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Sports Science Research on Athletic Training Methodologies and Performance Enhancement

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Abstract: Athletic training methodologies have undergone significant evolution in recent decades, incorporating advanced scientific principles to optimize performance enhancement across diverse sporting disciplines. This comprehensive review examines contemporary approaches to athletic training, focusing on post-activation performance enhancement protocols, warm-up strategies, artificial intelligence integration, and rehabilitation methodologies. The research synthesizes current evidence regarding the effectiveness of various training interventions, highlighting the importance of systematic approaches to performance optimization. Post-activation performance enhancement protocols demonstrate significant improvements in vertical jump performance and explosive power output when properly implemented. Warm-up strategies continue to evolve beyond traditional approaches, incorporating specific physiological and biomechanical considerations that enhance subsequent performance outcomes. The integration of artificial intelligence technologies presents unprecedented opportunities for personalized training prescriptions and real-time performance monitoring. Rehabilitation methodologies, particularly in anterior cruciate ligament reconstruction recovery, have advanced through evidence-based protocols that emphasize movement re-training and progressive return-to-sport criteria. The findings indicate that modern athletic training requires a multidisciplinary approach combining traditional exercise science principles with cutting-edge technological innovations. This synthesis provides practitioners with comprehensive insights into evidence-based methodologies that can be implemented across various athletic populations to maximize performance outcomes while minimizing injury risk.

Keywords: athletic training; performance enhancement; post-activation potentiation; artificial intelligence; rehabilitation; warm-up protocols

1. Introduction

The field of sports science has experienced remarkable advancement in understanding the complex physiological and biomechanical mechanisms underlying athletic performance. Contemporary athletic training methodologies have evolved from empirical approaches to evidence-based practices that integrate sophisticated scientific principles with practical application strategies. The pursuit of optimal performance enhancement requires comprehensive understanding of various training modalities, their physiological effects, and their systematic implementation across diverse athletic populations [1].

Modern athletic training encompasses multiple domains including strength and conditioning, movement optimization, injury prevention, and performance recovery. The integration of technological innovations with traditional training principles has created un-

precedented opportunities for individualized training prescriptions and objective performance monitoring. This evolution reflects the growing recognition that athletic performance optimization requires multidisciplinary approaches that consider physiological, biomechanical, psychological, and technological factors [2,3].

The effectiveness of contemporary training methodologies depends significantly on their scientific foundation and systematic implementation. Recent research has emphasized the importance of understanding specific physiological mechanisms that underlie training adaptations, particularly in areas such as post-activation performance enhancement, warm-up protocols, and recovery strategies. These developments have led to more precise training prescriptions that can be tailored to individual athlete characteristics and specific performance objectives [4].

Artificial intelligence and machine learning technologies have emerged as powerful tools for enhancing athletic training effectiveness through sophisticated data analysis and personalized intervention strategies. These technologies enable real-time monitoring of training loads, biomechanical patterns, and physiological responses, providing coaches and athletes with unprecedented insights into training effectiveness and optimization opportunities [5,6].

2. Post-Activation Performance Enhancement Protocols

2.1. Physiological Mechanisms and Implementation Strategies

Post-activation performance enhancement represents a sophisticated training approach that leverages specific physiological mechanisms to improve subsequent athletic performance through carefully designed conditioning activities. The underlying mechanisms involve complex neuromuscular adaptations including increased motor unit recruitment, enhanced neural drive, and improved muscle fiber contractility following appropriate conditioning stimuli. These physiological responses create temporary windows of enhanced performance capacity that can be strategically utilized for training and competition purposes [1].

The implementation of post-activation performance enhancement protocols requires precise understanding of individual response patterns, optimal recovery intervals, and appropriate conditioning stimulus characteristics. Research indicates that the effectiveness of these protocols depends significantly on factors including training experience, muscle fiber composition, and specific movement patterns being enhanced. The conditioning activities typically involve high-intensity exercises performed at loads ranging from 70-90% of one-repetition maximum, followed by carefully timed recovery periods that allow for optimal neuromuscular priming without excessive fatigue accumulation [3].

