparative studies	Lecturers IT specialists demining professionals	High burnout anxiety and emotional exhaustion under chronic war stress	Extreme occupational stress in wartime	Occupational mental health risks require targeted preventive strategies

Table 1. Continued

Articles	Study aim	Study design	Population	Key outcomes	War-related focus	Expert comment
54, 59, 60	Examine posttraumatic growth and positive adaptation	Mixed methods and correlational studies	Students and forced migrants	Posttraumatic growth linked to meaning making resilience and improved well being	War related trauma and adaptation	Positive psychological transformation is possible despite chronic stress
61, 62	Develop diagnostic tools for war related stress	Psychometric instrument development and validation	Civilian adult populations	Reliable scales capturing chronic war related stress dimensions	Daily and prolonged war stress exposure	Validated instruments strengthen methodological rigor of war related mental health research
Psychosocial adaptation and social functioning						
63, 64, 65, 66, 67	Conceptualize individual and collective psychosocial adaptation to war	Theoretical conceptual and analytical syntheses	General population and communities affected by war	Adaptation is driven by resilience coping strategies collective stability and transformational responses to chronic stress	Prolonged armed conflict and societal disruption	Provides integrative frameworks explaining psychosocial adaptation mechanisms under war
68, 69, 70, 71	Analyze community and collective identity transformation during war	Theoretical and mixed conceptual empirical studies	Youth and general population	War reshapes national identity values patriotism and collective trauma processing influencing social cohesion	Information psychological warfare and full scale invasion	Highlights identity based resources and risks for societal adaptation
72, 73, 74, 75	Examine family systems and intergenerational psychosocial adaptation	Theoretical analyses empirical and intervention studies	Families parents children wounded personnel	Family support parenting styles and parental identity enhance child resilience and recovery	Family functioning under war stress and injury	Family system acts as a key buffer for psychosocial adaptation
76, 77, 78, 79, 80	Assess psychosocial adaptation of children and youth in educational contexts	Longitudinal surveys empirical educational and conceptual studies	Schoolchildren students and youth	Educational environments support motivation social skills and identity adaptation but war increases anxiety and distancing	Disruption of education and distance learning during war	Education serves as a central arena for youth psychosocial resilience
81, 82, 83, 84, 85	Analyze psychosocial adaptation of vulnerable groups under war	Quantitative qualitative and mixed studies	Refugees IDPs persons with disabilities elderly and parents of disabled children	Higher distress and social losses coexist with resilience linked to support and needs satisfaction	Forced migration vulnerability and social exclusion	Demonstrates differentiated adaptation patterns among vulnerable populations

Table 1. Continued

Articles	Study aim	Study design	Population	Key outcomes	War-related focus	Expert comment
86, 87, 88, 89	Examine professional occupational and institutional adaptation during war	Analytical reviews surveys and applied qualitative studies	Police nurses educators social workers	Professional adaptation depends on psychological skills training and trauma informed practices	Occupational stress and institutional disruption under martial law	Highlights need for institutional psychosocial capacity building
90, 91, 92	Evaluate psychosocial interventions support programs and alternative resources	Qualitative program analyses and theoretical reviews	Displaced persons children and general population	Support groups psychological tourism and counseling enhance social connection and resilience	Displacement trauma and social isolation due to war	Interventions strengthen social functioning and recovery resources
Clinical and physiological health under stress conditions						
93, 94	Assess somatic and psychosomatic health under war stress	Comparative clinical and observational studies	Children and adolescents from conflict affected regions	High prevalence of somatic complaints psychosomatic symptoms fatigue emotional lability anxiety and reduced adaptive capacity	Direct exposure to armed conflict displacement and chronic threat	Clear evidence of combined physical and psychosomatic vulnerability in minors under war stress
95, 96	Examine health behaviors and lifestyle changes during wartime	Cross sectional and longitudinal observational studies	University and medical students	Deterioration of self-rated health reduced physical activity weight gain increased smoking alcohol use and unhealthy behaviors	War related stress combined with educational disruption and distance learning	Lifestyle mediated health decline represents an indirect but significant physical health risk
97, 98	Assess health related quality of life under armed conflict	Narrative review and clinical observational study	War affected populations and patients with chronic diseases	Reduced physical mental and social quality of life with functional limitations depression and anxiety	Direct exposure to war displacement and chronic stress	Quality of life integrates physical and mental health deterioration under war conditions
99	Identify physiological stress markers and allostatic load during war	Repeated laboratory observational study	University students aged 18 to 21	Altered neutrophil and monocyte profiles indicating increased allostatic load after war onset	Chronic war related stress combined with pandemic impact	Objective physiological confirmation of stress induced health burden

