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CENTRO UNIVERSITÁRIO DE LISBOA

FACULDADE DE EDUCAÇÃO FÍSICA E DESPORTO

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Training Load and Fatigue in Elite Male Volleyball: Applications for Performance Optimization and Recovery

Tese de Doutoramento apresentada a provas públicas para a obtenção do grau de Doutor, na especialidade de Didática da Educação Física e Desporto, orientada pelo Professor Doutor João Rafael Pereira

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TRAINING LOAD AND FATIGUE IN ELITE MALE VOLLEYBALL: APPLICATIONS FOR PERFORMANCE OPTIMIZATION AND RECOVERY

VERSÃO FINAL

Tese defendida por André Gomes Rebelo em provas públicas na Universidade Lusófona, Centro Universitário de Lisboa no dia 26/06/2025, perante o júri, nomeado pelo Despacho de Nomeação n.º: 347/2025, de 26 de maio de 2025, com a seguinte composição:

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2025

Epigraph

You're going to lose sleep, you'll doubt whether it'll work, you'll stress to make ends meet, you won't finish your to-do list, and you'll wonder whether you made the right call, with no way to know for years. This is what hard feels like, and that's okay. Everything worth doing is hard. The more worth doing it is, the harder it will be; the greater the payoff, the greater the hardship. If it's hard: good. It means no one else will do it. More for you.

Alex Hormozi

Dedicatória

Thank you for being a beacon of light in my times of confusion and sorrow. Thank you for bringing laughter, joy, and comfort to my life. Thank you for staying with me at times I'm hard to handle.

Para os meus avós, por me devolverem a simplicidade de ser criança novamente sempre que me perco neste mundo dos adultos. Para o meus pais, por me ensinarem que a preocupação com aqueles que gostamos vai para além de uma mensagem e de uma chamada. Para o meu irmão, que exige que eu seja um exemplo para ele. Para os de sempre, por me mostrarem que posso abrir o meu coração sempre que quiser.

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No ano letivo que iria dar início em 2019, a minha aventura académica empurrou-me para um segundo mestrado. Desta feita, em Treino de Alto Rendimento. Não só porque era, sem dúvidas, a área dentro das ciências do desporto que mais me fascinava, mas porque era uma oportunidade de escrever e produzir ciência (visto que não era um mestrado profissionalizante como o primeiro que tinha concluído, um ano antes). Lembro-me bem da forma como terminei esta secção aquando da escrita da minha Dissertação de Mestrado, dois anos depois, em 2021. Na altura, era claro para mim que o passo seguinte seria seguir esta viagem com o Doutoramento. Eu nunca me vi assustado com as exigências mais práticas destas etapas académicas. Realizar mais um ou menos um trabalho científico nunca me colocou expectante para tomar qualquer decisão que fosse. Para mim, os desafios foram sempre outros. Na minha cabeça, combinar toda esta ambição com aquilo que realmente nos mantém lúcidos era o mais difícil. De uma forma um pouco egoísta, em 2021, realizei o seguinte pedido: "*Às pessoas que mais me são próximas, peço que a vossa paciência não se esgote quando eu próprio tiver esgotado e que continuem a sorrir para mim quando eu achar que o sorriso não é a solução*". Àqueles que fizeram disto possível, deixo aqui o meu profundo agradecimento.

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Resumo

Esta tese explora as relações entre as cargas de treino, a fadiga e a recuperação em atletas de voleibol de elite, com o objetivo de otimizar a performance, através de sete estudos distintos, quer de revisão, quer de cariz observacional. Os estudos de revisão estabelecem os alicerces da tese, ao examinarem as cargas de treino externa e interna, demonstrando as limitações das métricas mais utilizadas e dando ênfase à necessidade de se integrarem estratégias de monitorização. Os estudos observacionais analisam a fadiga neuromuscular e a recuperação durante a fase competitiva, revelando relações importantes entre as cargas de treino e a recuperação nas suas dimensões biológica, psicológica e social. Os resultados mostram a importância de abordagens holísticas de monitorização, integrando testes como o salto com contramovimento com avaliações subjetivas da recuperação. Também são discutidos temas como calendários competitivos congestionados, oferecendo recomendações práticas para a construção de protocolos de avaliação de treino e recuperação. Os resultados estabelecem as bases para a investigação futura procurando, assim, que o conhecimento sobre a otimização da performance aumente e que a gestão da carga no voleibol profissional seja realizada de forma mais sustentável.

