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Call for Papers
Volume I, Issue 2(2), Summer 2026
Journal of Advanced Research in Sports: Interdisciplinary Approach

The *Journal of Advanced Research in Sports: Interdisciplinary Approach* (JARSIA) is an international, peer-reviewed journal dedicated to the dissemination of high-quality research that advances understanding of sport, exercise, and physical activity through an interdisciplinary perspective. The journal welcomes original empirical studies, systematic reviews, theoretical papers, and applied research that integrate insights across multiple disciplines to enhance performance, health, and well-being.

JARSIA encourages submissions that connect the biological, psychological, social, and technological dimensions of sport. Areas of interest include, but are not limited to: exercise physiology, biomechanics, sports medicine, injury prevention, sports psychology, coaching science, performance analysis, data analytics, physical education, sports management and business, sports economics and law, and sociocultural studies of sport.

The journal aims to foster collaboration among researchers, practitioners, and policymakers to promote innovation and evidence-based practice in sport and physical activity. By emphasizing methodological rigor and interdisciplinary integration, JARSIA seeks to serve as a leading platform for advancing contemporary research in the sports sciences.

Interdisciplinary Scope and Research Domains

The journal seeks to promote interdisciplinary dialogue and innovative approaches that integrate scientific, clinical, and practical perspectives. By encouraging cross-disciplinary research, JARSIA aims to contribute to a holistic understanding of sport as a multifaceted human endeavor. The scope of the journal includes, but is not limited to:

- Sports Performance (Exercise Physiology and Biomechanics; Physical Activity and Public Health; Physical Education and Pedagogy; Coaching Science and Athletic Performance; Training Design and Periodization; Performance Assessment and Evaluation; Workload Monitoring and Analysis; Performance Enhancement Methodologies and Practices; Accessibility and Inclusive Training Programs; Adapted Physical Activity and Disability Sport);
- Sports Medicine, Health, and Well-Being (Sports Medicine and Injury Prevention; Rehabilitation and Adapted Physical Activity);
- Sport Psychology and Mental Health (Psychological Theory, Research, and Intervention Strategies in Sport and Exercise Psychology; Applied Psychology; Mental Health in Sport; Motivation; Stress Management; Mental Toughness; Cognitive Performance; and Psychological Support for Athletes);
- Technology and Innovation in Sport (Wearable Technologies; Artificial Intelligence; Performance Tracking; Athletic Performance; Digital Technologies; Motion Analysis and Biomechanics; Digitalization in Sport);
- Sports Economics and Law (Sports Analytics and Data Science Applications; Sports Management, Policy, and Business; Socioeconomic Impacts of Sport; Sports Events and Event Economics; Sports and Health Economics; Sport Tourism Economics; Sports Law and Economic Regulations; Sports Sponsorship and Advertising; Sports Marketing; Sporting Goods and Products; Sports Facilities and Infrastructure; Econometric and Statistical Analysis Methods; Sports Betting and Legal Regulations; National and International Sports Organizations; Professional Sports and Clubs; Sport Consumer Behavior; Social Entrepreneurship in Sport);
- Sociocultural Aspects of Sport (Sociology; Sociocultural and Ethical Dimensions of Sport; Active Living; Adventure Sports; Tourism and Recreation Planning; Social Responsibility; Sport's Societal Impact; Sport as a Tool for Social Justice, Inclusion, Equality, and Cultural Integration).

Who Should Contribute to JARSIA

The Journal of Advanced Research in Sports: Interdisciplinary Approach (JARSIA) welcomes submissions from scholars, researchers, and professionals engaged in the interdisciplinary exploration of sports science, medicine, psychology, biomechanics, physiology, coaching, technology, management, education, and sociology. The journal invites high-quality theoretical, empirical, and applied research from diverse academic and professional communities, including:

- Academics and Researchers from diverse disciplines including sports science, medicine, psychology, biomechanics, physiology, education, sociology, economics, management, and data science who contribute to advancing interdisciplinary research in sport, exercise, and physical activity.

- Interdisciplinary Scholars exploring the intersections between biological, psychological, social, technological, and economic dimensions of sport and physical activity, fostering integrative approaches to human performance and well-being.
- Practitioners and Professionals (coaches, sports scientists, healthcare professionals, and performance consultants) applying academic findings to athlete development, injury prevention, rehabilitation, and performance enhancement in both elite and community sport settings.
- Policy Analysts and Advisors, experts within governmental agencies, sport federations, think tanks, and international organizations developing or evaluating evidence-based sport, health, and physical activity policies.
- Data Scientists and Technology Specialists investigating artificial intelligence, wearable technologies, motion analysis, digital performance tracking, and computational models that inform training, strategy, and sport innovation.
- Sports Economists and Management Experts analyzing sports economics, business models, sponsorship, event management, governance, and socioeconomic impacts of sport at local and global levels.
- Sociocultural and Ethical Researchers examining the social, cultural, and ethical dimensions of sport, including inclusion, equality, sustainability, and sport's role in social justice and community development.
- Graduate Students and Early-Career Researchers seeking to contribute innovative, interdisciplinary perspectives that bridge theory and practice in the global sports research community.

All submissions undergo double-blind peer review and must adhere to the COPE standards of publication ethics, ensuring transparency, rigor, and scholarly integrity.

Through this global audience, JARSIA bridges academic research and practical application, creating an inclusive intellectual space for dialogue, innovation, and policy impact.

Publishing schedule and frequency: *Journal of Advanced Research in Sports: Interdisciplinary Approach* is a Quarterly journal published in March, June, September and December.

Deadline for submissions and expected publication schedule:

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1st of May, 2026 for Issue 2(4)	30th of June, 2026
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1st of November, 2026 for Issue 4(6)	30th of December, 2026

The Publisher is committed to a high quality of its contents and the accepted papers will be published online following the completion of the review process and will be included in the forthcoming 'Issue in Progress'. After the completion of the issue, the issue will be published in its final form.

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Journal of Advanced Research in Sports: Interdisciplinary Approach

Epigenetic Markers of Enhanced Athletic Performance Associated with Creatine Monohydrate Supplementation

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Abstract:

Purpose – This study investigates whether long-term creatine monohydrate supplementation is associated with distinct epigenetic modifications linked to enhanced athletic performance. While creatine's physiological effects are well documented, its potential to influence gene regulation through DNA methylation remains largely unexplored.

Design /methodology/ approach – We compared genome-wide DNA methylation profiles (Illumina EPIC850k array) in saliva from resistance-trained adults who had used creatine monohydrate for an average of 6.2 years (n = 107) and non-creatine users with similar training backgrounds (n = 243). Differentially methylated CpG sites were identified using linear modelling with a significance threshold of $p \leq 0.001$ and mapped to genes relevant to muscle physiology, energy metabolism, neuromuscular function, and recovery.

Findings – Sixty-four CpG sites (mapping to 34 genes) showed significant methylation differences between groups. Creatine users exhibited hypomethylation in promoters of genes that support muscle differentiation, angiogenesis, fatty acid oxidation, and cellular recovery (e.g., DYRK2, TLE1, CDH5, PEX10, CYP1A1). Conversely, hypermethylation occurred at loci associated with inhibitory or fatigue-related pathways, such as SST (somatostatin. These methylation patterns collectively suggest an epigenetic profile that may enhance training adaptations, including improved vascularisation, metabolic efficiency, neuromuscular resilience, and anabolic potential.

Originality/ value – This study is the first to demonstrate that chronic creatine supplementation is associated with specific epigenetic signatures related to athletic performance. The findings highlight a potential mechanism by which long-term supplementation could contribute to physiological adaptation through modulation of gene regulation.

Research limitations – As a cross-sectional analysis, causality cannot be inferred, and saliva-based methylation profiles may not fully reflect muscle-tissue epigenetics. Future longitudinal and tissue-specific studies are needed to confirm mechanistic pathways.

Practical implications – These results suggest that creatine supplementation may exert long-term biological effects beyond its immediate ergogenic role, offering potential for personalised training, recovery strategies, and epigenetic monitoring in athletic populations.

Keywords:

Epigenetics, Creatine Monohydrate, Nutrition, Sports Performance, DNA methylation;

MeSH (Medical Subject Headings):

H02.403.830.500, H02.533.645.

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Introduction

Creatine monohydrate is a widely used dietary supplement in sport and exercise, renowned for improving high-intensity exercise performance and muscle hypertrophy. Numerous studies have confirmed that creatine supplementation, combined with resistance training, enhances muscle strength, power, and lean mass gains (Wu *et al.* 2022). Creatine primarily acts by increasing intramuscular phosphocreatine stores, thereby augmenting ATP resynthesis during intense contractions, and can also influence cell hydration and signaling pathways that promote protein synthesis. However, less is known about whether long-term creatine usage can induce lasting changes in gene expression regulation.

Environmental factors like exercise and diet can modulate gene expression through epigenetic mechanisms, including DNA methylation. DNA methylation involves adding methyl groups to cytosine bases (usually in CpG dinucleotides), often leading to altered transcriptional activity without changing the DNA sequence. Changes in DNA methylation profiles can affect the transcription of multiple genes and are increasingly recognized as a mode of adaptation to chronic exercise (Światowy, 2022). A growing body of evidence indicates that exercise training – both endurance and resistance – can reprogram the DNA methylation landscape in skeletal muscle and other tissues, thereby influencing metabolic and structural pathways (Światowy, 2022). Endurance exercise has been shown to induce hypomethylation (and corresponding upregulation) of genes involved in oxidative metabolism in muscle, while resistance training can alter methylation of genes related to muscle growth and differentiation (Światowy, 2022). These exercise-induced epigenetic changes may underlie some of the health and performance benefits of physical activity.

Nutrition and supplements might similarly exert epigenetic effects. Creatines role in energy buffering and training adaptation raises the question of whether chronic creatine supplementation can prime the epigenome in ways that enhance athletic performance. Epigenetic modifications are dynamic and can be influenced by long-term dietary exposures (Plaza-Diaz *et al.*, 2022). If creatine users develop a distinct DNA methylation pattern, this could reflect upregulation of performance-enhancing genes or downregulation of genes that impede muscular adaptation.

To date, few studies have examined the epigenetic impact of nutraceutical supplements in humans. This study focuses on DNA methylation differences associated with prolonged creatine monohydrate use. We profiled genome-wide CpG methylation in saliva of resistance-trained individuals who either consistently used creatine for several years or never used creatine. We hypothesized that long-term creatine use may be associated with differential methylation in genes related to muscle energy metabolism, growth, and recovery. We further postulated that creatine users might exhibit an epigenetic signature that could enhance expression of genes beneficial for athletic performance (e.g. metabolic enzymes, muscle growth factors) or silence genes that could hinder performance (e.g. those related to fatigue or growth inhibition).

One emerging idea is that creatine may influence gene regulation indirectly through the methylation cycle. Endogenous creatine synthesis consumes substantial amounts of S-adenosylmethionine (SAM), a universal methyl donor. Exogenous creatine intake therefore has the potential to ‘spare’ SAM, alter homocysteine levels, and modulate global or locus-specific DNA methylation patterns (Ostojic, and Rátgéber, 2025). Recent epidemiological work has begun to link habitual dietary creatine intake with DNA methylation-derived biomarkers of mortality risk and biological aging, hinting that creatine status may indeed be reflected in the epigenome (Ostojic, and Kavecan, 2025). However, these studies are not designed to address specific performance-related loci or long-term supplementation in trained individuals.

In parallel, research on exercise epigenetics has expanded rapidly. Multiple recent reviews and meta-analyses show that both acute and chronic endurance or resistance training can remodel DNA methylation in skeletal muscle and blood, with changes occurring in promoters, gene bodies, enhancers and intergenic regions (Etayo-Urtasun, Sáez de Asteasu, and Izquierdo, 2024). These exercise-induced methylation shifts often correspond to altered transcription of genes involved in energy metabolism, mitochondrial biogenesis, myogenesis, and inflammatory signaling, and may contribute to the concept of an ‘epigenetic memory’ of prior training. Longitudinal studies in humans suggest that structured training can partially rejuvenate the skeletal muscle methylome and is associated with improved metabolic health (Etayo-Urtasun, Sáez de Asteasu, and Izquierdo, 2024).

We report the differential DNA methylation patterns between creatine users and non-users and map these differences to genes and biological pathways. We interpret whether the affected genes are known to influence athletic capacity – including energy production, muscle hypertrophy, neuromuscular function, and exercise recovery – and discuss how altered methylation might translate to functional effects. This work provides novel insights into the potential epigenetic mechanisms by which a long-term supplementation regime like creatine may contribute to training adaptations and performance enhancements.

1. Method

Study Design and Participants

This study analyzed two groups of resistance-trained adult humans. The Focus group (creatine users, n = 107) consisted of individuals who had been consuming creatine monohydrate (approximately 3.2 g per day) for an average of 6.2 years. All focus group members also regularly consumed protein supplements (from various sources) but reported no usage of other sport supplements. The Complement group (non-users, n = 243) included individuals with similar resistance training experience who used protein supplements but had never used creatine.

Key participant characteristics were as follows: the creatine focus group had a mean age of 36 years and was 70% male (30% female), with an average resistance training history of 5.1 years. The non-creatine complement group had a mean age of 32 years and was 60% male (40% female), with an average of 7.2 years of resistance training. Thus, the groups were generally comparable in training status, although the creatine group was slightly older and had a somewhat shorter training duration on average. All participants gave informed consent, and the study was conducted in accordance with institutional ethical guidelines for human research (approval code and details omitted for brevity).

DNA Methylation Profiling

Muhdo Health Ltd repository was accessed using DNA methylation analysis gathered via the Illumina Infinium MethylationEPIC BeadChip (850K) array, following the manufacturer's standard protocols via Eurofins Denmark. This array interrogates over 850,000 CpG sites across the human genome, covering gene promoters, gene bodies, CpG islands, shores, and enhancers. Beta values (proportion of DNA methylated at each CpG site, ranging 0–1) were calculated using Illumina GenomeStudio.

Raw methylation data underwent quality control and preprocessing. Probes with unreliable measurements, we also excluded probes located on the X chromosome to avoid sex bias (given group differences in sex composition). After QC (>99.5%), beta values for each CpG were compared between groups.

Differential Methylation Analysis

We performed differential methylation analysis to identify CpG sites with significantly different methylation between the creatine focus and non-creatine complement groups. A linear model was fitted for each CpG, with group (focus vs. complement) as the main predictor. Given the slight age and sex differences between groups, we examined models adjusting for age and sex; however, as the focus of the study was the creatine effect and the dataset already excluded X-linked CpGs, we present here the unadjusted group comparison results for clarity. Statistical significance was determined by p-value (from moderated t-tests) with a threshold of $p \leq 0.001$ to identify differentially methylated positions. This cutoff was chosen as a balance between stringency and retaining enough CpGs for meaningful interpretation.

From the analysis, we obtained the set of significant CpGs meeting $p \leq 0.001$. For each significant site, the direction and magnitude of methylation difference were noted as the difference in mean beta value between the focus (creatine) and complement (non-creatine) group. A positive difference indicates higher average methylation in the creatine group, whereas a negative difference indicates lower methylation (hypomethylation) in the creatine group relative to non-users.

Annotation and Gene Mapping

Significant CpG sites were annotated to genes using the Illumina MethylationEPIC annotation file (EPIC850kManifest v1.0 annotation). Each CpG is annotated with the associated gene(s). We mapped each significant CpG to its nearest gene(s) and recorded whether the CpG lies in a promoter region (TSS200/TSS1500/5'UTR) or within the gene body. This allowed us to infer potential impacts on gene expression (since promoter methylation typically inversely correlates with transcription, while gene body methylation may correlate positively with gene activity in some cases).

For interpretation, we focused on genes with functions related to exercise performance: energy metabolism, muscle growth and differentiation, vascular and neuromuscular function, and recovery/adaptation processes. We conducted a literature search on each gene to understand its known biological roles, especially any links to muscle physiology or exercise. No formal pathway enrichment test was performed due to the relatively small number of genes, but we qualitatively grouped genes into functional categories.

2. Results

Differentially Methylated CpGs in Creatine Users vs. Non-Users

Genome-wide methylation analysis identified 64 CpG sites (supp info 1) that differed significantly between the creatine focus and non-creatine complement groups ($p \leq 0.001$). These differentially methylated positions (DMPs) were distributed across the genome (on autosomal chromosomes; X-chromosome probes were excluded). Of the 64 significant CpGs, 35 showed lower methylation in the creatine group (negative β), while 29 showed higher methylation in the creatine group (positive β). The average absolute difference in methylation (Δβ) between groups was on the order of a few percent, with the largest differences around 10–12%. Although such differences are moderate in magnitude, they occurred consistently across many individuals and at loci with relevant gene functions, as detailed below.