Table 1. Continued

Articles	Study aim	Study design	Population	Key outcomes	War-related focus	Expert comment
100, 101, 102	Analyze cardiovascular and endocrine responses to chronic war stress	Clinical observational and retrospective studies	Patients with hypertension and endocrine disorders	Impaired blood pressure regulation increased arrhythmias higher cardiovascular risk under chronic stress	Full scale invasion martial law and prolonged anxiety exposure	War stress exacerbates the course of chronic somatic diseases
103, 104, 105, 106	Assess eating behavior and nutrition under martial law	Questionnaire based and cohort observational studies	Students adults and pregnant women	Disordered eating nutrient imbalance stress related dietary changes fatigue and reduced well being	Disruption of daily routines food access and psychosocial stress due to war	Nutritional disturbances represent a significant physiological risk under prolonged war stress
Physical activity and sport under wartime conditions						
107, 108, 109, 110	Analyze organization and adaptation of sport training under wartime constraints	Questionnaire based surveys intervention and comparative longitudinal studies	Military cadets boxers students youth footballers	Restricted access to facilities led to adaptation of training formats use of shelters limited space programs and modified training loads while maintaining or improving selected performance indicators	Martial law air raids mobility restrictions and wartime safety requirements	Demonstrates feasibility and effectiveness of adapted sport training under wartime constraints
111, 112	Assess physical activity as a means of stress reduction and rehabilitation during and after war	Experimental intervention and narrative analytical studies	Combatants and war veterans	Regular running and football based programs reduced stress supported rehabilitation and facilitated social reintegration	Combat stress and post war adaptation	Physical activity is reported in the included studies as being associated with stress reduction and rehabilitation support under wartime conditions.
113, 114	Examine physical activity and physical education of children and youth under wartime conditions	Observational survey and testing studies	Schoolchildren and adolescents	Wartime distance education and stress reduced physical activity levels while structured exercises improved functional state and reduced anxiety	Educational disruption shelter use and psychosocial stress	Youth physical activity is highly vulnerable to wartime conditions but responsive to targeted physical education measures
115	Assess athlete well-being and quality of life under wartime conditions	Cross sectional questionnaire study	Esports athletes	War related stress associated with changes in psychological health and quality of life with identified coping and mitigation approaches	War and pandemic related uncertainty	Highlights sport related quality of life and well-being under indirect physical activity conditions

legend provide full thematic specification. As shown in Figure 1, research on mental health and stress-related responses (Category 1) clearly dominates the body of published research. In contrast, clinical and physiological outcomes (Category 3) and studies addressing physical activity (Category 4) are substantially less represented.

Discussion

The aim of this study was to conduct a systematic analysis and thematic structuring of scientific publications addressing the impact of the war in Ukraine on mental health, psychosocial adaptation, and physical activity of the population. The qualitative analysis identified four aggregated thematic categories that reflect the main directions of scholarly interpretation of war related consequences. These categories include mental health and stress related responses, psychosocial adaptation and social functioning, clinical and physiological consequences of chronic stress, and physical activity and sport under conditions of war.

The interpretation of the findings should be considered in light of the structural characteristics of the included evidence base. The majority of the reviewed publications were observational, descriptive, or theoretical in nature, while experimental and randomized controlled designs were limited in number. In addition, no formal methodological quality assessment was conducted. Therefore, the present synthesis reflects thematic prevalence and research orientation rather than graded evidence strength or causal verification.

The largest body of publications was concentrated in the domain of mental health and stress related responses, indicating the priority of this topic within the scientific discourse. Categories related to psychosocial adaptation and clinical and physiological consequences were represented more moderately and encompassed a wide range of populations and contextual settings. Studies addressing physical activity and sport under wartime conditions constituted the smallest but methodologically diverse group, reflecting both adaptive modifications of physical activity and its rehabilitative potential.

Taken together, these findings provide an integrated view of the structure and distribution of research interests in this field. The identified thematic configuration establishes a foundation for further interpretative analysis of the evidence base concerning population health, adaptation, and physical activity under conditions of war.