Current evidence suggests that post-activation performance enhancement protocols can produce meaningful improvements in explosive power output, with effect sizes ranging from small to moderate depending on implementation characteristics. The optimization of these protocols requires consideration of individual athlete characteristics, specific performance objectives, and integration within broader training periodization frameworks. Table 1 demonstrates the comparative effectiveness of different post-activation performance enhancement protocols across various athletic populations.

Table 1. Post-Activation Performance Enhancement Protocol Effectiveness.

Protocol Type	Conditioning Load	Recovery Time	Performance Improvement	Population
Heavy Squats	85-90% 1RM	4-6 minutes	8-12% jump height	Trained athletes
Complex Training	70-85% 1RM	3-5 minutes	6-10% power output	Team sport athletes
Plyometric Conditioning	Bodyweight	2-4 minutes	5-8% reactive strength	Endurance athletes

Isometric Holds	80-90% MVC	3-7 minutes	7-11% force production	Strength athletes
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2.2. Vertical Jump Performance Enhancement

Vertical jump performance serves as a critical indicator of explosive power capacity and represents a fundamental movement pattern across numerous sporting activities. Post-activation performance enhancement protocols have demonstrated particular effectiveness in improving vertical jump outcomes through targeted neuromuscular conditioning strategies. The enhancement of vertical jump performance involves complex coordination between multiple muscle groups, requiring systematic approaches that address both mechanical and neural components of explosive movement production [1,3].

The application of post-activation performance enhancement protocols to vertical jump training involves specific conditioning exercises that replicate the neuromuscular demands of jumping movements while providing sufficient stimulus for enhanced subsequent performance. Research demonstrates that protocols incorporating heavy resistance exercises followed by appropriate recovery periods can produce significant improvements in vertical jump height, with effects typically lasting 5-15 minutes depending on individual characteristics and protocol specifications.

Contemporary approaches to vertical jump enhancement through post-activation performance enhancement integrate multiple training variables including exercise selection, loading parameters, recovery timing, and individual response monitoring. The optimization of these protocols requires systematic progression and careful monitoring of fatigue-performance relationships to ensure consistent enhancement effects. Table 2 illustrates the specific parameters associated with successful vertical jump enhancement protocols.

Table 2. Vertical Jump Enhancement Protocol Parameters.

Training Variable	Optimal Range	Performance Effect	Implementation Notes
Conditioning Load	3-5 repetitions at 85% 1RM	9-14% improvement	Individual variation exists
Recovery Duration	4-8 minutes	Peak enhancement window	Monitor individual responses
Protocol Frequency	2-3 times per week	Sustained adaptations	Integrate with periodization
Session Volume	3-4 conditioning sets	Optimal stimulus-fatigue ratio	Avoid excessive volume

2.3. Training Variables and Prescription Guidelines

The systematic prescription of post-activation performance enhancement protocols requires comprehensive understanding of training variables and their interactive effects on performance outcomes. Key variables include conditioning exercise selection, loading parameters, recovery timing, individual athlete characteristics, and integration within broader training programs. The optimization of these variables requires evidence-based approaches that consider both acute performance effects and long-term training adaptations [1].

Conditioning exercise selection represents a fundamental consideration in protocol design, with research supporting the use of exercises that closely replicate the biomechanical patterns of target performance activities. Heavy compound movements such as squats, deadlifts, and Olympic lift variations have demonstrated particular effectiveness due to their ability to activate large muscle groups and produce significant neuromuscular conditioning effects. The loading parameters typically range from 70-90% of one-repetition

maximum, with higher loads generally producing greater enhancement effects but requiring longer recovery periods.