Each significant CpG was mapped to one or more genes. In total, the 64 CpGs corresponded to 34 unique genes (excluding intergenic sites and duplicate mappings). Table 1 highlights a subset of differentially methylated genes that are functionally relevant to exercise performance, along with the direction of methylation change in creatine users and the potential implications for gene expression and physiology.

Table 1. Differentially methylated genes in creatine users vs. non-users, with methylation differences and putative functional implications

Gene (Symbol)	β (Focus – Complement)	Methylation Change in Creatine Users	Notable Gene Function and Potential Performance Implication
DYRK2	–0.117 (–11.7%)	Hypomethylation at promoter (TSS200)	Encodes a kinase regulating myogenesis. Up-regulation of DYRK2 may promote muscle fibre differentiation (especially fast-twitch fibres) potentially enhancing strength and hypertrophy.
TLE1	–0.070 (–7.0%)	Hypomethylation at promoter (5'UTR)	Transcriptional co-repressor in Wnt/Notch pathways. Reduced methylation suggests higher TLE1 expression; TLE1 can modulate muscle stem cell differentiation (context-dependent effect on muscle development).
CYP1A1	–0.056 (–5.6%)	Hypomethylation at promoter (TSS1500)	Cytochrome P450 1A1, involved in oxidative metabolism of xenobiotics and oestrogen. Up-regulation may improve clearance of exercise-induced metabolites or toxins, potentially reducing oxidative stress.
CDH5 (VE-cadherin)	–0.017 (–1.7%)	Hypomethylation at promoter (TSS200)	Endothelial adhesion protein critical for blood vessel integrity (angiogenesis). Higher CDH5 expression may support capillarization and blood flow to muscles, aiding endurance and recovery.
NOS3 (eNOS)	–0.021 (–2.1%)	Hypomethylation (promoter/5'UTR/exon)	Endothelial nitric oxide synthase produces NO for vasodilation. Change in promotor methylation may reflect elevated NOS3 activity. Enhanced NO production improves exercise endothelial function; NOS3 gene variants associate with elite endurance/power status.
PEX10	–0.022 (–2.2%)	Hypomethylation at promoter (TSS1500)	Peroxisome biogenesis factor, required for fatty acid oxidation. Up-regulation of PEX10 could increase peroxisomal capacity, improving lipid metabolism and energy supply during prolonged exercise.
PHYH	–0.022 (–2.2%)	Hypomethylation at promoter (TSS1500)	Phytanoyl-CoA dioxygenase, a peroxisomal enzyme for branched-chain fatty acid catabolism. Higher expression may enhance utilization of fatty acids for energy, contributing to metabolic flexibility.

Gene (Symbol)	β (Focus – Complement)	Methylation Change in Creatine Users	Notable Gene Function and Potential Performance Implication
ATG4D	–0.025 (–2.5%)	Hypomethylation (gene body)	Autophagy-related protease. Autophagy is crucial for removing damaged cell components and is required for training adaptations. Increased ATG4D expression may improve muscle recovery and endurance capacity via enhanced autophagy.
SST (Somatostatin)	+0.032 (+3.2%)	Hypermethylation (gene body)	Peptide hormone that inhibits growth hormone (GH) release. Hypermethylation in creatine users might indicate lower SST expression, potentially leading to higher exercise-induced GH secretion, which could Favor muscle anabolism and recovery.
POMC	–0.022 (–2.2%)	Hypomethylation at promoter (TSS1500)	Pro-opiomelanocortin, precursor of β-endorphin, ACTH, etc. Up-regulation of POMC could reflect greater β-endorphin release, contributing to higher pain tolerance and improved stress response during exercise.
ACCN2 (ASIC1)	–0.042 (–4.2%)	Hypomethylation (gene body)	Acid-sensing ion channel 1, involved in sensing muscle pH and pain. Exercise training is known to downregulate ASICs to reduce exercise-induced pain. Changes in ACCN2 methylation may indicate reduced ASIC1 activity in creatine users, possibly delaying fatigue and pain onset.
ADARB1	–0.013 (–1.3%)	Hypomethylation (5'UTR and body)	RNA editing enzyme (ADAR2) highly expressed in brain (edits neurotransmitter receptor transcripts). Increased expression could affect neuromuscular junction function or central fatigue resistance via altered RNA editing in neural tissues.
DNM1	–0.040 (–4.0%)	Hypomethylation (gene body)	Dynamin-1, a GTPase in synaptic vesicle recycling. Often neuron-specific; hypomethylation might reflect greater immune-cell DNM1 expression or a systemic proxy for neural adaptation, potentially supporting neuromuscular coordination.
GPRC5C	–0.017 (–1.7%)	Hypomethylation at promoter (TSS1500)	Orphan G-protein-coupled receptor involved in metabolic sensing (e.g., of saccharides and amino acids). Up-regulation might influence energy substrate utilization (e.g., branched-chain amino acid metabolism) and insulin sensitivity, beneficial for exercise metabolism.

Source: by authors.

Table 1. Selected differentially methylated genes in creatine users vs. non-users, with methylation differences and putative functional implications. Negative β indicates hypomethylation in the creatine group (which often corresponds to higher gene expression if in a promoter region), while positive β indicates hypermethylation in creatine group (potentially lower gene expression if in promoter).

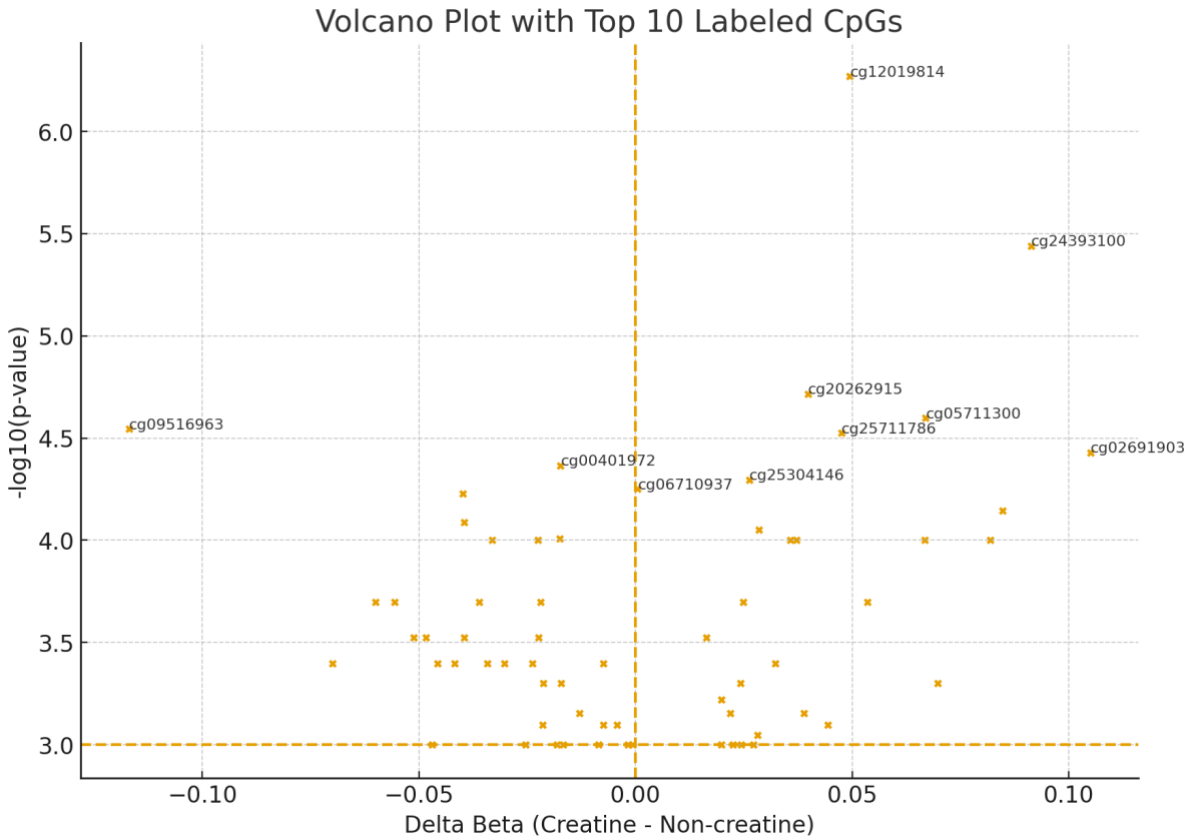
Several clear patterns emerged from the list of differentially methylated genes (Graph 1). Creatine users tended to be hypomethylated relative to non-users at gene loci that are beneficial for exercise performance. For example, multiple genes involved in energy metabolism and mitochondrial/peroxisomal function were hypomethylated in the creatine group: CYP1A1, PEX10, PHYH, and AKR7A3 (an aldo-keto reductase for detoxification) all showed lower methylation, suggestive of higher expression and a more active metabolic system. In addition, genes related to vascular function (NOS3 and CDH5) were hypomethylated, which is consistent with an epigenetic profile favoring better blood flow and oxygen delivery to muscles. A locus in ACCN2 (encoding the acid-sensing ion channel ASIC1) was hypomethylated in creatine users (relative to complement, though the absolute difference was modest). ASIC1 in muscle afferents mediates acute exercise pain (Khataei *et al.*, 2020).

Conversely, creatine users showed hypermethylation (higher methylation) at certain loci that could be considered detrimental to performance if overexpressed. One prominent example is SST (somatostatin), where creatine users had higher methylation. Since somatostatin is a hormone that blunts growth hormone release, its suppression via hypermethylation could remove a brake on anabolic processes, potentially allowing greater muscle and strength gains.

Several genes with multiple CpG sites showed differential methylation lend strength to observations. For instance, the TLE1 gene had two significant CpGs in its promoter/exon region (both hypomethylated in creatine users), indicating a consistent difference in that gene's regulatory region. TLE1 is a transcriptional corepressor that interacts with MyoD and Wnt signaling; persistent hypomethylation could mark a stable upregulation or altered differentiation state. Likewise, PEX10 had at least two CpGs in its promoter region significantly hypomethylated in creatine users, suggesting robust upregulation of peroxisomal biogenesis pathways. The detoxifying enzyme CYP1A1 also appeared at two promoter-proximal sites hypomethylated in creatine users. Recurrent hits in the same gene region underscore that these are genuine differences rather than statistical flukes.

It is also noteworthy that some Y-chromosome genes emerged among the significant CpGs (e.g., KDM5D, NLGN4Y, EIF1AY were annotated for a few top hits). These reflect the higher proportion of males in the creatine group (70% vs 60% in complement), rather than a supplement effect per se. Therefore, these were eliminated.

Figure 1. Volcano plot of CpGs



Source: the authors..

In summary, the DNA methylation differences between groups localized to genes that align with physiological processes important for exercise. Creatine users have an epigenetic profile that in many ways mimics the molecular signatures of exercise training adaptation – for example, higher oxidative metabolism gene activity, greater angiogenic capacity, enhanced muscle differentiation signals, and blunted inhibitory pathways (pain, somatostatin/GH axis). These results suggest that long-term creatine supplementation could be associated with such adaptive epigenetic modifications, which might synergies with training to improve performance.

3. Discussion

This study is the first, to our knowledge, to demonstrate that chronic creatine monohydrate supplementation is associated with distinct DNA methylation patterns in genes linked to athletic performance. We found 64 CpG loci (mapping to 34 genes) that differed in methylation between long-term creatine users and non-users, even though all participants were physically active and consuming protein supplements. The direction of methylation changes in creatine users – with hypomethylation of many performance-enhancing genes and hypermethylation of potential performance-limiting genes – suggests an epigenetic shift toward a more pro-athletic gene expression profile.

Many of the differentially methylated genes have well-established roles in exercise physiology or muscle cell biology. The pattern of hypomethylated promoters in creatine users implies upregulation of those genes. One clear example is endothelial nitric oxide synthase (NOS3). NOS3 produces nitric oxide in blood vessels, a critical mediator of vasodilation that improves muscle blood flow and endurance capacity. Aerobic exercise training is known to increase NOS3 expression and NO bioavailability in the vasculature. We observed lower methylation in NOS3 (creatine vs. non-users), consistent with a potential upregulation of NO production pathways. Genetic studies have previously linked NOS3 polymorphisms to elite endurance and power athlete status (Ramírez-Vélez *et al.*, 2013; Eider *et al.*, 2014), underlining the importance of this gene for performance. The epigenetic finding raises the possibility that creatine supplementation, perhaps via facilitating greater training loads or recovery, might lead to an in vivo increase in NO pathway activity, paralleling the effects of endurance training on the epigenome.

Another notable gene was CDH5 (VE-cadherin), essential for endothelial cell adhesion and new capillary formation. Capillarization of muscle increases with training to enhance oxygen delivery. We found CDH5 hypomethylated in creatine users, suggesting higher expression that could support better vascular adaptation in muscle. Enhanced angiogenesis and blood supply would be beneficial for both endurance and recovery, aligning with creatine users possibly engaging in more intense training due to improved recovery between sessions.

Energy metabolism and mitochondrial/peroxisomal function genes figured prominently in our results. PEX10 (a peroxisome biogenesis factor) and PHYH (phytanoyl-CoA hydroxylase) are involved in fatty acid oxidation. Their hypomethylation in creatine users indicates an epigenetic state favoring lipid metabolism. Improved fatty acid utilization can spare glycogen and delay fatigue in endurance exercise. Similarly, CYP1A1, a cytochrome P450 that helps metabolize various compounds including possibly exercise-induced lipid peroxides or hormones, was hypomethylated at multiple sites. Although primarily known for detoxifying xenobiotics, higher CYP1A1 expression might confer some protection against exercise-induced oxidative stress. Collectively, these changes suggest creatine users may have an upregulated oxidative metabolic capacity at the gene regulation level, which could complement creatine's known role in anaerobic energy buffering by also improving aerobic energy pathways.

Our data also pointed to genes regulating muscle growth and fiber type. DYRK2 (dual-specificity tyrosine-phosphorylation regulated kinase 2) was one of the top hits, with markedly lower methylation in creatine users at a promoter CpG. Recent research in developmental models indicates that DYRK2 positively regulates muscle formation – for instance, overexpressing DYRK2 increases MyoD levels and promotes fast-twitch muscle differentiation. In our context, hypomethylation of DYRK2 could mean it's more highly expressed in creatine users' cells. If this epigenetic upregulation also occurs in muscle tissue (which we did not measure, using saliva as a proxy), it might Favor an increase in fast-twitch muscle fiber development or maintenance. Fast-twitch (Type II) fibers are crucial for power and strength; the very attributes creatine supplementation is known to improve. An epigenetic boost to a kinase that promotes fast-twitch fiber gene programs is a compelling mechanistic link: creatine could be not just acutely improving power output, but chronically helping the body epigenetically commit to a more fast-twitch muscle phenotype.

Another regulatory gene, TLE1, was consistently hypomethylated at its promoter in creatine users. TLE1 is a transcriptional corepressor involved in developmental pathways (Wnt/β-catenin, Notch) that also play roles in muscle stem cell differentiation and regeneration. The functional outcome of increased TLE1 expression in muscle is complex – it might repress certain pro-myogenic genes, but it is also known as an antagonist of adipogenesis in mesenchymal stem cells. One could speculate that higher TLE1 in muscle progenitors might tilt them away from adaptogenic or fibrotic fates and keep them in the muscle lineage, potentially aiding muscle quality. This remains hypothetical but warrants investigation.

In terms of recovery and adaptation, creatine users showed epigenetic changes consistent with better stress response. The POMC gene (pro-opiomelanocortin) – which yields β-endorphin and ACTH – was hypomethylated, possibly reflecting an upregulated endorphin system. Exercise is well known to trigger endorphin release that elevates pain threshold and mood ('runner's high') (Cohen *et al.*, 2010). A chronically more active POMC/endorphin system in creatine users might mean they experience less pain and stress during intense exercise, enabling harder training sessions. Another gene, SST (somatostatin), was hypermethylated in creatine users. Since somatostatin

inhibits growth hormone release (Chalmers *et al.*, 1979), its lowered expression could permit larger pulsatile GH secretion during and after exercise. GH and downstream IGF-1 are key anabolic and recovery hormones; indeed, studies show creatine users often have training regimens that lead to higher IGF-1 responses. Our data provide a mechanistic hint that epigenetic silencing of somatostatin might underlie an enhanced endocrine environment for muscle growth in creatine users.

Conclusion

This study demonstrates that long-term creatine monohydrate supplementation is associated with distinct DNA methylation patterns in resistance-trained adults, particularly at genes involved in muscle development, energy metabolism, vascular function, neuromuscular signaling, and recovery. Creatine users showed hypomethylation at promoters of genes that may promote muscle fibre differentiation, angiogenesis, fatty acid oxidation, and cellular repair, along with hypermethylation at loci related to inhibitory or fatigue-associated pathways. Collectively, these findings suggest that chronic creatine intake may contribute to an epigenetic profile that supports enhanced training adaptations and athletic performance.