Palavras-Chave: Monitorização Atlética; Carga de Treino; Fadiga Neuromuscular; Recuperação; Voleibol.

Abstract

This thesis explores the interplay between training load, fatigue, and recovery in elite volleyball athletes, aiming to optimize performance. Through seven distinct studies, both review-based and empirical, it provides a broad understanding of training load monitoring and its implications. The narrative and systematic reviews establish a foundation by examining external and internal training loads, highlighting the limitations of current metrics and emphasizing the need for integrated monitoring strategies. Empirical studies analyse neuromuscular fatigue, perceptual well-being, and recovery during in-season periods, revealing key relationships between training loads and recovery across biological, psychological, and social dimensions. Key findings underscore the importance of holistic monitoring approaches, integrating objective metrics like countermovement jump variables with subjective recovery assessments. Position-specific demands and the impact of congested match schedules are also discussed, offering practical recommendations for tailored training and recovery protocols. The thesis emphasizes the need for individualized strategies to manage acute and chronic training loads effectively, enhancing athlete readiness and reducing injury risks. Contributing to both scientific knowledge and practical applications, this thesis provides actionable insights for coaches and practitioners. Its findings lay the groundwork for future research, advancing the understanding of performance optimization and sustainable workload management in high-performance volleyball.

Key Words: Athlete Monitoring; Training Load; Neuromuscular Fatigue; Recovery; Volleyball.

Abbreviations

ACWR	Acute:chronic workload ratio
CK	Creatine kinase
CMJ	Countermovement jump
CNS	Central nervous system
DALDA	Daily Analysis of Life Demands for Athletes
ES	Effect size
ETL	External training load
FO	Functional overreaching
GPS	Global positioning system
HR	Heart rate
HRV	Heart rate variability
HRR	Heart rate recovery
IMU	Inertial measurement unit
ITL	Internal training load
MD	Matchday
MTDS	Multicomponent Training Distress Scale
MVC	Maximal voluntary contraction
NFO	Non-functional overreaching
OTS	Overtraining syndrome
POMS	Profile of Mood States
RESTQ-Sport	Recovery-Stress Questionnaire for Athletes
RESTQ-Sport-36	36-item version of the Recovery Stress Questionnaire for Athletes
RPE	Rating of perceived exertion
RSI	Reactive strength index
S&C	Strength and conditioning
sRPE	Session rating of perceived exertion
SSC	Stretch-shortening cycle
STROBE	Strengthening the Reporting of Observational Studies in Epidemiology
T:C	Testosterone-to-cortisol
TRIMP	Training impulse

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Chapter I - Introduction

"You don't have to see the whole staircase, just take the first step."

Martin Luther King Jr.

Since the 1940s, researchers have recognized that the body's response to training depends on the specific type and intensity of exercise stimulus applied [1]. Seminal research has shown that tissues such as tendons, muscles, bones, and joints each exhibit unique adaptations and susceptibilities to injury, depending on how they are loaded [2]. For instance, while high chronic loads can enhance muscle resilience, they may also increase joint injury risk. Conversely, sudden increases or decreases in load can place stress on tendons, often leading to injury. Practitioners now face the question of whether it is feasible to achieve an "optimal" training load that supports both performance and injury risk reduction across all these tissue types.