Mental health and stress related responses

Analysis of the Ukrainian body of publications indicates that the dominant research directions addressing the mental consequences of war focus on anxiety and depressive manifestations, post-

traumatic symptoms, and reduced psychological well-being in the general population. This pattern is consistent with meta-analytic evidence reporting a high prevalence of depression and post-traumatic stress disorder in conflict-affected groups [5, 6, 7, 8, 9]. Within Ukrainian studies, these outcomes are further specified through the identification of vulnerable subgroups, particularly students and educational settings, in which emotional exhaustion, sleep disturbances, and reduced stress tolerance are frequently reported. These manifestations are commonly interpreted as cumulative effects of prolonged exposure to chronic stress, disrupted daily routines, and sustained social uncertainty [29, 30, 31, 32, 33, 34]. Taken together, this thematic focus suggests that Ukrainian research complements international prevalence-based findings by providing a more differentiated understanding of context-specific vulnerability patterns and stress responses within civilian populations exposed to prolonged warfare.

Similarly, elevated risks of anxiety, fear, and post-traumatic stress disorder among children and adolescents, including internally displaced persons, align with international evidence on the psychological vulnerability of displaced populations and those living in threat-exposed areas. Systematic reviews and meta-analyses by Morina et al. demonstrated a high prevalence and persistence of depression and post-traumatic stress disorder among refugees, internally displaced persons, and civilians remaining in war-affected regions [5, 6]. Meta-analytic studies further showed that these disorders constitute a substantial share of the global mental health burden in countries affected by armed conflict and occur at significantly higher rates than in stable regions [7, 8, 9, 10]. In the Ukrainian corpus, however, greater emphasis is placed on school and family contexts as central environments shaping the experience of war-related stress [35, 36, 37, 38, 39]. A distinctive feature of Ukrainian publications is the pronounced focus on adaptive resources, including resilience, coping strategies, and post-traumatic growth. This perspective extends the predominantly deficit-oriented framework of global assessments by highlighting buffering factors and recovery potential [40, 41, 42, 43, 44, 45, 46, 47, 48, 59, 60]. The presence of studies addressing psychological interventions and diagnostic tools reflects a practice-oriented shift within the Ukrainian research corpus and corresponds to the international trend toward moving beyond symptom description to the evaluation of supportive approaches and instruments for assessing war-related stress [49, 50, 51, 52, 61, 62]. Taken together, these differences indicate that Ukrainian-language research not only reflects global patterns of war-related psychological burden but also contributes context-specific insights into adaptive mechanisms

and applied support strategies relevant to prolonged and large-scale societal stress.

International systematic reviews and meta-analyses consistently confirm the universal and cumulative nature of the mental health consequences of armed conflicts across national and cultural contexts. Large-scale reviews and meta-analyses have documented consistently elevated prevalence rates of depression, anxiety, and post-traumatic stress disorder among refugees, internally displaced persons, and civilians living in war-affected regions, as well as the persistence of these disorders long after active hostilities cease [5, 6, 7, 8, 9, 10]. Contemporary meta-analytic evidence further demonstrates persistently high prevalence rates of post-traumatic stress disorder, depression, and anxiety disorders among civilian populations in conflict regions, with comparable levels observed across countries exposed to prolonged violence and chronic insecurity [116, 117]. Global reviews indicate that refugees, internally displaced persons, and populations remaining in active conflict zones exhibit similar patterns of mental disorders, supporting the transnational comparability of war-related mental health outcomes. An overview of reviews additionally emphasizes that the cumulative effects of prolonged and recurrent conflicts generate a long-term burden of mental disorders that extends well beyond the acute phase of hostilities. Taken together, this body of international evidence provides a robust comparative framework for interpreting national-level findings within the broader context of global mental health research on war-related stress.

Overall, the findings of this subsection indicate a high degree of convergence between Ukrainian and international research in identifying the scale and persistence of war-related mental health problems. At the same time, important contextual distinctions are evident. International evidence primarily establishes the prevalence, cumulative nature, and long-term burden of depression, anxiety, and post-traumatic stress disorder across conflict-affected populations. Ukrainian-language studies, however, emphasize context-specific vulnerability patterns. They also highlight the role of educational and family environments, as well as the significance of adaptive resources and applied support strategies. Together, these perspectives provide an integrated understanding of mental health and stress-related responses to prolonged warfare. They reflect both shared global patterns and nationally specific features of psychological adaptation.