Limitations

Several limitations must be acknowledged. First, the cross-sectional design prevents causal inference; the observed methylation differences may reflect long-term training behaviors, lifestyle variation, or biological characteristics rather than supplementation alone. Second, although sex-linked CpGs were excluded, residual confounding due to age, sex balance, and training history cannot be fully ruled out. Third, saliva-derived DNA provides a non-invasive proxy for systemic epigenetic modifications but may not fully reflect epigenetic states within skeletal muscle, where performance-related adaptations primarily occur. Finally, the statistical threshold used identifies meaningful loci but does not fully account for multiple testing, and effect sizes remain modest.

Future Research

Future studies should adopt longitudinal or interventional designs to determine whether creatine supplementation directly drives epigenetic change and to track methylation dynamics over time. Muscle biopsy–based analyses would allow direct confirmation of the mechanisms suggested by saliva methylation data. Integration of methylation with gene expression, proteomics, metabolomics, and performance metrics would provide a more complete mechanistic understanding. Larger cohorts with balanced demographics and structured training controls would strengthen generalizability. Finally, exploration of whether specific methylation signatures can serve as biomarkers for supplement responsiveness or training adaptation could contribute to personalized sports nutrition and precision performance strategies.

Credit Authorship Contribution Statement:

Christopher Collins: write the contribution of first author choosing the relevant actions, but not limited to (Conceptualization, Investigation, Methodology, Project administration, Software, Formal analysis, Writing – original draft, Supervision, Data curation, Validation, Writing – review and editing, Visualization).

Arturas Puras: write the contribution of the second author choosing the relevant actions, but not limited to (Conceptualization, Investigation, Methodology, Project administration, Software, Formal analysis, Writing – original draft, Supervision, Data curation, Validation, Writing – review and editing, Visualization).

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Journal of Advanced Research in Sports: Interdisciplinary Approach

Optimization of Simple and Choice Reaction Time in Adolescent Football Players

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Abstract:
This study examined junior football players aged 12–14 years competing in the U14 category of the National Football Championship during the 2024/2025 competitive season. The purpose of the research was to monitor changes in reaction time following an eight-month structured training program focused on agility-based exercises. Assessment protocols included both physical variables (reaction speed and agility) and cognitive components (reaction time and task accuracy). Simple reaction time and choice reaction time were evaluated using the Cognitrom Assessment System (CAS++). Measurements were conducted at two time points: before and after the training intervention. Data analysis focused on mean reaction time, number of errors, omissions, and reaction time stability. Statistically significant improvements were observed between pre- and post-intervention assessments for both simple reaction time ($t(19) = 9.509$, $p < .001$, Cohen's $d = 1.94$) and choice reaction time ($t(19) = 6.35$, $p < .001$, Cohen's $d = 1.30$). These findings are consistent with existing literature indicating that reaction time in competitive athletes can be enhanced through targeted training programs. The results suggest that sustained, sport-specific training can significantly improve speed, agility, and reaction time in junior football players, contributing to enhanced overall performance.

Keywords:
junior football players; reaction time; training program.

JEL Classification:
Z20; Z29.

Introduction

A long-term training program for young soccer players should focus on developing motor skills, adapting different functional systems to effort and competition. It should also take into account the unique aspects of the game of soccer. Even at a young age, soccer requires quick reactions to variable and unexpected situations, which trains the child's voluntary attention. During the game, the child focuses on the essential elements – the ball, the position and movements of the opponent – ignoring external stimuli. In this age group (12-14 years), the emphasis is particularly on learning the basic kicks: passing, shooting and dribbling (Fonseca *et al*., 2023, Ihsan *et al*., 2022, Ling *et al*., 2020).

The peculiarities of the football game for 12-14 years old juniors

As a complicated psycho-pedagogical process, sports training aims to influence the complete personality and the entire psycho-behavioral system, which occurs on the basis of biological, functional changes, in addition to the physical development of athletes depending on their degree of motor skills. The reason for this is that the success of performance can only be achieved by carefully examining the determinant components of performance capacity, which has a complex structure combining biological, psychological and social aspects (Lee *et al*., 2024, Marques *et al.*, 2013). After 10-12 years of consistent practice, it is known that young footballers begin to compete at a high professional level. In other circumstances, the training period is reduced or increased due to the special qualities of cultivating sports education in football (Prasetyo *et al*., 2019).

The structure and stages of long-term training for junior footballers must be based on solid principles and compliance with the highest sporting standards, so as to fully utilize the natural abilities of the players and ensure the achievement of the maximum level of performance at an optimal age for its manifestation.

It is important to emphasize the importance of coordination in the development of football players and the requirements of football games, as well as to indicate what the basic coordination elements are and in what situations they are used.

Performance capacity has multiple definitions found in the specialized literature, mainly being given by biological parameters, health status and level of training. The priority factors in achieving high performance in the game of football are presented as a combination of individual talent, the skills of each athlete, the collective value of the team, training (including all training factors), individual and collective attitude as well as the social environment (staff attitude, support from fans, media, etc.) but also financial structures.

Physical training represents 'the performance of athletes especially in competitions and training, because maintaining the sports form of players throughout the competitive period, especially for team sports is one of the central problems in the athlete training system' (Khasanah, and Hariyoko, 2023).

Speed and reaction time in football

The increase in sports performance has offered a different vision of speed and agility, which is why França *et al*., 2022 introduced the term game speed.

Game speed is a 'context-specific ability in which an athlete maximizes sports performance through the application of a sport-specific movement with optimal speed, precision, efficiency, and control - both in anticipation of and in response to major perceptual stimuli and the skill demands of the game' (Buhaș, 2015). This definition implies a series of key elements that affect how we might build an effective game speed development program.

If these responses are not practiced and developed, the player will always risk being slow to respond to the requiered task and therefore unable to maximize his performance, regardless of the innate speed of the capabilities. In addition, the player's ability to react and respond depends on the ability to assume an efficient body position from which to maximize the next movement.

Regarding modern training methods, the SAQ (Speed, Agility, Quickness) method stands out as one of the most effective and validated in the specialized literature (Pearson, 2001; Polman *et al*., 2009).

1. Material and Methods

The research used two computerized psychological tests to assess the reaction time: the simple reaction time test and the reaction time test in choices, implemented through the CAS (Cognitrom Assessment System) platform. The simple reaction test measures the speed of basic sensorimotor processing. Procedurally, a single visual stimulus appears on the screen, to which the participant must immediately respond by pressing a predetermined key.

The platform recorded reaction time (the interval between the appearance of the stimulus and the response), response stability (the variation in the times obtained) and any omissions. The choice reaction test assesses the speed and accuracy of decision-making under conditions of discrimination between multiple stimuli. In this test, different stimuli (e.g., colors or geometric shapes) appear on the screen, each associated with a distinct key, and the participant is instructed to select the appropriate response. The parameters analyzed included the average reaction time, the number of errors (incorrect responses), omissions and performance stability. Both tests were administered at two times: before and after the application of the exercise programs. This approach allowed for the comparison of initial and final performances, in order to highlight the effects of the exercises on the processing speed, attention and reaction capacity of the participants.

Participants

The participants in this study were 20 junior football players, registered at a school sports club in the Oltenia area. Their age ranged between 12-14 years, competing in the 2024/2025 competitive season in the U14 category within the National Football Championship. The participants' guardians were informed about the protocol for conducting the experiment and were informed about the method of testing motor capacity as well as the results recorded by the athletes.

Procedure

The aim of the study is to track the evolution of reaction times, following a training program based on agility exercises, based on the SAQ method for developing coordination capacities in speed training in junior footballers (12–14 years old). The program was conducted over an 8-month period.

Both testing sessions (initial testing and final testing) were conducted under the same environmental and organizational conditions, to ensure the comparability of the results. The tests applied targeted both physical parameters (reaction speed, agility, lower limb strength, specific resistance) and cognitive components (reaction time, accuracy in solving tasks).

Throughout the study, ethical principles in research were respected. Participants were informed in advance about the purpose and conduct of the experiment, expressed their consent to participate, and the data obtained were treated confidentially and used exclusively for scientific purposes. The data were subsequently compared between the two evaluation stages, aiming to quantify the progress achieved.

Materials

Reaction time testing (via the CAS platform)

The research used two computerized psychological tests to assess reaction speed: the simple reaction test and the choice reaction test, implemented through the CAS (Computerized Assessment System) platform. The simple reaction test measures the speed of basic sensorimotor processing.

Procedurally, a single visual stimulus appears on the screen, to which the participant must immediately respond by pressing a preset key. The platform recorded the reaction time (the interval between the appearance of the stimulus and the response), the stability of the responses (the variation between the times obtained) and any omissions.

The choice reaction test assesses the speed and accuracy of the decision under conditions of discrimination between multiple stimuli. In this test, different stimuli (for example, colors or geometric shapes) appear on the screen, each associated with a distinct key, and the participant is instructed to select the appropriate response.

The analyzed parameters included the average reaction time, the number of errors (incorrect answers), omissions and the stability of performance. Both tests were administered at two times: before and after the application of the exercise programs.

This approach allowed for the comparison of initial and final performances, in order to highlight the effects of the exercises on the participants' processing speed, attention, and reaction capacity.

Data analysis

In order to organize the data and test the hypotheses, the statistical analysis program IBM.SPSS.25 (IBM Corp, 2016) was used.

2. Results

Analysis of the data obtained from the simple reaction test revealed a significant improvement in the participants' performances after applying the exercise program. The mean initial reaction time (T1) was 420.2 ms (SD = 232.2), while at the final test (T2) an average of 333.4 ms (SD = 199.9) was recorded.

The difference between the two assessment times was 86.87 ms, with a 95% confidence interval between 67.96 and 105.76 ms.

The paired-samples t-test confirmed the significant nature of this difference, $t(19) = 9.509$, $p < .001$, indicating that the result was not due to chance. Also, the effect size calculated by Cohen's d ($d = 1.94$) shows a very large impact of the exercise program on reaction speed.

Table 1. Simple reaction test results

	Min	Max	Mean	Stdv	Skew.	Kurtos.	t	p	Cohen
RT_simple_T1	249.0	1183.	420.2	232.2	1.94	3.945	9.509	.000	1.94
RT_simple_T2	170.5	1005.	333.4	199.85	2.05	4.699			

Source: Compiled by Authors.

In practical terms, these results suggest that the applied program led to a considerable acceleration of response times, which reflects an improvement in sensorimotor processing and attentional capacity.

Although the data distributions showed some asymmetry (Skewness ≈ 1.9; Kurtosis ≈ 3.9), the consistency of the differences and the magnitude of the effect provide robustness to the conclusion that the intervention had a clear positive effect on the participants' performance on the simple reaction test.

Table 2. Results of the reaction test in choices

	Min	Max	Mean	Stdv	Skew.	Kurtos.	t	p	Cohen
RT_in choices_T1	421.1	3951.1	1276.1	736.48	2.175	7.017	6.349	.000	1.30
RT_in choices_T2	356.9	2858.	1008.2	577.53	1.723	3.818			

Source: Compiled by Authors.

The analysis of reaction times in elections revealed a significant improvement after the application of the exercise program.

At baseline (T1), reaction times ranged from 421.1 to 3951.1 ms, with a mean of 1276.1 ms (SD = 736.48). The distribution showed positive skewness (Skew = 2.175) and a high flatness index (Kurtosis = 7.017), suggesting the presence of extreme values and a high variability of performances.

At the final time point (T2), after the intervention, reaction times decreased, ranging from 356.9 to 2858 ms, with a mean of 1008.2 ms (SD = 577.53). The distribution remained slightly positively skewed (Skew = 1.723) and leptokurtic (Kurtosis = 3.818), but closer to normality compared to T1.

The paired-samples t-test showed a statistically significant difference between the two time points, $t(19) = 6.35$, $p < .001$, confirming the reduction in reaction times after the exercise program. The effect size, calculated by Cohen's d, was 1.30, corresponding to a very large effect.

3. Discussion

Regarding the CAS platform assessment (Cognitrom Assesment System), the analysis of the results obtained in the simple reaction and choice reaction tests highlights a convergent trend: after applying the exercise program, the participants' response times were significantly reduced in both experimental conditions. In the case of the simple reaction, the reduction was approximately 87 ms, with a very large effect size (d = 1.94), indicating a substantial acceleration of basic sensorimotor processing. In the choice reaction test, the difference between the two moments was more pronounced, approximately 268 ms, accompanied by a decrease in interindividual variability and a more balanced distribution of performances. This suggests that the exercise programs not only reduced the average reaction time, but also uniformed the level of performance among the participants.

Conclusions and Further Research

The results obtained confirm the hypothesis that the Work Program applied to junior football players positively influences simple reaction time and reaction time in choices. Thus, the applied exercises had a positive impact on the reaction speed, both in simple situations and in contexts that involve choosing between several options. Overall, it can be concluded that the implemented exercise program contributed significantly to the development of the ability to react quickly and correctly, an essential aspect in activities that require prompt and precise responses to external stimuli.

Football requires the management of a large number of short and repeated high-intensity actions, such as shooting at goal, sprinting, jumping, acceleration and deceleration, often including changes of direction (COD), crucial determinants of success or failure in the game and also good predictors of the level of performance of players (Lockie *et al*., 2018). However, the specialized literature indicates that studies on the development of

coordination are still insufficiently explored (Liakh and Vitkovskij, 2010), although it plays a determining role in the efficiency of technical executions (Gu, 2021). The development of coordination abilities is closely linked to the growth and maturation of children, and the stages of childhood, puberty and adolescence are favorable periods for perfecting this ability (Burhaein *et al*., 2020; Gil *et al*., 2007).

The development of reaction time is also closely linked to the development mechanism of the human body, thus (Kumar, 2017).

Also, according to Rosznay *et al*. (2021), to improve acceleration, it is not enough to introduce a single exercise in training because it cannot constitute the main tool, and no single method is sufficient. It is necessary to develop an integrated approach in which several methods can be combined to streamline the development of speed and agility (Rumf *et al*., 2016).

Several authors in the literature (Papp *et al*., 2022) see the central nervous component as the ability to coordinate and regulate subsequent movements of contraction-relaxation cycles.

Morphological indices are not the same in all sports, but are different. The most commonly used are (Prasetyo *et al.*, 2019), but reaction times remain among the most important of them.

Credit Authorship Contribution Statement:

Amalia-Raluca Stepan: write the contribution of the second author choosing the relevant actions, but not limited to (Conceptualization, Investigation, Methodology, Software, Formal analysis, Writing – original draft, Data curation, Validation, Writing – review and editing, Visualization);

Caius-Ionel Drulă: write the contribution of the second author choosing the relevant actions, but not limited to (Conceptualization, Investigation, Methodology, Software, Formal analysis, Writing – original draft, Data curation, Validation, Writing – review and editing, Visualization);

Sebnem Sarvan Cengiz: write the contribution of the second author choosing the relevant actions, but not limited to (Conceptualization, Investigation, Methodology, Software, Formal analysis, Writing – original draft, Data curation, Validation, Writing – review and editing, Visualization);

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Alexandru-Marian Cosma: write the contribution of the third author choosing the relevant actions, but not limited to (Conceptualization, Investigation, Methodology, Software, Formal analysis, Writing – original draft, Data curation, Validation, Writing – review and editing, Visualization).

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Journal of Advanced Research in Sports: Interdisciplinary Approach

Continental Dimensions of Sports Law and Governance

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Abstract:
As sports have developed into a globalized industry characterized by international competitions, substantial financial investments, and extensive media and commercial interests, effective governance mechanisms have become crucial. This paper examines how different continental jurisdictions regulate and govern sport in order to promote transparency, ethical practices, fair competition, institutional accountability, and protection of stakeholders' rights. The research adopts a comparative legal and governance-based approach, examining regulatory models across selected jurisdictions. The analysis reveals that harmonization of governance standards remains a key challenge in global sport, particularly where national legal systems intersect with international sports regulations. The study emphasizes the need for more coherent and collaborative governance approaches that can mitigate regulatory fragmentation whilst safeguarding the institutional autonomy fundamental to international sporting bodies. The primary objective is to conduct a comparative analysis of sports law across continents, identifying variations in scope. The continental dimensions of sports law and governance reveal a distinct yet interconnected legal system in which sporting governance structures, media and broadcasting rights, match-fixing controls, safeguarding obligations, employment relations, human rights standards, dispute resolution mechanisms, stadium safety, intellectual property regimes, integrity frameworks, sports agency representation, private investment, sponsorship and commercialization, anti-doping regulation, and liability for sports injuries must be coherently integrated to ensure that sport remains ethically governed, commercially viable, and legally sustainable across diverse jurisdictions.