Training load management has thus become central to elite sports, with a primary aim to maximize performance and mitigate injury risk [3]. The task involves a delicate balance between driving performance adaptations and allowing adequate recovery. Studies indicate that insufficient training intensity fails to sufficiently engage anaerobic systems and fast-twitch muscle fibers, whereas consistently high volumes may hamper recovery and impede aerobic adaptations [4,5]. These considerations underline the complexity of load management, where the type, intensity, and timing of training must be precisely calibrated to meet athletes' physical demands.

System modelling, particularly in endurance sports, has demonstrated success by linking load monitoring with performance outcomes [6]. However, translating these models to team sports is challenging due to the multi-faceted nature of physical demands and the intricate relationship between individual performance and overall team success. For example, while an athlete's physical output might be optimized, this does not always guarantee a favourable result for the team. Nevertheless, recent frameworks suggest that training monitoring—encompassing both external and internal load metrics—may offer a pathway to understanding and potentially improving individual fitness in relation to team performance [7].

Volleyball, with over 500 million participants worldwide, stands among the most popular team sports, particularly in regions like Brazil, Italy, Russia, and the USA [8]. At the elite level, volleyball athletes face a unique set of physical demands. For many, the cycle of training and competition is relentless, especially for those balancing commitments to both club and national teams. This intense schedule imposes considerable physical strain, accentuating the need for precise load management strategies [9,10]. S&C coaches play a critical role in monitoring these demands, tailoring training to improve physical capacities, and ensuring athletes are physically prepared to meet the competitive demands of the sport [11].

To address this research problem, the following research questions have been formulated:

1. How do different external and internal training loads affect neuromuscular fatigue and subsequent recovery in elite volleyball players?
2. In what ways can training load monitoring be optimized to maximize performance outcomes in elite volleyball?
3. How can chronic and acute training load management improve an athlete's physical readiness and recovery throughout the competitive season?
4. What is the relationship between various training load metrics and recovery indicators in elite volleyball athletes?
5. To what extent can effective training load management reduce fatigue accumulation and enhance performance sustainability over a congested period of the season?

These questions aim to explore the interplay between training load, performance, fatigue, and recovery, providing practical insights that can inform and refine load management practices in high-performance volleyball.

1.1. Thesis' objectives

Given the problematic outlined earlier, this thesis seeks to address the interplay between training load, fatigue, and recovery to optimize performance in elite volleyball athletes. The general objective of the thesis is to advance the understanding of how external and internal training loads can be effectively monitored and managed to maximize performance outcomes and enhance recovery processes in high-performance sport. To achieve this overarching aim, seven distinct studies were conducted, each addressing specific aspects of the research problem:

1. Study I provides a broad foundation by reviewing the physical demands and injury risks in volleyball, highlighting the critical role of S&C programs. This narrative review aims to establish a comprehensive understanding of volleyball's unique physical requirements, setting the stage for subsequent investigations into training load management.
2. Study II narrows the focus to external training load (ETL) metrics in volleyball, offering a scoping review that identifies gaps in the literature and evaluates current methodologies and technologies used to monitor ETL in this sport. The study underscores the need for more precise measurement techniques tailored to the sport's specific demands.
3. Study III critically evaluates internal training load (ITL) monitoring in professional volleyball, specifically through the use of the rating of perceived exertion (RPE). This systematic review highlights the nuances of ITL measurement, including best practices for data collection and its implications for athlete performance and recovery.
4. Study IV examines the interaction between external and internal loads, focusing on their collective impact on neuromuscular fatigue and well-being in volleyball athletes. This systematic review explores how load interactions can influence performance and recovery, providing valuable insights for integrated monitoring strategies.
5. Study V transitions into empirical research, analysing how both external and internal training loads influence neuromuscular fatigue and perceptual well-being during an in-season mesocycle in elite male volleyball athletes. This study provides real-world data on training load management and its implications for performance optimization.
6. Study VI focuses on the impact of congested match schedules on countermovement jump (CMJ) metrics, exploring how these metrics serve as indicators of fatigue and recovery. By identifying performance changes during high-stress competitive periods, this study informs strategies to maintain athlete readiness throughout the season.
7. Study VII addresses the relationship between training load metrics and recovery across biological, social, and psychological dimensions. This study aims to provide a holistic understanding of how training loads affect recovery processes, highlighting the need for balanced load management in elite volleyball.