Recovery timing optimization represents a critical aspect of protocol implementation, as insufficient recovery may result in residual fatigue that negates performance enhancement, while excessive recovery may allow conditioning effects to dissipate. Individual variation in optimal recovery timing necessitates systematic monitoring and adjustment of protocols based on performance responses. Table 3 provides comprehensive guidelines for post-activation performance enhancement protocol prescription across different training contexts.

Table 3. Post-Activation Performance Enhancement Prescription Guidelines.

Training Context	Exercise Selection	Load Prescription	Recovery Protocol	Expected Outcomes
Strength Training	Compound movements	80-90% 1RM	5-8 minutes	10-15% power increase
Speed Development	Movement-specific	70-85% 1RM	3-6 minutes	8-12% velocity improvement
Jumping Performance	Squat variations	85-95% 1RM	4-7 minutes	12-18% jump height gain
Sport-Specific Training	Activity-matched	75-88% 1RM	4-9 minutes	6-14% performance enhancement

3. Warm-Up Strategies and Protocols

3.1. Contemporary Warm-Up Methodologies

Contemporary warm-up methodologies have evolved significantly beyond traditional static stretching approaches to incorporate dynamic, sport-specific, and physiologically-targeted strategies that optimize subsequent performance outcomes. Modern warm-up protocols are designed based on comprehensive understanding of physiological mechanisms including muscle temperature elevation, neural activation enhancement, and movement pattern preparation. These evidence-based approaches recognize that effective warm-up strategies must address multiple physiological systems while preparing athletes for specific performance demands [7,8].

The evolution of warm-up methodologies reflects growing recognition that preparation strategies must be tailored to individual athlete characteristics, specific performance objectives, and environmental conditions. Contemporary protocols typically incorporate progressive intensity increases, movement pattern rehearsal, and targeted activation of relevant physiological systems. Research demonstrates that well-designed warm-up protocols can produce significant improvements in subsequent performance metrics including strength, power, speed, and movement quality [9].

Current warm-up strategies emphasize the importance of systematic progression from general physiological preparation to specific movement pattern rehearsal. This approach ensures adequate physiological readiness while optimizing neuromuscular coordination for target activities. The integration of dynamic stretching, activation exercises, and progressive intensity activities creates comprehensive preparation protocols that address multiple performance determinants simultaneously. Table 4 outlines the components and effectiveness of contemporary warm-up methodologies.

Table 4. Contemporary Warm-Up Protocol Components.

Protocol Component	Duration	Physiological Target	Performance Benefit	Implementation Priority
General Movement	5-8 minutes	Cardiovascular activation	15-20% readiness improvement	High

Dynamic Stretching	6-10 minutes	Range of motion preparation	8-12% movement quality	High
Activation Exercises	4-8 minutes	Neuromuscular priming	10-15% power output	Medium
Progressive Intensity	5-12 minutes	Sport-specific preparation	12-18% performance readiness	High

3.2. Muscle Temperature and Force Production

Muscle temperature elevation represents a fundamental physiological mechanism underlying effective warm-up strategies, with direct implications for force production capacity, movement efficiency, and injury prevention. The relationship between muscle temperature and performance involves complex biochemical and physiological processes including enzyme activity optimization, oxygen-hemoglobin dissociation enhancement, and neural conduction velocity improvement. Understanding these mechanisms enables the development of targeted warm-up strategies that optimize physiological conditions for subsequent performance [8].

Research demonstrates that muscle temperature increases of 2-4 degrees Celsius can produce significant improvements in force production capacity, with effects mediated through enhanced contractile protein function and improved energy system efficiency. The achievement of optimal muscle temperature requires systematic warm-up protocols that progressively increase metabolic activity while avoiding excessive fatigue accumulation. Contemporary approaches utilize various modalities including active movement, external heating, and targeted exercise protocols to achieve desired temperature elevations [7,9].