Keywords:
Global Sports Law, Comparative Sports Governance, regulatory compliance in sport, sport dispute resolution, athlete rights and protections, ethics in sport;

JEL Classification:
Z20; Z21; Z28; Z29.

Introduction

Due to the immense commercial, social, and cultural impact of modern sport, sports law has emerged as an indispensable and specialized legal discipline governing the relationships, rights, and responsibilities of stakeholders within the global sports industry. Rather than constituting a single, unified body of law, sports law functions as an interdisciplinary legal framework that draws upon diverse areas of law, including contract law, employment law, intellectual property law, antitrust regulation, taxation, corporate governance, data privacy, and dispute resolution.

The commercialization of sport has significantly expanded the range of actors participating in the industry. Contemporarily, sports teams, leagues, governing bodies, sports agencies, universities, investors, broadcasters, and private equity firms are deeply involved in sport, all of whom require specialized legal guidance to manage

regulatory and business challenges. The sports law plays an essential role not only in resolving disputes but also in facilitating the governance, organization, and sustainable development of the global sports sector.

One of the prominent reasons for the growing importance of sports law is the expansive commercialization and media integration of modern sport. Contemporary sporting events are closely connected to broadcasting networks, digital streaming platforms, global sponsorship agreements, and large-scale merchandising operations. These commercial partnerships generate substantial revenue but also create intricate legal questions concerning broadcasting rights, sponsorship and endorsement agreements, licensing and merchandising arrangements, and the protection of intellectual property such as league trademarks and logos. The additional key legal issues include addressing athlete rights related to the commercial use of their name, image, and likeness (NIL), which has become a major issue in contemporary sports governance.

Sports law plays a pivotal role in ensuring effective governance and regulatory compliance within sports organizations. Modern sports institutions, encompassing professional leagues, international federations, and university athletic conferences, operate in many ways like corporate entities and therefore require structured governance systems and legal oversight. Legal regulation is particularly important in areas such as league governance structures, athlete eligibility rules, anti-discrimination and anti-harassment policies, and compliance with gender equality requirements. Furthermore, sports law addresses issues related to athlete privacy rights, data protection, and the regulation of sports agents and agencies to ensure transparency and accountability within the industry.

The competitive and high-stakes nature of sport inevitably leads to disputes among athletes, teams, agents, leagues, and investors. Sports law provides formal mechanisms for resolving such conflicts efficiently and fairly, often through arbitration or specialized dispute resolution bodies designed specifically for sports-related disputes. Common disputes include breaches of athlete contracts, disagreements over agent fees, conflicts relating to team relocation, ownership disputes among investors, trade disclosure disagreements, and regulatory violations committed by teams or athletes. Effective dispute resolution mechanisms are essential to maintaining stability, fairness, and credibility within the sports industry.

Another significant *raison d'être* of sports law is the protection of athletes' rights and welfare. Although athletes are central to the success and economic value of the sports industry, many have conventionally faced exploitation, discrimination, or unfair contractual conditions. Sports law, therefore, provides essential safeguards related to fair employment contracts, health and safety standards during training and competition, and privacy protections regarding personal information. It also safeguards athletes' rights to control their personal brand, endorsements, and sponsorship opportunities while ensuring compliance with regulations governing athlete agents. In addition, sport law seeks to avert discrimination, harassment, and abuse within sports institutions, thereby promoting a more equitable and respectful sporting system.

Sports law is also important in the development and financing of sports infrastructure, encompassing stadiums, arenas, and training facilities. These large-scale projects frequently involve intricate legal and financial arrangements, such as public-private partnerships, municipal financing mechanisms, environmental regulations, and detailed construction agreements. Legal professionals play an important role in negotiating stadium development agreements, structuring municipal bond financing, ensuring compliance with land-use and environmental laws, resolving construction-related disputes, and drafting licensing agreements for stadium operations (Holland and Knight, n.d.).

Beyond commercialization, governance, and infrastructure development, sports law is vital in addressing major global challenges that affect the integrity and fairness of sport. Issues such as doping, match-fixing, corruption, gender inequality, human rights concerns, and the regulation of emerging technologies have intensified the need for robust legal oversight. In contemporary global sport, law and governance are essential for safeguarding the integrity of sporting competitions, protecting athlete welfare, and ensuring that sport continues to operate in a transparent, fair, and accountable manner.

Continental Analysis of Sports Law and Governance

Sports law and sports governance are regarded as **key domains** essential for regulating and overseeing global sport (Kamenecka-Usova *et al*., 2025). The continental perspective on sports law and governance provides critical insights into how legal norms and governance practices converge, diverge, and adapt across jurisdictions. Sports law has advanced far beyond a niche discipline and has become a multidimensional domain with global relevance, reflecting the intricate interplay of regulatory, commercial, human rights, and technological considerations that define contemporary sport.

At its core, sports law encompasses the legal norms, principles, and jurisprudence governing sports activities and legal relationships among athletes, federations, clubs, sponsors, and regulators. It includes areas

such as Contract Law, Labor Law, Commercial Law, Competition Law, Human Rights Law, IP and IT law, and dispute resolution through arbitration or national courts. Conventionally fragmented along national lines, the field is now shaped by international regulations, private governance mechanisms, and public law principles.

Recent developments reflect the dynamic and advancing nature of global sports law. Athlete rights movements, governance reforms, legal challenges to eligibility rules, the integration of ESG and sustainability metrics, and the rise of artificial intelligence in athlete monitoring and fan engagement have all introduced novel legal issues. Concurrently, concerns over sports washing have intensified scrutiny under human rights due diligence frameworks. Global sports law is progressing into a hybrid legal order, blending private regulation with public oversight, commercial interests with human rights protections, and local enforcement with transnational norms (Keller, and Wiki, 2025).

Global sports law encompasses an integrated system that governs the **organization, commercialization, and ethical conduct** of sport across jurisdictions. It regulates governance structures and compliance mechanisms, guides sports finance and the development of facilities and stadia, and oversees brand management, licensing, sponsorships, and event operations. Legal oversight ensures integrity and ethical standards, including anti-doping, fair play, and responsible gambling, while strategic rights management safeguards broadcasting, media, and intellectual property interests. Dispute resolution mechanisms, including arbitration and specialized tribunals, provide efficient resolution for conflicts, while athlete representation, covering contracts, image rights, and endorsements, remains a central focus (Foster, 2003).

Sports Law and Governance in Asia

Asia constitutes one of the most dynamic and heterogeneous regions in global sports. The region encompasses a wide spectrum of laws, economic capacities, and governance structures, ranging from **well-established and highly institutionalized regulatory regimes** to **jurisdictions where sports governance mechanisms are still emerging and undergoing institutional consolidation.**

The growing commercialization and professionalization of sport across Asia, along with increasing participation in global competitions, has encouraged governments and sporting bodies to strengthen legal and regulatory mechanisms. These efforts have focused particularly on safeguarding athlete rights, enforcing anti-doping regimes, establishing structured dispute-resolution mechanisms, and promoting ethical governance within sports organizations. Parallel developments have also occurred in areas such as sports broadcasting rights, sponsorship regulation, and the legal management of large-scale sporting events.

However, despite significant institutional progress in several jurisdictions, the region continues to face challenges related to uneven regulatory capacity, varying levels of transparency, and inconsistent enforcement of sports governance standards. Differences in legal infrastructure, political priorities, and institutional capacity contribute to a fragmented regulatory structure. Against this backdrop, this section analyses the sports governance mechanisms and regulatory approaches in selected Asian jurisdictions.

China's Sports Law, enacted in 1995 by the National People's Congress, established the foundational legal framework for sports governance in the country. The law was comprehensively revised in 2022, with the updated version taking effect on January 1, 2023. The revised Sports Law comprises twelve chapters and 122 articles, covering national fitness, competitive sports, anti-doping, sports organizations, and the sports industry, along with sports arbitration and supervision mechanisms (The National People's Congress of the People's Republic of China, 2022).

China's approach to sports law seeks to balance state oversight with market-oriented participation. It confirms state oversight of sports through regulatory structures, administrative practice, and centralized funding, while addressing critical issues such as improving international prestige through athletic success, organizing effective sports associations, and preventing misconduct such as doping and bribery. Concurrently, the legislation also supports **non-governmental initiatives**, allowing market-oriented sports associations to organize and fund sports activity and impose sanctions within their scope (Nafziger, 2004).

Japan's sports law reflects the country's strategic commitment to professionalizing and internationalizing its sports sector. Conventionally, the regulation of sport relied on a combination of association rules and general civil or commercial law, but the hosting of major international events, along with Japan's escalating engagement in global sports governance, has prompted the development of more formalized laws and regulations. Central to this framework is the **Basic Act on Sport (Act No. 78 of 2011)**, which emphasizes principles of governance, integrity, and compliance. The Japan Sports Agency and major federations have been reinforcing governance codes and clearer standards for transparency, athlete welfare, and anti-doping measures. Commercialization has also become a critical component of Japan's sports law. Legal attention is directed toward intellectual property, sponsorship, image rights, and media rights. On the dispute-resolution front, domestic sports actors are showing a preference

for arbitration and mediation mechanisms provided by the **Japan Sports Arbitration Agency (JSAA)** (Scott and Jarret, n.d.).

In Japan, anti-doping activities are overseen by the Japan Anti-Doping Agency (JADA) and formalized through the Japan Anti-Doping Code, aligned with the World Anti-Doping Agency's standards, with the Act on the Promotion of Anti-Doping Activities in Sport enacted in 2018. Integrity and match-fixing are addressed through both criminal sanctions and internal organizational compliance systems, while sports betting remains largely prohibited under the Penal Code except for state-sanctioned lotteries or cases where public agencies are specifically authorized by special laws to operate gambling establishments. Issues of data protection and personal information are governed by Japan's Personal Information Protection Law, which requires clear consent for the use of athlete data (Igarashi et al., 2025).

India's National Anti-Doping Act, 2022, codifies India's obligations under the World Anti-Doping Agency (WADA) framework and establishes mechanisms for the prevention, detection, and sanctioning of doping in sport. The Act empowers the **National Anti-Doping Agency (NADA)** and the **National Dope Testing Laboratory (NDTL)** to conduct strategic testing, and develop educational resources and sensitization programmed for athletes, including specialized content for athletes with disabilities, thereby promoting both fairness and inclusivity in sport (The National Anti-Doping Act, 2022). Beyond anti-doping, India's sports governance mechanism is characterized by a multi-tiered structure in which national federations, state associations, and local sports bodies implement programs ranging from grassroots development to elite competition. Legal instruments and policy initiatives also address athlete welfare, dispute resolution, and institutional accountability, including mechanisms to monitor ethical conduct, prevent corruption, and regulate commercial activities.

Significantly, the Union Government has notified the **National Sports Governance (National Sports Bodies) Rules, 2026,** under the **National Sports Governance Act, 2025**, establishing a statutory framework for the governance of National Sports Bodies and Regional Sports Federations. The Rules define the composition of the General Body and Executive Committee, election procedures, disqualification criteria, and the inclusion of **Sportspersons of Outstanding Merit (SOMs)**, with mandatory representation of women SOMs in both bodies. The Rules stipulate that National Sports Bodies amend their bye-laws in conformity with the Act within six months, while allowing the Central Government discretionary power to relax provisions for up to twelve months in exceptional cases. Notification of these Rules represents a significant step in operationalizing the statutory governance introduced by the 2025 Act, promoting transparency, inclusivity, and structured participation of athletes in the administration of Indian sport (Ministry of Youth Affairs and Sports, 2026).

Sports Law and Governance in Europe

The European sport model is built on a values-based system that emphasizes openness of competitions, promotion and relegation systems, solidarity mechanisms, and close connections between grassroots and elite level sport. Rather than treating sport purely as a commercial industry, the European approach recognizes sport as a social and cultural activity that promotes inclusion, diversity, equality, and community engagement. The governance structures in Europe aim to maintain equilibrium where participation, development, and high-level competition coexist within fairness and sustainability.

The European sports model operates through a combination of autonomous sports federations and oversight by European legal institutions. Sport governing bodies are generally granted autonomy to regulate their respective sports, organize competitions, and establish disciplinary and regulatory rules. However, this autonomy is not absolute; it operates within the boundaries of European Union law. The Court of Justice of the European Union has been instrumental in shaping the model by ensuring that sporting regulations respect EU principles. Through its rulings, the court has attempted to strike a balance between recognizing the 'specificity of sport' and averting governing bodies from abusing their regulatory powers (European Commission, 2025).

A key practical pillar of the European sport model is good governance, which promotes transparency, accountability, democratic decision-making, and athlete participation in sport bodies. Good governance is not only a legal expectation but also a practical necessity to maintain public trust, commercial investment, and fan engagement in contemporary sport. The professional sport generates significant economic activity and media attention; therefore, strong governance mechanisms help preserve the credibility and legitimacy of sporting competitions. This section examines the governance models and legal mechanisms of the European nations.

The **European** Sports Charter (ESC) serves as a significant reference model for the development of sports policy across Europe. It establishes fundamental principles to guide national sports policies and encourages governments to ensure that citizens have accessible opportunities to participate in sport under clear and well-regulated conditions. The Charter assists policymakers in improving existing legislation and developing coherent sports policies that recognize sport's social, educational, and health benefits.

The primary objective of the Charter is to guide governments in designing and implementing legal and policy measures for sport that promote the core values of human rights, democracy, and the rule of law.

The revised European Sports Charter (2021) expands the earlier 2001 version to 20 articles, introducing additional provisions that strengthen its policy relevance. The updated Charter places greater emphasis on ensuring access to sport for all social groups, particularly through investment in inclusive infrastructure and community-based opportunities for physical activity both within and outside educational institutions (Council of Europe, n.d.).

The **ESC** provides a framework for sports policy across Europe, complemented by the **Code of Sports Ethics.** It guides governments in providing citizens with opportunities to participate in sport under structured guidelines. Sport, according to the Charter, should be **accessible to all,** particularly children and young people; **healthy, safe, fair, and ethically sound**; capable of fostering **personal development; environmentally responsible**; protective of **human dignity;** and free from **exploitation.**

Its main achievements include establishing **stable parameters for sports policy,** providing a **common structure and guiding principles** for national sports policies, and ensuring a **balanced division of responsibilities** between governments and non-governmental actors, promoting complementarity and effective governance (COE, n.d.).

Doping poses a serious threat to sports ethics and athletes' health. Historically, it has been the first major concern of the Council of Europe in the field of sport. As early as 1967, the Committee of Ministers adopted the first international legal instrument on this issue. This commitment was subsequently strengthened through the Anti-Doping Convention (1989), and its Additional Protocol (2002) (CoE, n.d.). The Anti-Doping Convention establishes binding legal standards designed to harmonise anti-doping regulations across participating states. It strengthens measures to prevent access to and use of prohibited substances, including anabolic steroids, while promoting the development and funding of effective anti-doping testing programmes. The Convention also links strict compliance with anti-doping rules to the granting of subsidies and support to sports organisations and athletes, thereby reinforcing accountability within the sports system. In addition, it mandates regular doping control procedures during and outside competitions, including in other nations (COUNCIL OF EUROPE, n.d.).

The governance of sports in the **United Kingdom** operates through multiple bodies involving Sport England, UK Sport, and various National Governing Bodies (NGBs) responsible for individual sports. These bodies collectively oversee the development, regulation, and promotion of sport from grassroots participation to elite performance. At the governmental level, the Department for Digital, Culture, Media and Sport (DCMS) oversees sports policy and funding, with objectives that include increasing public participation, enhancing elite athletic performance, and safeguarding the integrity of sport.

The UK sports sector is supported by a structured legal and regulatory mechanism addressing governance, equality, safety, integrity, and commercial regulation. The Sports Governance Code, developed by UK Sport and Sport England, establishes principles of transparency, accountability, and financial probity for funded organisations. Equality in sport is reinforced through the Equality Act 2010, which prohibits discrimination on protected grounds and promotes inclusive access. Safety obligations derive from the Health and Safety at Work Act 1974, which imposes duties on organizers and venue operators to ensure the well-being of participants, staff, and spectators. Anti-doping compliance is regulated by UK Anti-Doping (UKAD), operating in alignment with international standards to uphold fair competition. Additionally, commercial aspects of sport, including sponsorship agreements, broadcasting rights, and athlete contracts, are governed by general principles of contract law alongside regulatory mechanisms established by sport-specific authorities such as domestic leagues and international federations (Singer and Chambers, 2025).