Together, these objectives form a cohesive framework to address the thesis' central problematic. Each study builds on the previous one, moving from theoretical reviews to empirical applications, and collectively advancing the understanding of training load management in volleyball. This integrated approach not only deepens the knowledge of performance optimization and recovery but also offers practical insights to improve athlete readiness and sustainability in high-performance environments.

1.2. Thesis structure and chapter overview

The organization of this thesis follows the current trend in scientific research, where doctoral work is increasingly centred on the production of publishable manuscripts intended for submission to high-impact peer-reviewed journals. This structure not only allows for a focused investigation of specific research questions but also contributes to the broader body of knowledge in the field, ensuring that the research is relevant, accessible, and rigorously vetted.

The thesis is organized into six chapters, each serving a distinct purpose in articulating and advancing the research narrative. Chapter I, the Introduction, lays the foundation for the thesis, explaining the research problem, the specific themes and questions being investigated, the importance of this work within the context of high-performance sports, and the overarching objectives of the thesis.

Chapter II, the Theoretical Framework, provides an in-depth review of the relevant literature, examining the current state of knowledge on key topics. This chapter not only contextualizes the research within existing studies but also identifies gaps and areas where this thesis aims to contribute new insights, forming the theoretical basis for the studies that follow.

Chapter III, the Methods, outlines the methodology used in the research. Here, the specific methods and procedures implemented in each study are detailed, including descriptions of participant selection, data collection techniques, and analysis protocols. This chapter ensures that the research is transparent and replicable, providing a clear account of how each study was designed and executed to achieve reliable and valid findings.

Chapter IV comprises the core of the thesis: the presentation of the seven original articles developed as part of this research. Each article is introduced along with the journal in which it was published, and together, they represent a cohesive body of work that addresses the central research questions of the thesis. The chapter reflects the multidisciplinary nature of high-performance sports research, covering diverse yet interconnected topics that contribute to the understanding of training and performance optimization.

Chapter V, the Discussion, synthesizes the findings across the seven studies, analysing the results in light of the research questions and objectives outlined in the Introduction. This chapter also addresses the limitations inherent in the research, discussing how these constraints impact the interpretation of the results and offering recommendations for future studies that can build on this work.

Finally, Chapter VI, the Conclusions, presents the main conclusions of the thesis, summarizing the key contributions and implications of the research for the field of sports science. This chapter underscores the practical applications of the findings for S&C coaches and other professionals in high-performance sport, emphasizing how this work advances knowledge in athlete training, recovery, and performance.

Chapter II – Theoretical Framework

"You know that children are growing up when they start asking questions that have answers."

John J. Plomp

The purpose of this chapter is to provide a foundation for understanding the key concepts and theories underpinning this thesis. To address the relationships between training load, fatigue, recovery, and performance in elite volleyball, it is essential to explore these topics systematically. This chapter begins by examining the sport of volleyball itself, delving into its unique physical and physiological demands. Following this, the concept of training load is discussed, with an emphasis on its internal and external components, as well as the methodologies used to monitor it. The chapter then transitions into a detailed exploration of fatigue, focusing on its physiological and neuromuscular manifestations and the metrics used to assess it. Finally, the chapter concludes with a discussion of recovery, highlighting its critical role in mitigating fatigue and optimizing performance. Together, these topics provide the theoretical framework necessary to contextualize the research presented in this thesis.