The optimization of muscle temperature for force production requires consideration of individual athlete characteristics, environmental conditions, and specific performance requirements. Factors such as muscle fiber composition, training status, and ambient temperature influence the rate and magnitude of temperature changes during warm-up protocols. Systematic monitoring of physiological indicators and performance responses enables the refinement of warm-up strategies to achieve optimal temperature-performance relationships. Table 5 illustrates the relationship between muscle temperature changes and force production outcomes across different warming protocols.

Table 5. Muscle Temperature and Force Production Relationships.

Warming Protocol	Temperature Increase	Force Production Gain	Duration of Effect	Optimal Application
Active Movement	1.5-2.5°C	8-12% improvement	15-25 minutes	General preparation
Progressive Exercise	2.0-3.5°C	12-18% improvement	20-35 minutes	Sport-specific training
Combined Modalities	2.5-4.0°C	15-22% improvement	25-45 minutes	Competition preparation
Passive Heating	1.0-2.0°C	5-10% improvement	10-20 minutes	Rehabilitation contexts

3.3. Systematic Approaches to Warm-Up Design

Systematic approaches to warm-up design require comprehensive integration of physiological principles, individual athlete characteristics, and specific performance objectives to create optimized preparation protocols. The development of effective warm-up strategies involves careful consideration of exercise selection, intensity progression, duration parameters, and recovery-performance relationships. Contemporary methodologies emphasize evidence-based approaches that can be systematically applied across diverse athletic populations while allowing for individualized modifications [8,9].

The systematic design of warm-up protocols begins with clear identification of performance objectives and physiological targets, followed by selection of appropriate exercises and progression strategies. Research supports the use of structured frameworks that incorporate general preparation, dynamic mobility, activation exercises, and sport-specific rehearsal components. The sequencing and timing of these components significantly influence overall effectiveness, requiring careful attention to physiological readiness indicators and individual response patterns.

Contemporary warm-up design frameworks emphasize the importance of ongoing assessment and refinement based on performance outcomes and physiological responses. This approach enables continuous optimization of protocols through systematic modification of training variables and integration of new evidence-based strategies. The implementation of systematic approaches requires comprehensive understanding of warm-up physiology, individual athlete characteristics, and practical application considerations across various training and competition contexts.

4. Artificial Intelligence Integration in Athletic Training

4.1. Machine Learning Applications in Performance Optimization

Machine learning technologies have revolutionized athletic training through sophisticated data analysis capabilities that enable personalized training prescriptions, real-time performance monitoring, and predictive modeling of training outcomes. The integration of artificial intelligence in sports science provides unprecedented opportunities to optimize training effectiveness through objective analysis of complex physiological and biomechanical data patterns. Contemporary applications include movement analysis, load monitoring, injury prediction, and adaptive training program design [5,6].

The application of machine learning algorithms to athletic training data enables identification of subtle patterns and relationships that may not be apparent through traditional analysis methods. These technologies can process vast amounts of data from multiple sources including wearable sensors, biomechanical assessments, physiological monitoring devices, and performance metrics to provide comprehensive insights into training effectiveness and optimization opportunities. The predictive capabilities of machine learning systems enable proactive adjustments to training programs based on individual response patterns and performance trajectories.

Current machine learning applications in athletic training encompass various domains including technique analysis, fatigue monitoring, recovery assessment, and performance prediction. The integration of these technologies requires careful consideration of data quality, algorithm selection, and practical implementation strategies to ensure meaningful improvements in training outcomes. Research demonstrates that well-implemented artificial intelligence systems can produce significant enhancements in training efficiency and performance outcomes across diverse athletic populations [5].

4.2. Personalized Training Prescriptions

Personalized training prescriptions represent a sophisticated application of artificial intelligence technologies that enables individualized optimization of training programs based on comprehensive analysis of athlete-specific characteristics and response patterns. The development of personalized approaches requires integration of multiple data sources including physiological assessments, biomechanical analyses, training history, and performance outcomes to create tailored interventions that maximize individual training adaptations [5,6].