Sports Law and Governance in North America

Sport is a defining and deeply embedded feature of the North American continent, shaping both its cultural identity and regulatory structure. North America has played a foundational role in the development of several organized sports and is characterized by a well-established, commercially driven, and professionally regulated sporting system. This section examines the governance structures and sports law of selected North American nations.

In the **United States**, doping-related conduct may constitute a criminal offence under federal law. The Rodchenkov Anti-Doping Act authorizes U.S. authorities to prosecute individuals involved in doping conspiracies connected to international sporting events involving American athletes, sponsors, or broadcasters. In the United States, doping issues within professional sports leagues are primarily managed through internal regulatory systems established under collective bargaining with players' associations. Each league sets its own drug-testing protocols, typically involving random blood or urine testing conducted by independent laboratories, and determines its list of prohibited substances. Sanctions include fines, suspensions, and, in serious cases, lifetime bans.

In 2018, the U.S. Supreme Court invalidated the Professional and Amateur Sports Protection Act (PASPA), thereby permitting individual states to legalize sports gambling. While the expansion of legal betting increases concerns regarding match-fixing and in-game manipulation, most state laws do not explicitly criminalize match-fixing, relying instead on existing criminal provisions to protect sporting integrity.

At the federal level, the Sports Bribery Act prohibits the bribery-based manipulation of athletic contests, making it a felony to influence a sporting event through corrupt inducements. However, the statute does not address related forms of misconduct such as extortion, insider tipping, or betting by individuals capable of affecting outcomes. Some states have enacted complementary legislation to cover such gaps (Kishner *et al*., 2025).

The United States does not have unified statutory governance for esports. Instead, the industry is governed by a patchwork of existing laws, primarily gambling and wagering regulations, intellectual property rights, contract and labor law, and consumer protection and privacy rules. While this resembles the legal structure for traditional sports, esports raise distinct challenges due to its digital nature and the significant control game publishers exert over their titles.

At the federal level, gambling laws are particularly relevant. Statutes such as the Interstate Wire Act, the Illegal Gambling Business Act, and the Unlawful Internet Gambling Enforcement Act regulate betting activity, including restrictions on interstate wagers and unlawful online gambling transactions. Although certain skill-based contests may fall outside these prohibitions, whether esports qualifies remains unsettled. These laws, not designed with esports in mind, but are increasingly tested.

Intellectual property is another key consideration. Unlike conventional sports, publishers own the underlying games, giving them substantial control over tournaments, broadcasting, sponsorships, and merchandising. This requires careful management of player likenesses, branding, and content usage.

At the state level, regulation varies. For example, New York penal law prohibits unlicensed gambling and permits regulated mobile sports betting, but it remains unclear whether esports falls within the definition of a 'sporting event,' leaving operators in a legal grey area. Additional state laws, such as publicity rights and privacy protections, also apply, particularly in educational esports programs.

The absence of esports-specific regulation has supported industry growth but continues to create legal uncertainty, especially in the context of wagering.

In the United States, several sport-specific tribunals address domestic sports-related disputes. For instance, the American Arbitration Association ('AAA') maintains a dedicated sports division that handles a wide range of matters, including contract disputes, disciplinary actions, and eligibility challenges across multiple sports. It also provides arbitration and mediation services for issues such as doping allegations, sponsorship and endorsement conflicts, and intellectual property disputes.

Similarly, JAMS, an alternative dispute resolution provider, operates a sports resolution division that focuses on disputes involving sports contracts, broadcast rights, safety concerns, and certain intellectual property issues. In addition to these independent bodies, major professional leagues, such as the NFL, MLB, NBA, NHL, and MLS, maintain their own internal ADR mechanisms to resolve disputes involving players, teams, and ownership.

Moreover, the National Collegiate Athletic Association ('NCAA') governs intercollegiate sports, administers its own dispute resolution mechanism. This system addresses violations and penalties involving member institutions and coaches, as well as contractual matters related to student-athlete name, image, and likeness ('NIL') rights.

Separately, the U.S. Olympic and Paralympic Committee operates the Athlete Ombuds office. Although not an ADR forum, this office provides team USA Olympic athletes with confidential, independent advice and assistance on a range of sport-related matters, including applicable rules, policies, and dispute processes.

Not all disputes, however, may be resolved through sports-related tribunals. Matters involving criminal conduct are not subject to arbitration, and claims arising under antitrust or civil rights laws generally fall outside the scope of these forums (Etna et al., 2025).

Sports law and governance in **Canada** operate within a decentralized mechanism, shaped by both federal and provincial authority. At the federal level, the Physical Activity and Sport Act (2003) acknowledge the essential role that physical activity and sport play in Canadian culture and society, and it establishes the foundation for national sport policy. However, governance is largely carried out by National Sport Organizations (NSOs), which regulate their respective sports in alignment with international federation rules. The Canadian Olympic and Paralympic Committees similarly oversee Olympic sport governance, including matters of sponsorship, privacy, intellectual property rights, and athlete eligibility. Dispute resolution is primarily handled by the Sport Dispute Resolution Centre of Canada (SDRCC), created under the federal statute, which provides specialized arbitration through tribunals addressing selection disputes, doping, safeguarding under the Universal Code of Conduct to Prevent and Address Maltreatment in Sport (UCCMS), and appeals. While courts remain available, the SDRCC

serves as the central alternative dispute resolution body in Canadian sport. The system is characterized by a hybrid model that combines statutory mechanisms, policy-based governance and self-regulation, with increasing emphasis on safe sport, integrity, and accountability (Soubliere, 2025).

Sports Law and Governance in South America

Sports law and governance in South America reflect both the region's deep cultural attachment to sport, especially association football, and the growing need for structured regulation, transparency, and international alignment. A defining feature of South American sports governance is its integration with international frameworks. The sports law and governance in South America operate at the intersection of tradition and modernization. This section examines the governance models and sports law of selected South American nations.

Brazilian professional sport is governed under a decentralized framework, primarily established by the Pelé Law (Law No. 9,615/1998), which regulates Article 217 of the Federal Constitution. The national sports system comprises autonomous and private sports governing bodies, leagues, and clubs that operate under their by-laws while coordinating collaboratively within their respective sports modalities. Public entities, including the Secretariat of Sports and the National Sports Council, provide oversight, approving the Brazilian Sports Code and the Anti-Doping Code. The Fiscal Responsibility Sports Law (Law No. 13,155/2015) further enforces principles of transparency, accountability, and sound financial management for professional football organizations.

Athletes are generally protected from civil and criminal liability for ordinary on-field conduct under the Civil Code (Law No. 10,406/2002) and Criminal Code (Decree-Law No. 2,848/1940), with clubs bearing indirect liability. Clubs must maintain life and accident insurance to cover professional risks under the Pele Law.

Doping matters are governed by the Brazilian Anti-Doping Code (aligned with the WADA Code) and enforced by the Brazilian Authority on Doping Control, with adjudication by the Anti-Doping Sports Justice. Athletes are strictly liable for substances in their bodies, while secondary liability extends to those facilitating doping.

Financial controls require clubs to comply with tax, labour, salary, and image-right obligations; failure can result in relegation or loss of subsidies.

Dispute resolution is managed by the Sports Justice system, which includes the Superior Court of Sports Justice, local courts, and disciplinary commissions. Proceedings held before the sports courts are governed by the Brazilian Sports Code. Arbitration is permitted for non-disciplinary matters, and football-specific disputes may go through the CBF National Chamber of Dispute Resolution or the Brazilian Centre of Mediation and Arbitration. FIFA regulations apply to international football disputes, with appeals ultimately heard by the Court of Arbitration for Sport (CAS). While Sports Justice decisions are generally binding, courts may intervene in exceptional cases, and Labor Courts handle athlete employment and transfer disputes grounded in constitutional labor rights (Nascimento Turano and Mariotto, 2019).

Argentina's sports system is governed primarily by Law No. 20,655 (the Sports Law), which promotes sporting activities nationwide and establishes a Registry of Sporting Institutions, mandatory for both amateur and professional participation. The National Sports Agency (created by Decree No. 92/2019) oversees enforcement and operational efficiency. Sports governing bodies operate as non-profit civil associations, with clubs typically following the same structure. Each sport, football, rugby, field hockey, basketball, and volleyball, is regulated by its respective national body: AFA (football), UAR (rugby), CAH (hockey), CAB (basketball), and FeVA (volleyball), all affiliated with their corresponding international federations.

Doping is regulated under Law No. 24,819 (the Anti-doping Law), with sanctions for athletes, managers, and trainers ranging from suspensions to criminal penalties. Sports betting is state-controlled under Law No. 25,295 (the Sports Forecast Law), prohibiting unlicensed betting. Match-fixing is criminalized, with prison terms for individuals offering or accepting illicit payments, alongside additional disciplinary sanctions by governing bodies.

Dispute resolution is handled internally by each sport's governing entities, typically through two-tiered disciplinary tribunals, while access to courts is restricted mainly to employment, civil liability, or exceptional matters. (Palazzi, 2023).

Sports Law and Governance in Africa

The sports industry in Africa is emerging into a dynamic and economically significant sector that accommodates professionals from diverse fields. The global growth of sport has had a profound impact on African nations, contributing not only to economic development but also to social cohesion and cultural exchange. As sport continues to expand in economic and social importance, the role of law will remain critical in ensuring integrity, fairness, and sustainable development across the continent. This section examines the governance models and sports law of selected African nations.

Significant developments in the state regulation of sport in **South Africa** reflect a shift towards greater governmental oversight and accountability in sports governance. The **National Sport and Recreation Act, 1998,** provides the legal mechanism for the promotion and development of sport and recreation in South Africa, establishing a coordinated relationship between the Sports Commission, national sports federations, and related agencies. The Act seeks to address inequalities by promoting equity, democracy, and inclusivity within sporting structures, while also providing formal mechanisms for dispute resolution. It grants the Minister the authority to issue regulations and empowers the Sports Commission, as well as the National Olympic Committee of South Africa (NOCSA) in relation to the Olympic Games, to coordinate, promote, and develop sport nationwide (Republic of South Africa, 1998).

The South African Institute for Drug-Free Sport Amendment Act 33 of 2024 aligns national anti-doping legislation with the World Anti-Doping Agency (WADA) 2021 Code, addressing previous gaps in compliance. The Act clarifies and strengthens the mandate of the South African Institute for Drug-Free Sport (SAIDS), enabling it to operate independently while cooperating with government departments and sporting bodies. Key provisions empower SAIDS to implement centralized doping control programmed, adopt and enforce anti-doping rules, maintain a registered testing pool, manage therapeutic use exemptions, conduct research on performance-enhancing substances, and educate athletes and the public about the risks of doping.

By harmonizing domestic legislation with international standards, the Act safeguards the health and rights of athletes, ensures fair play, and maintains South Africa's eligibility to participate in global competitions. It represents a significant step in reinforcing regulatory compliance, institutional accountability, and the integrity of sport (Doubell et al., 2024).

The **Kenya** Sports Act 2013 was enacted by the National Assembly following years of deliberation, proposals, and consultation. The Act provides a systematic legal mechanism to harness sports for national development, promote drug-free participation, and regulate the administration and management of sports in Kenya. It establishes key institutions, including Sports Kenya, the National Sports Fund, and the Kenya Academy of Sports, and sets out financial provisions, registration and licensing procedures, arbitration mechanisms for sports disputes, and other regulatory measures. The Act is structured into four schedules, covering applicable sports facilities, the constitutions of sports organizations, governance of boards and councils, and transitional provisions.

Sports Law and Governance in Oceania

Oceania presents a vibrant sports law jurisdiction. Sports law and governance in the region constitute a hybrid system that integrates local legal traditions, regional cooperation, and global sports regulation. Whilst nations such as Australia and New Zealand possess well-developed legal systems, other nations continue to develop and advance their governance capacity. This section examines the governance models and sports law of selected Oceanian nations.

In **Australia**, strong governance in sport has become more important as the industry has expanded in scale and influence. A range of sporting codes operate across the country, including football, rugby, cricket, and basketball, each governed by its own body responsible for setting and enforcing rules and regulations.

Sports law in Australia is shaped by a network of both national and international institutions. At the national level, the Australian Sports Commission provides oversight and guidance on governance and policy. Internationally, organizations such as the International Olympic Committee govern standards and practices across sporting disciplines.

Each sporting code maintains its own internal rules and enforcement mechanisms. For example, the Australian Football League operates a tribunal system to address disciplinary issues, while the National Rugby League maintains a similar structure for resolving infractions within its competition.

Beyond these sport-specific systems, the conduct of organizations and individuals is also regulated by general areas of law, including workplace health and safety, intellectual property, and anti-discrimination legislation (Fit Lawyers, n.d.).

Australia has enacted the **Sport Integrity Australia Act 2020** along with the **Sport Integrity Australia Regulations 2020**, both of which are federal legislative instruments with nationwide application. The **National Anti-Doping Scheme** sets out anti-doping rules and defines violations in line with the **World Anti-Doping Code**, providing a consistent mechanism for addressing doping in Australian sport (Conseil de l'Europe, 2023).

The **Sport Integrity Australia Act 2020** establishes Sport Integrity Australia as the primary body responsible for protecting the integrity of sport in Australia through a coordinated national framework. The Act provides for the implementation of the National Anti-Doping Scheme, aligning domestic regulation with international anti-doping obligations, and grants powers to investigate violations, enforce compliance, and maintain records of sanctioned individuals. Significantly, the Act sets out clear objectives, including ensuring fair and honest sporting

outcomes and performances, promoting ethical conduct among athletes and stakeholders, fostering a safe and inclusive sporting environment, and enhancing the reputation and public confidence in sport. Through this structure, the legislation adopts a preventive and unified approach to addressing integrity threats such as doping, corruption, and misconduct across all levels of sport (Department of Infrastructure, Transport, Regional Development, Communications, Sport and the Arts, 2021).

In **New Zealand**, the Sport and Recreation New Zealand Act 2002 forms the cornerstone of the legal and institutional mechanism governing sport and physical recreation. The Act establishes the mandate of Sport and Recreation New Zealand (SPARC) to promote, encourage, and support participation in sport as a matter of public policy and national well-being. Its functions extend beyond mere promotion to encompass the development and implementation of national strategies, allocation of funding in alignment with policy objectives, and the dissemination of research to inform evidence-based decision-making. Importantly, the Act embeds inclusivity and social responsibility within its ambit.

From a governance perspective, the Act integrates regulatory, developmental, and advisory roles by empowering SPARC to facilitate dispute resolution, coordinate stakeholders across national, regional, and local levels, and collaborate with sectors such as health and education. Furthermore, by enabling international representation of government policy interests and supporting infrastructure development, the Act positions New Zealand's sports governance model as one that balances autonomy with state oversight. The legislation exemplifies a structured and inclusive approach to sports law, aligning participation, integrity, and governance (Office of the Auditor-General, 2010).

In New Zealand, the betting market is legal but tightly regulated, with the New Zealand Racing Board (TAB NZ) operating as a statutory, state-controlled body responsible for overseeing wagering on racing and sports. Legislation requires TAB NZ to distribute a portion of gambling revenues to national sporting organizations, making betting a significant source of funding for sport.

To address integrity concerns, the Crimes Act (Match-Fixing) Amendment Act 2014 introduced section 240A, criminalizing match-fixing and spot-fixing where there is intent to influence a betting outcome. Such conduct is treated as obtaining by deception and is punishable by up to seven years' imprisonment. However, the provision is limited in scope, as it does not cover manipulation unrelated to gambling (Lloyd, 2023).

Conclusions and Further Research

As sport has developed into a commercialized and transnational industry, law and governance mechanisms play a central role in administering contractual relations, ensuring institutional accountability, resolving disputes, protecting athletes, and facilitating significant investments in infrastructure and development. Across continents, from established systems in Europe, North America, South America, and Oceania to progressive governance structures in Asia and Africa, sports law reflects a dynamic interplay between domestic regulation, regional cooperation, and global standards.

Beyond its commercial function, sports law plays a critical role in addressing pressing global challenges that threaten the integrity and sustainability of sport. Issues such as doping, match-fixing, corruption, gender discrimination, and human rights violations reflect the need for robust and harmonized legal responses. At the same time, disparities in regulatory capacity and enforcement across jurisdictions continue to pose significant challenges, particularly in developing regions where governance mechanisms remain in transition.

The ongoing digital transformation of the sports industry further amplifies the importance of adaptive legal systems. Data analytics, biometric tracking, and AI-driven insights raise legal issues around athlete privacy, ownership, and consent, particularly when personal information has commercial value. At the same time, digital media, streaming platforms, and virtual experiences are expanding global audiences, making robust intellectual property, media rights, and brand protection strategies essential.

Meanwhile, the rise of esports and virtual sporting systems further blurs the boundaries between conventional sport, gaming, and entertainment, necessitating innovative yet principled regulatory approaches.