2.1. Elite volleyball

The term "elite" in the context of athletes refers to those who perform at the highest levels of their sport. These individuals are typically within approximately 7% of world-leading or world-record performance, ranked among the top 4–300 athletes globally, depending on the sport's depth of competition, or actively participating in professional leagues and tournaments [12]. Many elite athletes are also included in registered testing pools or national testing pools, as defined by the World Anti-Doping Agency, underscoring their status within the sport's upper echelon.

Studying elite athletes presents unique challenges due to their limited availability and the relatively small number of individuals who compete at this level. Despite these difficulties, research involving elite athletes is invaluable. Such studies yield insights with exceptional ecological validity, as they directly reflect the demands and realities of high-performance sport. Consequently, findings from research at this level often translate seamlessly into practical applications, contributing to the optimization of training, recovery, and performance strategies in elite settings.

Elite volleyball athletes operate within a unique and demanding context, balancing commitments to both club and national teams. These athletes often navigate gruelling schedules that include domestic leagues, international tournaments, and preparation camps. For example, during the 2022/2023 season, top European male teams such as Italy, Poland, and France competed in an extensive series of events, including friendly matches, the FIVB Volleyball Nations League, the CEV European Volleyball Championship, and the FIVB Men's Olympic Qualifiers. Similarly, elite female volleyball players, such as those on the USA Women's National Team, faced equally intensive calendars, reflecting the relentless demands of high-performance volleyball.

This intense competitive environment underscores the importance of rigorous physical preparation, efficient recovery strategies, and comprehensive training load management. For S&C coaches, the challenge lies in optimizing players' physical performance while navigating the constraints of congested schedules. Studying elite volleyball not only provides insights into the physical and tactical demands of the sport but also offers practical solutions for enhancing athlete performance and recovery within this highly dynamic and competitive context.

The essence of volleyball lies in its fast-paced and strategic gameplay, where teams compete to score points by manoeuvring the ball over the net into the opponent's court, aiming to make it unreturnable or force an error. This goal is achieved through a combination of tactical skills, coordinated teamwork, and position-specific expertise [13]. Volleyball encompasses five primary positions, each with distinct roles critical to the team's success. The setter serves as the tactical mastermind, akin to a quarterback in other sports, orchestrating plays and creating opportunities for attackers [14]. The opposite hitter, stationed on the right side, combines offensive firepower with defensive blocking responsibilities [15]. Outside hitters are versatile players who excel in attacking and defensive tasks, taking on substantial responsibilities in both areas [16]. Middle blockers anchor the team's defence, executing quick offensive plays and effectively countering rapid opponent strikes [17]. Finally, the libero specializes in defence, excelling in digging and passing to stabilize the team's back row [18].

2.1.1. Structural elements of the game

A volleyball court measures 18 meters (59 feet) in length, stretching between opposing end lines, and spans a width of 9 meters (29.5 feet), from one sideline to the other [19]. The attack lines, located on both sides of the court, are positioned 3 meters (9.8 feet) from the centreline. The standard net height in men's volleyball is 2.43 meters (7.97 feet), while in women's volleyball, it is set at 2.24 meters (7.35 feet), both measured from the court centre [19]. Two white bands are fastened vertically to the net and placed directly above each side line. They are 5 centimetres (1.97 inches) wide and 1 meter (3.28 feet) long and are considered as part of the net. An antenna with 1.80 meters (5.91 feet) long is fastened at the outer edge of each side band [19].

The court features six rotational positions – three in the front row and three in the back row [19] (Figure II-1A). Position 1 is designated for the server, and players rotate to this position for their turn to serve. It is important to note that players can serve from anywhere behind the end line, not just directly behind position 1. The team rotates in a clockwise direction through these positions, following a predefined order set at the match's start [19]. A team rotates after winning a point on the opponent's serve [19] (Figure II-1B).