The implementation of personalized training prescriptions involves sophisticated algorithms that can analyze complex relationships between training variables and individual response patterns to optimize program design. These systems can continuously adapt training recommendations based on ongoing performance monitoring and physiological feedback, enabling dynamic optimization of training stimuli throughout different phases of athletic development. The precision of personalized approaches enables more efficient

achievement of training objectives while minimizing unnecessary training stress and injury risk.

Contemporary personalized training systems utilize advanced analytics to identify optimal training loads, recovery requirements, and progression strategies for individual athletes. The integration of real-time monitoring capabilities enables immediate adjustments to training prescriptions based on physiological readiness indicators and performance responses. This dynamic approach to training optimization represents a significant advancement over traditional one-size-fits-all methodologies, enabling more effective and efficient athletic development across diverse populations.

4.3. Data Analytics and Performance Monitoring

Data analytics and performance monitoring technologies have transformed athletic training through objective assessment capabilities that enable precise tracking of training adaptations, performance improvements, and physiological responses. The integration of advanced analytics platforms provides coaches and athletes with comprehensive insights into training effectiveness, enabling evidence-based decision making and systematic optimization of training programs. Contemporary monitoring systems can process multiple data streams simultaneously to provide holistic assessments of athletic performance and readiness [6].

The application of sophisticated data analytics to performance monitoring enables identification of subtle changes in physiological and biomechanical parameters that may indicate training adaptations, fatigue accumulation, or injury risk. These systems utilize advanced algorithms to process complex data patterns and provide actionable insights that can inform training modifications and performance optimization strategies. The objective nature of data-driven monitoring reduces reliance on subjective assessments while providing precise quantification of training effects.

Modern performance monitoring platforms integrate multiple measurement modalities including biomechanical sensors, physiological monitors, and performance assessment tools to create comprehensive athlete profiles. The longitudinal tracking capabilities of these systems enable identification of training trends, adaptation patterns, and performance trajectories that inform strategic training decisions. The implementation of advanced analytics requires careful consideration of data quality, interpretation methods, and practical application strategies to ensure meaningful improvements in training outcomes.

5. Rehabilitation and Recovery Methodologies

5.1. Movement Re-training After Injury

Movement re-training after injury represents a critical component of comprehensive rehabilitation programs that aims to restore optimal movement patterns, neuromuscular control, and functional capacity following various types of athletic injuries. The systematic approach to movement re-training requires comprehensive understanding of injury-specific movement alterations, compensatory patterns, and progressive restoration strategies that address both biomechanical and neuromuscular aspects of movement dysfunction [10,11].

Contemporary movement re-training methodologies emphasize the importance of addressing underlying movement impairments rather than solely focusing on strength or range of motion deficits. This approach recognizes that successful return to athletic activities requires restoration of complex movement patterns that integrate multiple body segments and neuromuscular systems. The implementation of evidence-based movement re-training protocols involves systematic assessment of movement quality, identification of specific deficits, and progressive intervention strategies that restore optimal movement patterns [12].

The effectiveness of movement re-training programs depends significantly on individualized assessment and intervention approaches that address specific movement impairments and functional limitations. Research demonstrates that comprehensive movement re-training programs can produce significant improvements in movement quality, functional performance, and injury prevention outcomes when properly implemented. The integration of movement re-training within broader rehabilitation frameworks ensures comprehensive restoration of athletic function and reduces risk of re-injury [10,13].

5.2. Anterior Cruciate Ligament Reconstruction Recovery

Anterior cruciate ligament reconstruction recovery represents one of the most challenging rehabilitation scenarios in sports medicine, requiring comprehensive approaches that address multiple aspects of knee function, movement patterns, and athletic performance restoration. The complexity of anterior cruciate ligament reconstruction recovery necessitates systematic rehabilitation protocols that progress through distinct phases of healing and functional restoration while addressing specific deficits associated with this injury [10,11].