In response, governance reforms across continents have emphasized transparency, ethical conduct, and institutional independence, often driven by external scrutiny and high-profile integrity. While meaningful progress has been achieved, the effectiveness of these reforms remains uneven, reflecting the need for international cooperation, regulatory harmonization, and capacity-building. Sports law will remain a pivotal instrument in balancing commercial growth, technological innovation, and ethical responsibility. Its continued advancement is essential to ensure that sport, as a global social and economic institution, remains fair, transparent, and sustainable.

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Analysis of a Multi-Day Fitness Program for Performance Enhancement in Competitive Tennis

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Abstract:
Tennis performance requires the integrated development of explosive power, reactive movement, upper-limb stability, grip strength, and wrist–forearm control. This article analyzes a variation-based fitness program designed for a competitive tennis player, with emphasis on its structure, functional logic, and relevance to tennis-specific conditioning. The study was conducted as an applied sport-science case analysis based on a four-part training program including explosive lower-body exercises, reactive footwork, grip- and ring-based upper-body work, and a specialized wrist–forearm circuit. Exercises were classified according to their main functional objectives and interpreted in relation to the kinetic-chain demands of tennis. The analysis showed that the program had a coherent multi-component structure and a strong sport-specific orientation. Its most distinctive feature was the systematic inclusion of wrist–forearm training targeting flexion-extension control, pronation-supination, rotational strength, grip-related pulling mechanics, and explosive distal action. The combination of lower-limb power drills, upper-limb stabilization, and distal segment specialization suggests an integrated conditioning model aligned with the biomechanical requirements of tennis. The program represents a practical and functionally relevant model for tennis-specific physical preparation. A structured variation-based approach may support the development of explosive power, coordination, grip robustness, and wrist–forearm function in competitive tennis players.

Keywords:
tennis performance; neuromuscular training; reactive strength; sport-specific conditioning; periodized training.

Introduction

Modern competitive tennis imposes complex physiological and biomechanical demands that require the integrated development of strength, explosive power, coordination, reactive ability, and upper-limb control. Tennis performance depends on repeated short-duration, high-intensity efforts, frequent changes of direction, rapid accelerations and decelerations, and the ability to generate force efficiently through the kinetic chain during serves, groundstrokes, and net play. In this context, physical preparation must go beyond general conditioning and should be tailored to the sport's specific movement patterns and neuromuscular requirements (Fernandez *et al.*, 2006; Reid and Schneiker, 2008).

An important aspect of tennis conditioning is the interaction between lower-limb force production and upper-limb force transmission. Stroke execution relies on an efficient kinetic sequence in which force generated from the legs and trunk is transferred through the shoulder, forearm, wrist, and hand to the racket. For this reason, deficiencies in explosive lower-body action, trunk stabilization, grip strength, wrist control, or shoulder stability may reduce stroke efficiency and increase mechanical stress on the upper limb. Accordingly, sport-specific conditioning programs increasingly combine explosive drills, reactive exercises, shoulder stabilization, and forearm-wrist

strengthening within the same training framework (Dines *et al.*, 2015; Shannon *et al.*, 2020; van der Hoeven and Kibler, 2006).

From a scientific perspective, there is growing interest in training models that integrate multiple physical qualities within a sport-specific framework. However, many existing studies still examine isolated training modalities, such as plyometric training alone, resistance training alone, or shoulder-prevention protocols alone. In applied high-performance settings, coaches often use hybrid programs that combine these elements in a highly specific and variation-based manner. Such programs may better reflect the real complexity of tennis preparation, but they are less frequently documented and analyzed in a structured scientific format. Therefore, examining a program that integrates explosive work, neuromuscular control, grip development, wrist-forearm specialization, and coordination drills may offer valuable practical and theoretical insights (Lambrich and Muehlbauer, 2023b).

The concept of exercise variation is also highly relevant. Variation-based programming may help maintain neuromuscular stimulus quality, reduce monotony, improve transfer across related motor tasks, and target complementary components of performance. In tennis, where performance depends on the interaction of strength, speed, coordination, stability, and precision, a varied yet coherent training structure may be more effective than narrowly focused routines. The program follows this logic by distributing different but functionally related exercise categories across several days, while preserving a consistent emphasis on tennis-specific physical qualities (Fernandez-Fernandez *et al.*, 2014; Reid and Duffield, 2014; Reinebo *et al.*, 2024).

The fitness program analyzed in this study reflects precisely this integrated perspective. The training includes a broad range of variations distributed across multiple training days, such as explosive lifts and jumps, BOSU-based unilateral lunges with swing actions, ladder drills, low rebounds, take-off drills, grip-intensive pulling exercises, rope climbing, ring-based bodyweight tasks, elastic-resistance exercises, and a specialized wrist-forearm circuit. Specifically, the program incorporates exercises such as split jerks, TRX squat jumps, 1-leg drop side lunges from BOSU, ladder split drills, low rebounds, towel-grip pull-ups, muscle-up progressions on rings, rope climbing, wrist push-ups, wrist curl pulley work, pronation exercises, hammer-grip internal-external wrist rotation, and explosive supination/internal-rotation actions. These elements indicate that the program was designed not as a conventional strength routine, but as a multi-component conditioning model targeting tennis-relevant neuromuscular capacities (Hansen *et al.*, 2025; Jacquier-Bret and Gorce, 2024; Lambrich and Muehlbauer, 2023a).

Among these components, wrist and forearm conditioning deserves special attention. Tennis strokes place substantial demands on grip function, forearm musculature, wrist stabilization, and rotational control, especially during topspin generation, serve acceleration, deceleration phases, and repeated high-velocity impacts. The training plan shows a strong emphasis on this segment through repeated inclusion of wrist push-ups, fist push-up press variations, wrist curls, pronation work, thumb press elastic drills, forearm biceps curls, and explosive internal/external rotational tasks. This concentration suggests a deliberate attempt to improve both performance-related force transfer and the structural robustness of the distal upper limb (Kibler *et al.*, 2012).

At the same time, the program does not isolate upper-limb development from global athletic performance. Lower-body and reactive components such as split jerks, squat jumps, BOSU drop lunges, skip drills, hip thrusts, ladder drop split-hop movements, and low rebounds indicate a strong focus on acceleration mechanics, elastic force utilization, and unilateral stability. These qualities are essential in tennis, where players must repeatedly produce force from open and semi-open stances, recover balance after strokes, and transition rapidly between offensive and defensive positions. The inclusion of coordination-based and unstable-surface drills further supports the idea that the program seeks to enhance movement control under sport-like constraints rather than merely increase isolated muscular strength (Chandler, 1995; Lambrich and Muehlbauer, 2023c).

Therefore, the present article aims to analyze and frame scientifically a multi-component tennis fitness program based on exercise variations targeting wrist-forearm strength, upper-limb stability, explosive lower-body performance, coordination, and reactive neuromuscular abilities. The working premise is that such an integrated program can provide a more complete support for tennis performance than isolated conditioning methods, particularly when designed around the functional demands of the sport. In this regard, the study seeks to contribute to the literature on sport-specific conditioning by proposing a structured interpretation of an applied training model with direct relevance for competitive tennis.

1. Materials and Methods

This study is structured as an applied sport-science case analysis centered on a variation-based tennis fitness program designed for a competitive player. The methodological approach is based on the scientific examination of a training plan, with emphasis on the internal logic of exercise selection, weekly distribution, functional targeting, and expected contribution to tennis-specific physical performance. Rather than treating the intervention as a generic strength routine, the present study interprets it as a multi-component conditioning model integrating explosive

power, neuromuscular coordination, grip development, shoulder control, and wrist-forearm specialization. This analytical approach is consistent with contemporary tennis-conditioning literature, which advocates multidimensional profiling and sport-specific testing rather than single-capacity assessment.

The participant is a 19-year-old male professional tennis player competing on the ITF circuit. He has an approximate height of 183 cm and a body mass of around 75 kg, which are typical physical characteristics for players at this level. He plays right-handed, using a dominant forehand and a two-handed backhand. Having started tennis at the age of four, he has accumulated approximately 15 years of training experience. His injury history is clear, with no major injuries reported. Currently, he is in the competitive phase of his season, actively participating in ITF tournaments. The program was prepared specifically for this athlete and tailored to his physical preparation needs. The individualized nature of the program was not intended as a general fitness template, but as a player-specific training plan, in line with athlete profiling approaches reported for competitive tennis populations.

The program is organized into Day 1, Day 2, Day 3, and Day 4/Circuit (described in Table 1), with each day emphasizing partially distinct but complementary physical objectives. Across the week, the intervention combines explosive lower-body work, reactive drills, upper-body stabilization, grip-intensive pulling, ring and rope exercises, and specialized distal upper-limb strengthening. This type of microcycle organization is consistent with tennis-specific strength and conditioning models that combine force production, movement efficiency, and local segment robustness within the same weekly structure (Suchomel *et al.*, 2016).

Table 1. Functional organization of the weekly training program

Training day	Main exercise examples	Dominant physical focus	Tennis-related rationale
Day 1	Ride bike @ 90%, Split Jerk, Squat jump TRX, 1-leg BOSU side lunge + swing, ladder splits, one-knee take-off, low rebounds, shoulder shrug, frontal raises	Explosive power, reactive strength, unilateral stability, shoulder preparation	Supports acceleration, elastic force production, lateral movement control, and proximal stability before stroke transfer
Day 2	Fist push-up press, Wrist push-up, Muscle-up rings progression, False-grip rings stand, L-sit, Pull-up towel grip, Climb rope, Elastics	Grip strength, bodyweight upper-body control, forearm loading, scapular stability	Supports racket control, pulling robustness, upper-limb stiffness, and closed-chain stability
Day 3	Ladder drop split hop + take-off push, BOSU side lunge swing racket, Skips, Squat belt, Hip thrust, Back flys, Wrist press, Wrist curl pulley	Reactive movement, movement transfer, lower-body support strength, wrist reinforcement	Supports footwork reactivity, lateral stroke patterns, posterior-chain support, and distal reinforcement
Day 4 / Circuit	Thumb press elastic, ER wrist curl, Wrist push-up, Close-grip pull-up machine, Wrist pronation, Forearm bicep curl, Wrist INT-EXT rotation, Explosive supination, Explosive internal rotation	Wrist–forearm strength, rotational control, local endurance, distal explosiveness	Supports spin production, racket stability, distal control, and repeated stroke-related loading

Source: Compiled by Author.

Day 1 exercises target shoulder support and upper-limb control through one-hand shoulder shrug, frontal floor raises, and shoulder circles. From the methodological point of view, Day 1 can be interpreted as targeting explosive lower-limb power, reactive force production, unilateral balance and force redirection, dynamic coordination, and preparatory shoulder stabilization (Liang *et al.*, 2023; Sheppard and Young, 2006).

Day 2 emphasizes grip strength, pulling strength, scapular and shoulder control, ring-based neuromuscular stability, forearm loading, and bodyweight strength under tennis-relevant upper-limb stress. The presence of false-grip support, towel-grip pull-ups, rope climbing, and wrist push-ups strongly supports the interpretation that distal upper-limb robustness and functional grip transfer are central objectives of the program.

Day 3 combines reactive footwork, unilateral movement reactivity, lower-body force support, posterior-chain reinforcement, upper-body postural assistance, and supplemental wrist strengthening. The use of side-lunge swing-racket movement gives this day a particularly direct tennis-transfer character, since it links movement mechanics with stroke simulation and loading patterns described in contemporary biomechanical studies of serve and stroke execution (Touzard *et al.*, 2023).

Day 4 is presented as a circuit format performed for five rounds, with a 30 s work and 1 min rest. This section of the program is methodologically central to the article because it demonstrates a concentrated intervention

specifically targeting wrist flexion-extension control, pronation-supination capacity, internal-external rotational function, forearm endurance, grip-related pulling mechanics, and explosive distal upper-limb action. The focus of this circuit is well aligned with current evidence on tennis-related upper-limb loading, scapular control, and injury-prevention frameworks (Schwank *et al.*, 2022).

The repeated and varied loading of the wrist-forearm complex suggests that the program was designed not only for strength development but also for functional stabilization and high-velocity control relevant to racket sports. In methodological terms, this supports interpreting the intervention through a kinetic-chain framework, in which distal segment function is inseparable from whole-stroke mechanics and cumulative shoulder-elbow-wrist loading (Martin *et al.*, 2014).

For analytical purposes, the exercises in the program were classified into the functional categories described in Table 2. This classification follows current recommendations for structuring tennis testing and training around discrete but interacting domains such as explosive power, reactive speed, segmental stability, and sport-specific transfer.

Table 2. Classification of exercises by functional objective

Functional category	Exercises from the program	Main adaptation target
Explosive lower-body power	Split Jerk, Squat jump TRX, Take off 1 knee floor, Low rebounds	Rate of force development, take-off ability, elastic response
Reactive and agility work	Splits on ladder, Ladder drop split hop, 100 skips cut time	Footwork speed, reactivity, rhythm, change-of-direction preparation
Unilateral stability and movement transfer	1 leg drop side lunge from BOSU + swing med, Drop from BOSU side lunge swing racket	Lateral balance, deceleration control, transfer to stroke mechanics
Grip and pulling strength	Pull up towel grip, Climb rope, Pull up/Lat Machine close grip	Grip endurance, pulling strength, forearm recruitment
Ring/bodyweight control	Muscle up rings progression, False grip rings stand, L-sit floor, Fist push up press	Closed-chain upper-body stability, scapular control, body tension
Shoulder support	1 hand shoulder shrug, Front floor frontal raises, Cercles shoulder, Back flys, Anteversion, Lateral raises high	Proximal support, shoulder balance, postural reinforcement
Wrist–forearm specialization	Wrist push up, Wrist press, Wrist curl pulley, Thumb press elastic, Wrist PRO, ER wrist curl, Wrist INT-EXT rotation, Explosive SUP move, Explosive INT ROTATION move	Distal strength, pronation-supination control, rotational robustness, local explosiveness

Source: Compiled by Author.

This classification was used to interpret the training logic and to connect exercise selection with the specific physical and biomechanical demands of tennis. In addition, the classification supports later linkage with tennis-specific outcome measures, including serve-related kinematics, stroke velocity, movement quality, and functional screening indices (Xiao *et al.*, 2024).

The program explicitly reports volume and, in many cases, intensity and recovery parameters. Volume is expressed as sets and repetitions or as time-based prescriptions, such as 5 × 30 s bike efforts, 4 × 5 repetitions, 4 × 10 repetitions, or 5 rounds of a circuit. Intensity is reported through bodyweight, medicine ball, elastic resistance, percentage-based loading, or maximal-speed/100% execution descriptors. Rest intervals are generally short, often around 0-1 min, indicating a substantial neuromuscular and metabolic density in several parts of the program.

From a methodological perspective, the intervention can therefore be characterized by multimodal loading, mixed contraction emphasis, short-to-moderate recovery, and high exercise variation across days with local specificity. For future implementation and monitoring, this type of intervention could be paired with a battery including jump and agility tests, closed kinetic chain upper-extremity stability assessments, functional movement screening, and return-to-sport decision frameworks (Smith et al., 2021; Tucci et al., 2014).

2. Results

The analyzed program revealed a **four-part weekly structure** organized around distinct yet complementary training objectives: Day 1, Day 2, Day 3, and Day 4/Circuit. The overall architecture was clearly multi-component, combining explosive lower-limb work, reactive and coordination-oriented drills, bodyweight and ring-based strength exercises, grip-intensive pulling tasks, elastic-resistance work, and a specialized wrist–forearm circuit. This confirms that the program was not designed as a conventional general-strength routine, but as a structured tennis-

specific conditioning model emphasizing both proximal and distal performance factors. The proposed outcome measures for a full intervention study are presented in table 3.

Table 3. Proposed outcome measures for a full intervention study

Domain	Recommended measure	Why it fits this program
Grip and distal upper limb	Handgrip dynamometry	Matches towel-grip pull-ups, rope climbing, false-grip work
Wrist–forearm strength	Wrist flexion/extension dynamometry; pronation-supination testing	Matches wrist curl, pronation, rotation, explosive supination/internal rotation
Explosive lower body	Countermovement jump, squat jump, unilateral jump tests	Matches split jerk, squat jump, take-off drills, low rebounds
Reactivity and footwork	Reactive strength index, short agility test, 5–10 m sprint	Matches ladder drills, split-hop, skips, BOSU movement
Shoulder and upper-limb support	Closed-chain shoulder stability test	Matches ring support, push-up variations, shoulder support work
Tennis-specific transfer	Serve speed, medicine-ball throw, stroke accuracy under movement	Matches kinetic-chain emphasis and swing-racket drills

Source: Compiled by Author.