As outlined previously, specific roles align with certain positions on the court. Typically, the setter plays in position 2 when in the front row and in position 1 when in the back row. Many teams position their setter in the front row, approximately one-third along the net from the right antenna, facilitating sets to the outside hitter and middle blocker. This positioning is advantageous for right-handed hitters (the majority) as they can hit a ball moving from right to left before it crosses their body, making it easier to track, time, and reach. In the front row, the outside hitter occupies position 4, and the middle blocker takes position 3. In the back row, these players typically occupy positions 5 or 6. The opposite hitter plays in position 2 when front row and position 1 when back row, often matching up against the opposing team's outside hitter and serving as a backup for the setter. The libero, usually starting in position 6, is substituted for the middle blocker as they rotate to position 4 (Figure II-1C).

Players must rotate through all six positions while also adhering to their specialized roles. This is achieved by switching places on the court as soon as it is feasible during play. All players must be in their correct rotational positions before the serve but can switch once the ball is served [19]. Premature movement results in a rotation fault, awarding a point to the opposing team [19]. While there's no rule against front and back row players switching places, back row players are prohibited from blocking or hitting the ball above the net's height from the area in front of the 3-meter line [19].

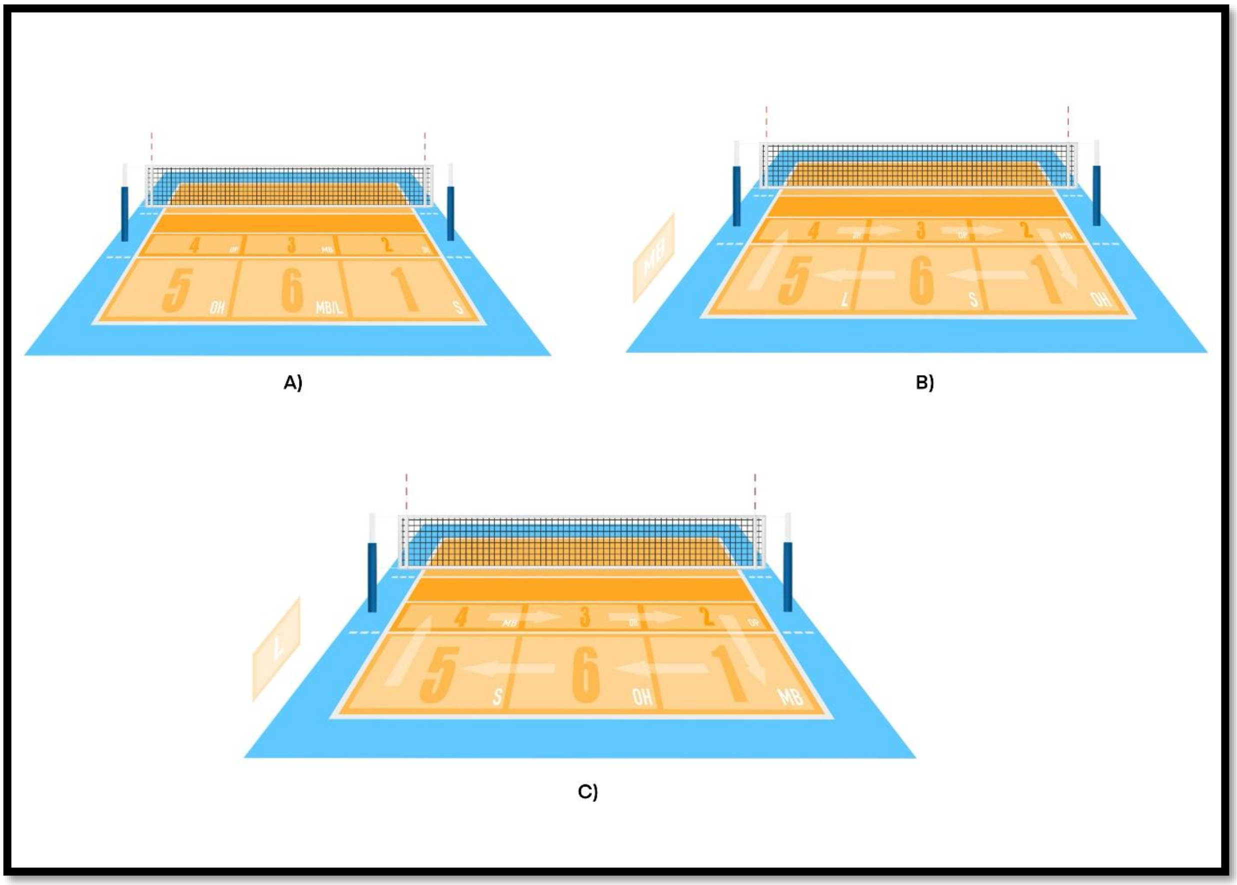

Figure II-1: Schematic representation of player positions and rotations in volleyball: A) shows the six rotational positions on the court; B) illustrates the clockwise rotation of the team through the six designated positions after winning a point on the opponent's serve; C) depicts a team rotation where the libero is substituted for the middle blocker, preventing the libero from rotating into the front row (position 4).

2.1.2. Technical and biomechanical elements of the game

Transitioning to the examination of technical gestures in the game, each element plays a pivotal role in the dynamics of volleyball, blending strategic importance with biomechanical intricacy. Among these elements, the serve emerges as a particularly fundamental skill, initiating play and setting the tone for the rally. The serve is not merely a means to start the game; it is a critical tactical component that can sway the match's momentum [20]. It offers the serving team a chance to score directly with an ace or place the opposing team under immediate pressure. This gesture embodies two main types: the float serve and the jump serve. To perform the float serve effectively, the server should initiate