Psychosocial adaptation and social functioning

Analysis of Ukrainian publications on psychosocial adaptation and social functioning demonstrates conceptual alignment with international research emphasizing the key role

of post-traumatic and post-migration stressors in disrupting social ties, integration processes, and participation in community life [14, 15, 16]. At the same time, the Ukrainian research corpus extends this perspective by focusing on adaptation under conditions of ongoing internal conflict without a post-migration recovery phase. This allows psychosocial adaptation to be conceptualized as a dynamic and multi-level process developing against a background of prolonged social instability [63, 64, 65, 66, 67].

In contrast to international reviews that predominantly focus on refugees and host communities [5, 14, 15, 16], Ukrainian studies place greater emphasis on the transformation of collective and national identity, family systems, and educational environments as key spaces of social adaptation. These findings complement evidence on impaired social functioning by highlighting not only maladaptation but also the emergence of new forms of solidarity, shared values, and mechanisms of collective resilience [68, 69, 70, 71, 72, 73, 74, 75].

Particular attention within the Ukrainian corpus is given to vulnerable groups, including internally displaced persons, people with disabilities, older adults, and children and youth in educational contexts. This focus aligns with international evidence indicating a coexistence of high psychological distress and preserved adaptive resources when social support is available [18]. Studies on psychosocial interventions and alternative forms of support further confirm meta-analytic conclusions regarding the positive effects of structured programs on social functioning. At the same time, they emphasize that intervention effectiveness depends strongly on the institutional and social context of implementation under wartime conditions, which is consistent with international findings reported by Schlechter et al. [19] and other reviews [86, 87, 88, 89, 90, 91, 92].

Contemporary systematic reviews and meta-analyses indicate that psychosocial adaptation of refugees and internally displaced persons in armed conflict settings is shaped by the interaction of traumatic war experiences and post-migration stressors. These stressors include social isolation, insecure legal status, and economic instability, all of which substantially affect social functioning and quality of life. Synthesized evidence shows that impairments in social functioning, such as difficulties in interpersonal relationships, social integration, and occupational participation, often persist even when clinical symptoms of post-traumatic stress disorder and depression partially decrease [16, 17, 18].

Systematic reviews of psychosocial interventions confirm that support and social reintegration programs can improve emotional well-being and social engagement. However, their effectiveness

varies depending on contextual factors, levels of social support, and structural conditions within host communities [118, 119]. Studies conducted in low- and middle-income countries further highlight the increased vulnerability of displaced populations due to limited access to resources. These conditions intensify social isolation and reduce adaptive capacity [120]. Meta-analytic evidence from child samples indicates that psychosocial interventions implemented during early school age produce moderate but stable positive effects on social functioning and emotional regulation [121].

Taken together, these findings suggest that psychosocial adaptation in forced displacement is a prolonged and context-dependent process. Effective support requires sustained social resources, early intervention, and sensitivity to structural and environmental constraints affecting displaced populations.

Overall, the reviewed evidence indicates that psychosocial adaptation and social functioning in war-affected populations are shaped by the combined influence of traumatic experiences, prolonged social instability, and contextual support conditions. International studies primarily focus on post-migration stressors and their impact on social integration among refugees, whereas Ukrainian research emphasizes adaptation processes unfolding under ongoing internal conflict. Ukrainian publications also highlight the role of collective identity, family systems, and educational environments as key spaces of social adaptation. Across both international and Ukrainian research, vulnerable groups demonstrate persistent impairments in social functioning alongside preserved adaptive resources. The effectiveness of psychosocial interventions is consistently shown to depend on the availability of social support, institutional capacity, and broader structural conditions under wartime circumstances.

Clinical and physiological health under stress conditions

Findings from Ukrainian clinical and physiological studies confirm conclusions drawn from international systematic reviews indicating that chronic stress related to armed conflict exerts a pronounced and multi level impact on somatic health that extends beyond purely mental consequences [4, 11, 12, 13]. In particular, evidence from child and adolescent samples in Ukraine demonstrates a combination of somatic and psychosomatic manifestations, including fatigue, emotional lability, anxiety, and reduced adaptive reserves. These patterns are consistent with international observations highlighting the heightened vulnerability of minors to prolonged stress and unstable living conditions [93, 94].