A central result of the analysis was the high degree of exercise variation embedded across training days. Rather than repeatedly stressing one physical capacity in isolation, the plan distributed performance demands across the week in a coordinated fashion. Explosive actions, unstable-surface drills, upper-limb stabilization, and distal forearm work were interwoven in a way that suggests deliberate targeting of the kinetic chain as a whole.

The first training block was dominated by exercises aimed at explosive strength, reactive force production, and dynamic coordination. This day included high-intensity bike efforts, split jerks performed explosively, TRX squat jumps, unilateral BOSU-based side lunges with swing movement, medicine-ball goalkeeper actions, ladder drills, take-off drills from kneeling position, and repeated low rebounds. In addition, the day ended with shoulder-support exercises such as one-hand shoulder shrug, frontal raises, and shoulder circles. From a performance-analysis perspective, Day 1 produced the following structural findings: a strong emphasis on lower-limb power generation; repeated stimulation of reactive and elastic neuromuscular actions; integration of unilateral stability and redirection mechanics; and inclusion of upper-limb preparatory support rather than isolated maximal strength work. This distribution suggests that Day 1 functioned as the main power and movement-efficiency session of the program.

The second training block showed a different profile, shifting the emphasis toward grip strength, bodyweight control, ring stability, and upper-limb robustness. This day included fist push-up press, wrist push-ups, muscle-up progression on rings, internal-rotation elbow floor work, false-grip ring standing holds, L-sit holds, towel-grip pull-ups, rope climbing, and a seven-exercise elastic-resistance block. The main result from this section of the program was the identification of a clear distal-to-proximal upper-limb conditioning theme. Several exercises required strong grip engagement, high forearm recruitment, scapular control, and stabilization under bodyweight conditions. Towel-grip pull-ups, false-grip ring work, and rope climbing in particular indicate a deliberate attempt to develop: grip endurance, forearm loading tolerance, pulling capacity, shoulder-girdle control, and closed-chain upper-limb stability. Thus, Day 2 appears to have served as the principal grip and upper-body control session within the weekly structure.

The third training block combined reactive footwork with lower-body support strength and additional wrist-oriented work. It included ladder drop split-hop actions with take-off push, BOSU side-lunge swing-racket drills, skip work under timed constraints, squat belt, hip thrust, back flys, anteversion, palm beats, high lateral raises, wrist press, and wrist curl pulley exercises. This session yielded several important findings. First, it reinforced the overall pattern of movement specificity, especially through the side-lunge swing-racket action, which closely approximates tennis-relevant lateral positioning and stroke transition. Second, it introduced posterior-chain support work through hip thrust and squat belt tasks, thereby complementing the more explosive loading of Day 1. Third, it maintained continuity in the distal upper-limb emphasis by including wrist press and wrist curl pulley exercises. As a result, Day 3 can be interpreted as a hybrid session, linking footwork reactivity, stroke-transfer movement, structural strength support, and continued wrist reinforcement.

The fourth training block, presented as a circuit repeated five times with timed work and rest, represented the most specialized and concentrated element of the entire program. It included thumb press elastic, external-rotation wrist curl, wrist push-up, close-grip pull-up or lat machine, wrist pronation, forearm biceps curl, hammer-grip wrist internal-external rotation, explosive elastic supination, and explosive weighted internal rotation. This was

the clearest result of the program analysis: the intervention placed unusually strong and systematic emphasis on the wrist–forearm complex. The circuit targeted multiple mechanical functions of the distal upper limb: flexion-extension control, pronation-supination work, internal-external rotational control, grip-related pulling mechanics, and explosive terminal-segment action. The breadth of this circuit indicates that the program was designed not only to build strength, but also to improve functional resilience, rotational coordination, and force-transfer capacity in the wrist–forearm segment. This finding is especially relevant for tennis, where distal control is essential for racket handling, spin production, stroke acceleration, and impact stabilization.

A major result of the analysis was that the weekly program distributed its content across **five dominant performance domains**:

1. **Explosive lower-body power**, mainly represented by split jerks, squat jumps, take-off drills, and low rebounds.
2. **Reactive movement and agility**, represented by ladder drills, split-hop patterns, and BOSU-based drop-lunge actions.
3. **Grip and pulling strength**, represented by towel-grip pull-ups, rope climbing, and close-grip pull-up/lat machine work.
4. **Shoulder and upper-body stabilization**, represented by shrug, frontal raises, back flys, anteversion, lateral raises, ring support, and elastic work.
5. **Wrist–forearm strength and rotational control**, represented by wrist push-ups, wrist curl pulley, wrist pronation, hammer-grip wrist rotation, explosive supination, and weighted internal rotation.

These findings support the interpretation that the program was deliberately structured to cover the full chain of physical capacities required in tennis, from lower-limb force generation to distal upper-limb control.

Another important result was the identification of a kinetic-chain-oriented training philosophy. The program did not separate lower-body explosiveness from upper-body transfer or distal stabilization. Instead, exercises were sequenced and distributed to reflect the interaction among: force production, balance and unilateral control, upper-body support, grip engagement, and wrist–forearm execution.

For example, the combination of explosive lower-limb drills on Day 1, ring and rope-based grip work on Day 2, movement-transfer drills on Day 3, and a specialized wrist circuit on Day 4 suggests a coherent training rationale in which tennis performance is treated as an integrated motor output rather than a sum of isolated muscle actions.

The program also showed a relatively dense loading structure, with frequent use of short rest intervals, repeated sets, timed efforts, and circuit organization. This implies that the intervention combined not only strength and coordination demands, but also a meaningful conditioning component. At the same time, the exercises varied substantially in modality, including: bodyweight tasks, elastic resistance, medicine-ball drills, unstable-surface exercises, rings, rope climbing, and pulley-based wrist work.

This high variability constitutes an important result in itself, because it shows that the program was organized around functional diversity with sport relevance, rather than repetitive traditional gym loading. In summary, the analysis of the training program produced the results presented in table 4.

The present study examined a variation-based fitness program designed for a competitive tennis player and identified a coherent multi-component conditioning structure centered on explosive lower-limb work, reactive footwork, grip development, upper-limb stabilization, and extensive wrist–forearm specialization. The program was organized across four training blocks and included split jerks, squat jumps, BOSU-based unilateral actions, ladder drills, towel-grip pull-ups, rope climbing, ring-based exercises, elastic-resistance work, and a dedicated wrist circuit. Taken together, these elements support the interpretation that the intervention was designed around the integrated demands of tennis rather than around isolated gym-based strength development.

A primary finding of the program analysis is the strong alignment between exercise selection and the biomechanical logic of tennis performance. Tennis strokes depend on effective force generation from the lower limbs, transmission through the trunk and shoulder complex, and precise delivery through the forearm, wrist, and hand to the racket. In this context, the coexistence of explosive drills such as split jerk, TRX squat jump, one-knee take-off, and low rebounds with grip-intensive and wrist-specific exercises suggests a kinetic-chain-oriented model in which performance is viewed as a linked neuromuscular process. The inclusion of side-lunge swing actions from BOSU and swing-racket drills further reinforces the sport-specific orientation of the program, because these exercises approximate lateral loading, balance recovery, and stroke preparation patterns encountered in match play.

Table 4. Main interpretive findings from the program analysis

Finding	Evidence from the program	Interpretation
Multi-component design	Four distinct blocks combining explosive, reactive, grip, stabilization, and wrist work	The program is integrated rather than isolated by single capacity
Strong wrist–forearm specialization	Dedicated circuit and repeated wrist exercises across days	Distal upper-limb conditioning is a central design principle
Kinetic-chain logic	Lower-limb power coexists with upper-limb and wrist work	Force generation and transfer are trained as linked processes
High exercise variation	BOSU, rings, rope, elastics, ladder, pulley, bodyweight, medicine ball	Variation is used functionally to stimulate complementary adaptations
Tennis specificity	Swing-based drills, lateral lunge patterns, reactive movement blocks	Exercise selection is aligned with stroke and footwork demands

Source: Compiled by Author.

One of the most distinctive aspects of the program is the systematic emphasis on the wrist–forearm complex. The plan repeatedly includes wrist push-ups, wrist press, wrist curl pulley work, thumb press elastic, wrist pronation, forearm biceps curl, hammer-grip internal-external wrist rotation, explosive elastic supination, and explosive weighted internal rotation. This concentration is unusual when compared with many standard tennis conditioning programs, which often privilege general strength, lower-limb power, or shoulder-prevention exercises while treating the distal upper limb more indirectly. Here, by contrast, the wrist and forearm appear as a central target of training. From an applied perspective, this is highly relevant because racket control, spin generation, acceleration at ball contact, and deceleration after impact all place repeated demands on the distal segment. Therefore, the program may offer a useful model for integrating performance enhancement and structural protection of the upper limb within the same conditioning framework.

The grip-oriented content also deserves attention. Towel-grip pull-ups, rope climbing, close-grip pulling, false-grip ring support, and muscle-up progression indicate that the athlete was exposed to repeated gripping under unstable or bodyweight-dominant conditions. This type of loading may have two practical advantages. First, it can improve general grip endurance and pulling strength, both of which support racket handling and repeated upper-limb effort. Second, it may improve force transfer and segmental stiffness in closed-chain contexts, contributing to the overall robustness of the shoulder-elbow-wrist continuum. In tennis, where the upper limb is repeatedly subjected to high-velocity and often asymmetrical stress, this integrated approach may be more functionally meaningful than isolated machine-based strengthening alone.

Another important discussion point concerns the role of exercise variation. The program does not rely on one dominant training modality. Instead, it alternates explosive power work, reactive and ladder-based movement, unstable-surface unilateral drills, ring and rope exercises, elastic-resistance blocks, and specialized wrist circuits. This variation likely serves several purposes. It may maintain the quality of neuromuscular stimulation, reduce monotony, expose the athlete to multiple coordinative demands, and enhance transfer across related movement tasks. In tennis, where performance requires the integration of speed, force, stability, timing, and precision, such structured variation may be especially beneficial. The present program seems to use variation not as random diversity, but as a deliberate organizational principle supporting complementary adaptation.

The lower-body and reactive components of the program also contribute meaningfully to its scientific value. Day 1 and Day 3 contain numerous exercises targeting explosive or reactive performance, including split jerks, squat jumps, take-off drills, low rebounds, ladder drop split-hop actions, and skip-based movement tasks. These elements suggest that the athlete's preparation was not limited to maximal strength or hypertrophy but was oriented toward rate of force development, elastic utilization, and movement reactivity. This is consistent with the demands of tennis, in which players must accelerate over very short distances, decelerate efficiently, reposition laterally, and rapidly re-establish balance before stroke execution. The addition of hip thrust, squat belt, and postural support exercises on Day 3 suggests that the program also sought to provide structural support for these reactive demands.

From a coaching standpoint, the program's structure is particularly valuable because it shows how several training priorities can coexist within one weekly microcycle. Rather than separating "power day," "injury-prevention day," and "tennis-specific day" into disconnected compartments, the plan blends these objectives within an integrated conditioning model. This may reflect the realities of high-performance sport, where practitioners must work efficiently within limited training time and must prioritize transfer over isolation. The program therefore has practical value not only as an example of tennis-specific physical preparation, but also as a possible template for

how coaches can combine explosiveness, coordination, grip work, and distal upper-limb conditioning in a coherent way.

In summary, the present discussion supports the interpretation that the analyzed program constitutes a highly specific and functionally rich model of tennis conditioning. Its most notable contribution is the integration of explosive lower-body training, grip and bodyweight upper-limb work, and an unusually comprehensive wrist–forearm specialization block within one coherent weekly structure. This combination appears well aligned with the kinetic-chain demands of tennis and may offer a useful applied framework for coaches, sport scientists, and performance practitioners working with competitive players.

3. Practical Applications

From an applied perspective, the analyzed program offers several useful directions for coaches, strength and conditioning specialists, and sport scientists working in tennis.

The program demonstrates that tennis conditioning should be organized around functional integration, not isolated strength categories. Coaches should aim to combine explosive lower-limb drills, reactive footwork, shoulder support, grip development, and wrist–forearm strengthening within the same weekly structure. This may improve transfer to match performance more effectively than programs based only on general resistance training.

The findings suggest that wrist–forearm training deserves a more central place in tennis preparation. The analyzed plan shows that distal upper-limb work can be developed systematically through multiple exercise types, including wrist push-ups, pronation-supination drills, rotational loading, and explosive forearm actions. For coaches, this means that wrist and forearm training should not be treated only as injury-prevention accessories, but also as performance-relevant elements linked to racket control, spin generation, and stroke stability.

The program highlights the value of grip-intensive exercises such as towel-grip pull-ups, rope climbing, ring support, and close-grip pulling. These exercises may be especially useful for improving forearm recruitment, shoulder-elbow-wrist integration, and upper-limb robustness under repeated loading. In practical programming, they can be introduced progressively according to athlete level and technical readiness.

The repeated use of ladder work, BOSU-based lateral drills, low rebounds, skip patterns, and take-off actions indicates that reactive and unilateral movement training should remain a constant feature of tennis preparation. These drills are valuable because they address short-distance acceleration, balance recovery, direction change, and stroke preparation mechanics under movement constraints similar to those encountered on court.

The study suggests that variation should be planned functionally. The usefulness of variation lies not in constantly changing exercises without logic, but in selecting different tasks that stimulate complementary capacities while preserving sport relevance. Coaches may therefore use exercise rotation to maintain neuromuscular quality, reduce monotony, and broaden adaptation, provided that the overall structure remains coherent.

The program may be adapted across several practical scenarios:

- **junior performance players**, with reduced load and simplified technical execution;
- **advanced competitive players**, with greater emphasis on explosive and grip-intensive work;
- **return-to-play phases**, with careful progression in wrist–forearm and shoulder loading;
- **pre-season periods**, with higher training density and broader physical emphasis;
- **in-season periods**, with lower volume but maintenance of reactivity, distal control, and grip robustness.

Finally, for applied monitoring, practitioners should consider tracking a combination of: grip strength, wrist control and endurance, jump and reactive measures, shoulder stability, serve speed, and movement efficiency during tennis-specific drills.

These practical indicators would help determine whether a variation-based tennis conditioning model such as the present one produces measurable improvements in both general athletic and sport-specific performance.

In practical terms, the analyzed program provides a valuable model for tennis-specific conditioning by integrating explosive power, reactive movement, grip development, and wrist–forearm specialization within a coherent weekly training structure.

4. Conclusions

The aim of this study is to analyze, from a scientific and applied sport-performance perspective, a multi-component tennis-specific fitness program based on structured exercise variations designed to improve explosive lower-limb power, upper-limb stability, wrist–forearm strength, grip function, coordination, and reactive neuromuscular performance. The program includes a combination of explosive drills, bodyweight and ring-based strength tasks, elastic-resistance exercises, unstable-surface movements, grip-intensive pulling exercises, rope climbing, and a

specialized wrist–forearm circuit, indicating an integrated conditioning model oriented toward the specific biomechanical and functional demands of tennis.

More specifically, the study aims to: characterize the internal structure of the fitness program according to its dominant functional components; examine how exercise variation is used to target complementary performance qualities relevant to tennis; evaluate the expected contribution of the program to the development of explosive power, wrist–forearm conditioning, neuromuscular coordination, and upper-limb control; and provide a scientific framework for interpreting such a training model in the context of competitive tennis preparation.

The present article analyzed a variation-based tennis fitness program and showed that its internal structure reflects a coherent, multi-component conditioning model rather than a conventional general-preparation routine. The program integrates explosive lower-limb work, reactive movement tasks, grip-intensive upper-body exercises, shoulder-support elements, and a specialized wrist–forearm circuit, indicating a training philosophy centered on the functional demands of tennis.

A major conclusion of the study is that the program is strongly organized around the logic of the kinetic chain. Lower-limb force production, lateral movement control, upper-limb stabilization, grip function, and distal wrist–forearm execution are trained as interconnected components of performance. This is especially relevant in tennis, where efficient stroke production depends not only on local muscular strength, but on coordinated force transfer from the legs and trunk toward the racket through the shoulder, forearm, and wrist.

Another important conclusion is that the most distinctive feature of the analyzed training model is the systematic specialization of the wrist–forearm segment. The repeated inclusion of wrist push-ups, wrist curl variations, pronation work, internal-external rotational drills, explosive supination, and weighted internal-rotation actions suggests that the program was deliberately designed to strengthen distal upper-limb function. In practical terms, this may contribute to improved racket control, better force transmission, greater rotational stability, and potentially enhanced resistance to repetitive mechanical stress.

The study also supports the conclusion that exercise variation is used here as a structured methodological principle rather than as simple diversification. The alternation of explosive, reactive, unstable-surface, grip-based, ring-based, and wrist-specific exercises appears to create a broad but functionally coherent stimulus profile. Such an approach may be particularly valuable in tennis, where performance depends on the simultaneous interaction of power, reactivity, coordination, balance, and distal control.