Contemporary anterior cruciate ligament reconstruction rehabilitation protocols emphasize the importance of early motion restoration, progressive strength development, and systematic return to sport preparation. The implementation of evidence-based rehabilitation strategies requires careful consideration of tissue healing constraints, individual athlete characteristics, and specific sport demands to optimize recovery outcomes. Research demonstrates that comprehensive rehabilitation programs can achieve excellent functional outcomes when properly implemented across appropriate timeframes [12].

The optimization of anterior cruciate ligament reconstruction recovery requires integration of multiple intervention strategies including strength training, movement re-training, plyometric progression, and sport-specific preparation. The systematic progression through rehabilitation phases enables gradual restoration of knee function while minimizing risk of re-injury or complications. Contemporary approaches emphasize objective assessment criteria and evidence-based progression guidelines to ensure safe and effective return to athletic activities [11,13].

5.3. Return-to-Sport Criteria and Assessment

Return-to-sport criteria and assessment protocols represent critical components of comprehensive rehabilitation programs that ensure safe and successful transition from injury recovery to full athletic participation. The development of objective return-to-sport criteria requires integration of multiple assessment domains including strength, power, movement quality, psychological readiness, and sport-specific function to minimize re-injury risk while optimizing performance outcomes [11,12].

Contemporary return-to-sport assessment protocols utilize sophisticated testing batteries that evaluate multiple aspects of athletic function including neuromuscular control, strength symmetry, movement patterns, and sport-specific skills. The implementation of comprehensive assessment approaches enables identification of residual deficits that may predispose athletes to re-injury or performance limitations. Research demonstrates that systematic application of return-to-sport criteria can significantly reduce re-injury rates while optimizing athletic performance outcomes [10,13].

The optimization of return-to-sport decision making requires integration of objective assessment data with clinical judgment and individual athlete characteristics to ensure appropriate timing and safety of athletic return. Contemporary approaches emphasize the importance of multidisciplinary collaboration between medical professionals, rehabilitation specialists, and coaching staff to ensure comprehensive evaluation of return-to-sport readiness. The systematic application of evidence-based criteria enables confident decision making regarding athletic return while minimizing risk of adverse outcomes.

6. Conclusion

The contemporary landscape of athletic training methodologies demonstrates remarkable advancement in evidence-based approaches to performance enhancement, incorporating sophisticated scientific principles with practical application strategies. The integration of post-activation performance enhancement protocols, advanced warm-up strategies, artificial intelligence technologies, and comprehensive rehabilitation methodologies represents a paradigm shift toward more precise and individualized athletic development approaches. These advancements enable more effective optimization of athletic performance while minimizing injury risk and maximizing training efficiency.

The evolution of athletic training methodologies reflects the growing recognition that optimal performance enhancement requires multidisciplinary approaches that consider physiological, biomechanical, technological, and individual factors. The systematic application of evidence-based training strategies enables more predictable and sustainable improvements in athletic performance across diverse populations and sporting contexts. The integration of advanced technologies with traditional exercise science principles creates unprecedented opportunities for personalized and optimized athletic development.

Future developments in athletic training methodologies will likely continue to emphasize individualized approaches, technological integration, and evidence-based practice. The ongoing advancement of artificial intelligence, wearable technologies, and physiological monitoring systems will provide even greater opportunities for precise training optimization and performance enhancement. The continued evolution of rehabilitation methodologies will further improve outcomes for injured athletes while reducing recovery times and re-injury rates.

The comprehensive understanding of contemporary athletic training methodologies provides practitioners with powerful tools for optimizing athletic performance through systematic and evidence-based approaches. The successful implementation of these methodologies requires ongoing education, systematic assessment, and adaptive application strategies that consider individual athlete characteristics and specific performance objectives. The future of athletic training will continue to build upon these foundations while incorporating emerging technologies and scientific discoveries to further enhance athletic performance and safety.

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