In contrast to reviews primarily focused on

refugees and humanitarian crises, Ukrainian studies provide a more detailed characterization of the clinical and physiological effects of war under conditions of ongoing conflict and a functioning yet overburdened healthcare system. This is reflected in documented declines in quality of life, increased cardiovascular risk, and worsening trajectories of chronic diseases, including arterial hypertension and endocrine disorders [97, 98, 100, 101, 102]. These findings are conceptually consistent with evidence on stress induced cardiovascular dysregulation and barriers to healthcare access in crisis settings [4, 13].

An additional contribution of Ukrainian research lies in the use of objective physiological stress markers, including indicators of allostatic load. This approach extends the interpretation of clinical and physiological consequences of war by incorporating laboratory confirmed alterations in immune and regulatory systems [99]. Alongside this, studies addressing dietary behavior and lifestyle patterns among students, adults, and pregnant women emphasize the role of indirect mechanisms, such as disrupted eating routines, reduced physical activity, and increased harmful habits, in shaping long term somatic risks [95, 96, 103, 104, 105, 106]. These findings complement international evidence on the multifactorial nature of stress related health disturbances [11, 12].

International research further confirms that prolonged exposure to war results in long-lasting clinical and physiological consequences. These effects are manifested through both somatic complaints and objective indicators of health deterioration [4, 11, 12, 13]. The concept of weathering suggests that war related trauma during adolescence and early adulthood is associated with the accumulation of somatic symptoms and poorer health outcomes in later life, reflecting biological wear resulting from sustained stress exposure [122]. Population level data from protracted conflict zones indicate unfavorable blood pressure trajectories and increased cardiovascular risk among individuals exposed to war related trauma, underscoring the physiological embodiment of chronic stress [123]. Synthesizing reviews demonstrate that war affects health not only through direct mechanisms but also via disruption of healthcare systems, deterioration of living conditions, and restricted access to medical services, thereby exacerbating chronic disease burden [124]. Clinical studies among refugees and asylum seekers further confirm close associations between psychological stress, cardiovascular disease, and somatic pain, highlighting the integration of mental and physiological mechanisms [125]. Meta analytic evidence on mortality indicates that cumulative exposure to war related stress is associated with an increased risk of premature death, reflecting the systemic nature of the clinical and physiological consequences of war [126].

Physical activity and sport under wartime conditions

Findings from Ukrainian studies on physical activity and sport under conditions of war are broadly consistent with international evidence indicating a positive role of regular physical activity in reducing psychological distress and maintaining functional capacity among individuals exposed to war related stress [20, 21, 24]. In particular, national studies show that even under severe constraints related to infrastructure, mobility, and safety, it is possible to maintain and adapt training processes through the use of shelters, limited spaces, and modified exercise loads. These adaptations occur without critical performance decline and, in some cases, with preservation or improvement of selected physical fitness indicators [107, 108, 109, 110].

In contrast to studies conducted in refugee camps and humanitarian centers, where physical activity is more often conceptualized as a structured psychosocial intervention [20, 23], Ukrainian evidence reflects the functioning of sport and physical education within an ongoing internal conflict. This perspective expands the interpretation of physical activity by framing it not only as a therapeutic tool but also as a component of everyday functioning, professional preparation, and social resilience under wartime conditions.

Research focusing on veterans and combatants [111, 112] further supports international conclusions regarding the non-pharmacological rehabilitative potential of physical activity. The authors note that regular running- and football-based programs are associated with reduced stress levels, improved psychological well-being, and enhanced social reintegration. These findings are conceptually consistent with international intervention studies reporting reductions in post-traumatic stress disorder, anxiety, and depression following the inclusion of physical exercise in psychosocial support programs [1, 20, 21, 22, 24].

In child and adolescent samples, Ukrainian studies highlight the high vulnerability of physical activity levels to remote education, stress exposure, and safety restrictions, which is consistent with observational evidence from other conflict and post conflict settings. At the same time, targeted forms of physical education and structured exercise programs have been shown to partially compensate for activity reduction and to exert beneficial effects on functional status and anxiety levels [113, 114].

Studies conducted in contexts of armed conflict and forced displacement consistently confirm the potential of physical activity and sport as non-pharmacological resources for supporting mental and physical health. Pragmatic randomized controlled trials carried out in refugee camps demonstrate that structured exercise and sport

programs lead to reductions in symptoms of post traumatic stress disorder, anxiety, and depression, alongside improvements in overall mental state [20, 23]. Additional evidence indicates concurrent positive changes in physical fitness indicators and cardiometabolic risk profiles, underscoring the multidimensional effects of physical activity under conditions of chronic stress [127, 128, 129]. Systematic reviews and meta analytic studies further confirm that sport and physical activity programs exert stable positive effects on the mental health of children, adolescents, and adults in post conflict and humanitarian settings, despite substantial variability in implementation conditions and intervention designs [130, 131]. Collectively, international evidence supports the view that physical activity represents a universal, culturally adaptable, and relatively accessible tool for psychosocial support under conditions of war, complementing clinical and social forms of assistance.