Several limitations are also acknowledged. First, the present article is based primarily on the scientific interpretation of a training program, not on a completed intervention with reported pre-post measurements. As a result, the discussion can identify the logic and potential value of the program, but it cannot yet claim demonstrated causal effects on performance variables. Second, the article focuses on one athlete-specific plan, which limits generalizability. Third, the training program does not include contextual variables such as age, competitive schedule, injury background, or concurrent tennis load, all of which would influence adaptation. For these reasons, the current analysis should be interpreted as a strong applied framework rather than as definitive outcome evidence.

Future research should extend this framework by collecting objective performance and health-related data before and after implementation. Particularly relevant measures would include handgrip strength, wrist flexion-extension strength, pronation-supination strength, countermovement jump, unilateral jump ability, reactive strength index, short-distance acceleration, serve speed, and stroke quality indicators. It would also be valuable to examine whether a program with pronounced wrist–forearm specialization can reduce symptoms associated with overuse in the distal upper limb while maintaining or enhancing stroke performance. Comparative studies could further test whether such an integrated variation-based model produces greater sport transfer than more traditional resistance-based tennis conditioning.

Overall, the analyzed program may be regarded as a relevant applied model for tennis-specific physical preparation. Although the present paper is based mainly on the scientific interpretation of the training plan and not yet on a full intervention with reported pre-post testing, the structure of the program suggests strong practical and theoretical value. Future studies should verify its effects using objective performance indicators, but the current analysis already indicates that this type of integrated conditioning design is well aligned with the physiological and biomechanical requirements of competitive tennis.

Credit Authorship Contribution Statement:

Popirlan Liviu: Conceptualization, Investigation, Methodology, Formal analysis, Writing – original draft, Data curation, Validation, Writing – review and editing.

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Journal of Advanced Research in Sports: Interdisciplinary Approach

Study on the Role of Extracurricular Activities in Student Life Adaptation

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Abstract:
Background: The importance of first-year students' participation in activities for adapting to student life is analyzed.
Methods: The study includes 30 prospective students from different specializations who have been admitted to faculty and 15 current students from different years. We aimed to conduct a study that demonstrates the efficiency of adaptation programs for student life through motor activities, knowledge and self-knowledge activities, lodge games, and team-building activities. At the end of the activities, we applied a 10-item questionnaire to obtain feedback on our proposed program.
Results: The results confirm the specialized literature, highlighting the positive role of extracurricular involvement.
Conclusions: Following participation in the adaptation program for student life, after analyzing the questionnaire results, we observe that extracurricular activities play an important role in adapting to student life, contributing to social integration and personal development.

Keywords:
students; motor activities; adaptation; extracurricular activities; integration; university life;

Introduction

Adaptation to student life represents a complex process, influenced by academic, social, and psychological factors. Extracurricular activities play an essential role in facilitating student integration, contributing to the development of social skills, stress reduction, and increased satisfaction with the university environment. Extracurricular activities are defined as activities organized outside the formal teaching schedule that contribute to the personal and professional development of students (Kuh, 2008). These include volunteering, sports, student organizations, cultural events, or academic projects.

Studies show that involvement in such activities is associated with better integration into the university community and superior academic results (Astin, 1999). However, not all students participate actively, and the real impact on adaptation differs depending on the context.

1. Research Background

The transition from pre-university to university education involves major changes on academic, social, and personal levels. Students face new requirements, increased autonomy, and the necessity of integrating into a different social environment. In this context, adaptation to student life becomes an essential factor for academic success and well-being. Adaptation to student life represents a complex process, influenced by academic, social, and psychological factors. Efficient integration into the university environment involves not only academic performance but also the development of social relationships and personal competencies.

Extracurricular activities are considered an essential instrument in this process. Studies show that participation in such activities contributes to the development of socio-emotional skills and increased satisfaction with the educational experience. For example, research conducted by Feraco and collaborators highlights that

extracurricular activities are positively associated with motivation, self-regulated learning, and overall student satisfaction (Feraco et al., 2023).

In the same sense, the study conducted by Balaguer and collaborators shows that participation in extracurricular activities contributes to the improvement of academic performance, though the impact differs based on individual factors such as age or socio-economic background (Balaguer et al., 2020). This observation indicates that the effects of activities are not uniform and depend on each student's context.

From the perspective of personal development, extracurricular activities contribute to the formation of social and professional competencies. Studies show that involvement in such activities develops skills such as leadership, communication, and initiative, which are essential for integration into the labor market (Assante and Lișman, 2023).

Furthermore, there is evidence regarding the impact on psychological health. Extracurricular activities can contribute to stress reduction and the maintenance of a balance between academic and personal life (Zarazaga-Peláez et al., 2024). This dimension is relevant in the context of student adaptation, where stress represents a major factor.

Regarding academic efficiency, research indicates a positive relationship between participation in extracurricular activities and school performance. However, this relationship is moderated by factors such as consistent involvement and the type of activities performed (Carbonaro and Maloney, 2019).

In the university environment, extracurricular activities are also associated with the development of self-efficacy. Students involved in such activities manifest a higher level of confidence in their own abilities and better adaptation to academic and social demands (Griffiths and Dickinson, 2021).

Additionally, recent research highlights that involvement in extracurricular activities is correlated with autonomous motivation and cognitive engagement, suggesting that extra-curricular active students are, in general, more involved in the educational process as well (Assante and Lișman, 2023).

2. Materials and Methods

The purpose of this article is to analyze the extent to which extracurricular activities contribute to students' adaptation to university life.

Adaptation to student life is a multidimensional process that involves academic, social, and emotional integration. According to Vincent Tinto's model, student success depends on the degree of integration into the university environment.

Extracurricular activities contribute to this integration through:

- The development of social relationships;
- Increasing the sense of belonging;
- The development of transversal skills.

According to Alexander Astin's theory of student involvement, the level of involvement in educational and social activities directly influences personal development and academic performance.

Additionally, George Kuh's research highlights that participation in extracurricular activities increases the degree of satisfaction with the university experience and reduces the risk of dropout.

Research Purpose

The purpose of this study is to analyze the impact of participation in extracurricular activities on the student adaptation process. To implement this program, we sought the most effective means and methods of structuring a team-building program that leads to the adaptation of freshmen to student life.

Working Hypothesis

We considered that by having freshmen participate alongside upperclassmen in shared activities—including motor activities, team building, knowledge and self-knowledge, and socialization—we will facilitate the process of freshmen adapting to student life.

Research Approach

The methodology used includes the application of a questionnaire to a sample of students, and the results highlight a positive correlation between extracurricular involvement and the level of adaptation. The study was conducted based on quantitative research, utilizing the questionnaire method. The questionnaire was administered to all participants at the end of the activities. The sample consisted of 45 students: 30 from the 1st year, 10 from the 2nd year, and 5 from the 3rd year of study.

Instruments

Questionnaire titled: *Questionnaire regarding the impact of extracurricular activities on adaptation to student life*
Instruction: Please check the option that applies to you.

1. Year of study
   Year I
   Year II
   Year III / IV

2. How do you evaluate the experience of the activities conducted at Bughea de Sus?
   Very good
   Good
   Satisfactory
   Poor

3. Did the activities help you integrate better into the group?
   Yes, a lot
   To some extent
   No

4. What type of activities did you like the most?
   Sports activities
   Lodge games
   Group/socialization activities

5. Do you consider that these activities reduce student stress?
   Yes
   Partially
   No

6. Did you interact with new classmates as a result of these activities?
   Yes
   No

7. Would you like to participate in such activities in the future?
   Yes
   No

8. What do you consider to be the main benefit?
   Socialization
   Relaxation
   Personal development

3. Results and Discussions

Item 1 (Table 1)
Total: 45 students

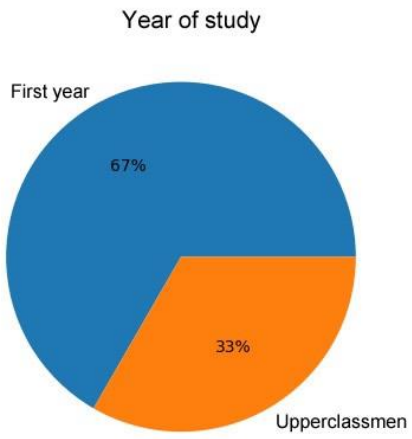
Table 1. Year of study

Category	No.	%
First-year students	30	67%
Upperclassmen	15	33%

Source: Compiled by Author.

The high percentage of first-year students, as seen in Figure 1, indicates the relevance of activities for initial integration.

Figure 1. Item 1 responses



Source: Compiled by Author.

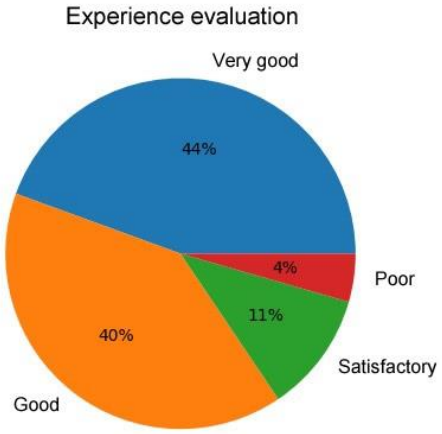
Table 2. Experience Evaluation

Answer	No.	%
Very good	20	44%
Good	18	40%
Satisfactory	5	11%
Poor	2	5%

Source: Compiled by Author.

The majority (84%) evaluate the experience positively. This result indicates a favorable impact of the activity organization.

Figure 2. Item 2 responses



Source: Compiled by Author.

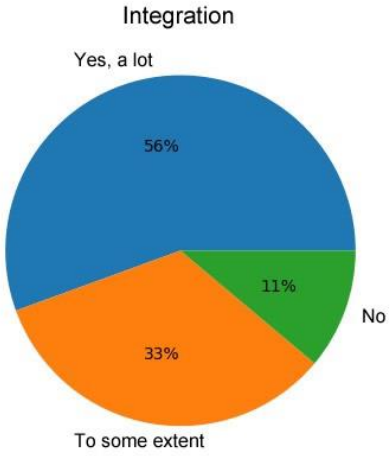
Table 3. Group Integration

Answer	No.	%
Yes, a lot	25	56%
To some extent	15	33%
No	5	11%

Source: Compiled by Author.

Over half of the students consider that the activities contributed significantly to their integration.

Figure 3. Item 3 responses



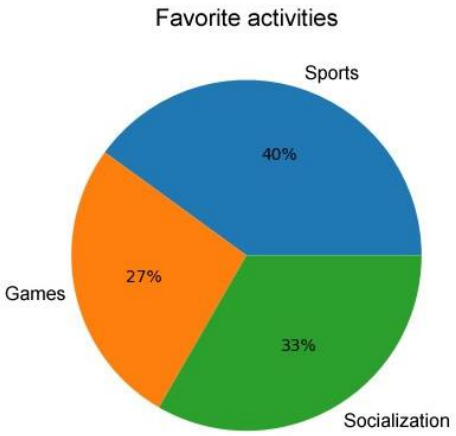
Source: Compiled by Author.

Table 4. Preferred Types of Activities

Answer	No.	%
Sports activities	18	40%
Lodge games	12	27%
Group/socialization activities	15	33%

Source: Compiled by Author.

Figure 4. Item 4 responses



Source: Compiled by Author.

Sports activities are dominant, but the social component remains important.

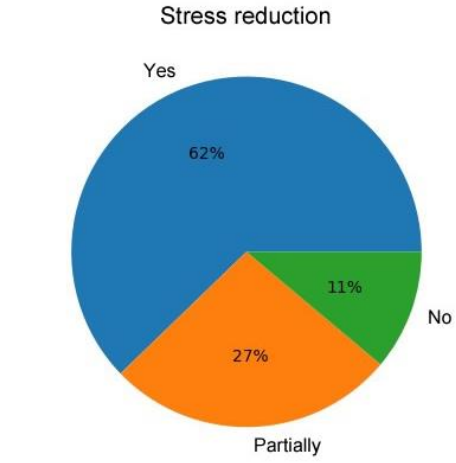
Table 5. Stress Reduction

Answer	No.	%
Yes	28	62%
Partially	12	27%
No	5	11%

Source: Compiled by Author.

The majority of students perceive the activities as an effective method for stress reduction.

Figure 5. Item 5 responses



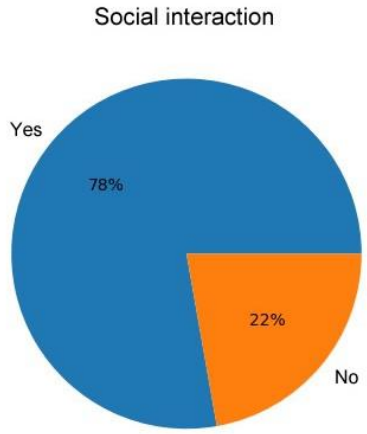
Source: Compiled by Author.

Table 6. Social Interaction

Answer	No.	%
Yes	35	78%
No	10	22%

Source: Compiled by Author.

Figure 6. Item 6 responses



Source: Compiled by Author.

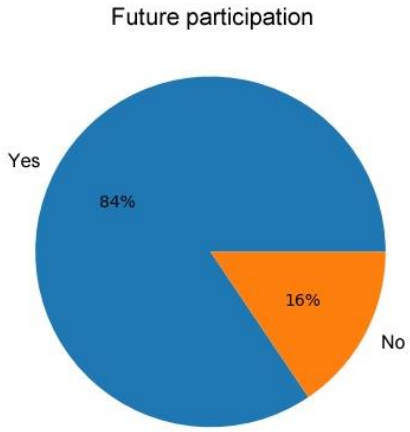
The high level of socialization is essential for student adaptation.

Table 7. Future Participation Intent

Answer	No	%
Yes	38	84%
No	7	16%

Source: Compiled by Author.

Figure 7. Item 7 responses



Source: Compiled by Author.

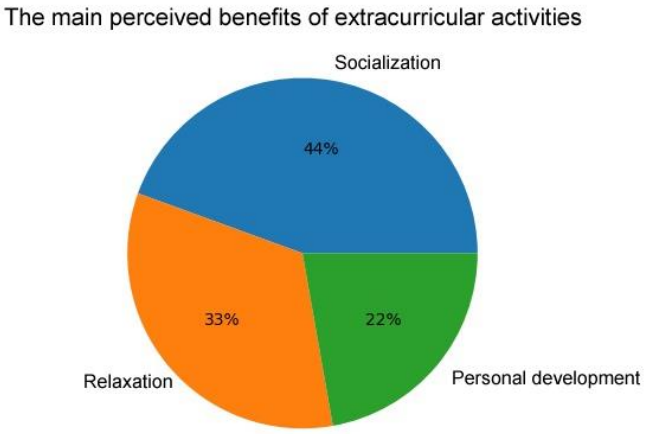
Interest is high for the continuation of these activities, which demonstrates a key indicator of success.

Table 8. Main Benefit

Answer	No	%
Socialization	20	44%
Relaxation	15	33%
Personal development	10	23%

Source: Compiled by Author.

Figure 8. Item 8 responses



Source: Compiled by Author.

The results indicate that the primary benefit perceived by students is socialization (44%), followed by relaxation (33%), and personal development (23%). These data suggest that the social dimension of extracurricular activities plays a central role in the process of adapting to student life.

The high weight of socialization confirms the importance of interaction between students, especially for those in their first year who are in the integration stage. Relaxation is also a relevant benefit, indicating the role of these activities in reducing academic stress. Although personal development has a lower percentage, it remains a significant benefit, suggesting that extracurricular activities also contribute to the formation of individual skills.

The results show that the majority of students participate occasionally in extracurricular activities, while those frequently involved demonstrate a higher level of adaptation.

The main benefits identified:

- Development of social relationships;
- Stress reduction;
- Increased self-confidence.

Students who do not participate cite:

- Lack of time;
- Lack of interest;
- Lack of information.

The results confirm the specialized literature, highlighting the positive role of extracurricular involvement.

4. Conclusions

Extracurricular activities play an important role in adapting to student life, contributing to social integration and personal development.

Active involvement:

- increases satisfaction with the university experience;
- reduces adaptation difficulties;
- supports academic performance.

It is recommended to:

- promote activities within universities;
- facilitate student access;
- integrate these activities into educational strategies.

Credit Authorship Contribution Statement:

Ion-Sebastian Enache: Conceptualization, Investigation, Methodology, Formal analysis, Writing – original draft, Data curation, Validation, Writing – review and editing.

Carmen Enache: Conceptualization, Investigation, Methodology, Formal analysis, Writing – original draft, Data curation, Validation, Writing – review and editing.

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