The findings of this review should be interpreted within the context of the war in Ukraine as a prolonged and high intensity armed conflict that differs in scale and duration from many contemporary military crises. Chronic hostilities, extensive civilian involvement, repeated disruption of basic living conditions, and persistent uncertainty shape a distinctive stress profile and limit direct comparability with short term or localized conflicts. Within this context, the predominance of descriptive and observational study designs in Ukrainian publications reflects objective structural and ethical constraints associated with conducting research during active warfare, rather than methodological weakness.

The synthesis across the four thematic domains indicates that the impact of the war in Ukraine is systemic and multi level, affecting mental health, psychosocial adaptation, clinical and physiological functioning, and physical activity within the population. Research on mental health and stress related responses remains the most extensively represented domain, reflecting the central role of chronic stress, trauma exposure, and loss of safety in shaping psychological outcomes. Findings related to psychosocial adaptation demonstrate that individual and collective resilience, social support, and institutional resources can partially mitigate adverse effects by sustaining social functioning under prolonged instability. Clinical and physiological studies further reveal that psychological distress is closely interconnected with somatic health disturbances, lifestyle changes, and objective physiological markers of stress, resulting in cumulative health burden. Finally, evidence from studies on physical activity and sport shows that, when adapted to wartime conditions, physical activity may function as an effective non

pharmacological resource for maintaining mental and functional health, integrating into broader contexts of rehabilitation and social resilience during armed conflict.

Limitations and Future Research

This systematic review has several limitations that should be considered when interpreting the findings. First, the analysis included publications published predominantly in Ukrainian scientific journals, which determines the specificity of research approaches and data presentation formats. A substantial proportion of the included studies were descriptive or narrative in nature and relied on observational data, while quantitative indicators, standardized measurements, and statistically robust analyses were applied inconsistently.

In addition, the restriction of the search to a single database and to publications in Ukrainian scientific journals limits the external generalizability of the findings. The results reflect the structure of the indexed Ukrainian-language scientific corpus rather than the entirety of global research on war-related health consequences.

Second, heterogeneity in study designs, samples, and methodological approaches limits direct comparability of findings across categories and subcategories. This limitation is particularly evident in studies addressing clinical and physiological indicators and physical activity, where the number of investigations using objective measurements remains relatively small.

At the same time, the specific characteristics of the war in Ukraine, including its prolonged duration, high intensity, and the convergence of military, social, and humanitarian crises, create a unique exposure context that is not fully comparable to earlier armed conflicts. This circumstance increases the scientific relevance of national research while simultaneously highlighting the need for the development of more methodologically rigorous approaches, including the use of validated instruments, longitudinal designs, and expanded statistical analyses.

Future research should prioritize the transition from predominantly descriptive models to analytical and explanatory studies. Particular emphasis should be placed on the integration of mental, physiological, and behavioral indicators within interdisciplinary designs. The accumulation of quantitative data enabling assessment of long term trajectories of war related consequences and evaluation of intervention effectiveness represents a key direction for further investigation.

Conclusions

This systematic review provides a structured thematic mapping of Ukrainian-language scientific publications addressing the impact of the war in Ukraine on population health and functioning. The resulting framework reflects the multidimensional nature of war related consequences and underscores the necessity of examining these effects through an interdisciplinary and integrative perspective.

Synthesis of the available evidence demonstrates that research in this field emerges at the intersection of psychology, medicine, health pedagogy, social adaptation, and physical culture, while remaining characterized by substantial heterogeneity in methodological rigor and analytical depth. This reinforces the importance of systematic organization and comparative analysis of publications as tools for enhancing interpretability and coherence of scientific evidence.

The findings indicate directions for further development of interdisciplinary research models aimed at comprehensive understanding of war-related impacts, while acknowledging the descriptive nature of the current evidence base. The thematic framework established in this review may serve as an analytical basis for future empirical studies, the design of population support programs, and the advancement of health related scientific policy under conditions of prolonged crisis.

Conflict of interests

The authors declare that there is no conflict of interests.

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