the process by tossing the ball forward, in line with the serving hand, and just beyond their maximum reach height [21]. The key to a successful float serve lies in the hand contact with the ball. As the arm comes through in a serving motion, a firm 'pop' off the ball with the hand is essential. This action, combined with a harder strike, creates a knuckle-ball effect, causing the ball to unpredictably change direction mid-air. The serving hand should be open and firm, with the wrist locked in alignment with the forearm, ensuring a rigid, controlled impact with the ball [21]. For the jump serve, the technique begins with a high ball toss. This toss should be executed in a way that allows the server to make contact with the ball at the apex of their jump [22]. Following the toss, the server mimics an attack approach: arms are gathered and swung back, and a four-step approach is taken, with the steps accelerating progressively [23]. For a right-handed server, the footwork typically follows a right-left-right-left pattern leading into the jump. For the float serve, the kinetic data suggests lower peak ground reaction forces compared to the jump serve [24] for his lower force output is consistent with the less explosive nature of the float serve. The prevalence of these serves varies across levels of play and between genders. In youth and collegiate levels, the float serve is predominant due to its consistency and lower skill demands [22]. At the professional level, there's a notable increase in the use of both types, with the jump serve being especially favoured among male players, reflecting the higher athleticism and physicality in men's volleyball [25]. Female players, proficient in both serves, tend to prefer the float serve for its strategic effectiveness and reliability [26].

Following a serve, the immediate challenge for the receiving team is to effectively manage the ball, setting the stage for a successful counterattack. The receiver's primary objective is to control the serve with precision, guiding the ball toward the net in such a way that it provides the setter ample opportunity to orchestrate the next move. Achieving this level of control allows the team to remain "in system," granting the setter the flexibility to choose among all attacking options. Conversely, a misdirected pass that limits the setter's choices forces the team "out of system," compromising their offensive strategy.

Transitioning from reception to setting, the latter is a critical skill that involves delivering the ball to attackers with precision [27]. The set is typically executed with an overhead motion, using the fingers to push the ball upward from the forehead towards the ceiling, aiming to deliver a ball that floats, rather than spins, to the hitter. Setters have the option of performing this action from a standing position or employing a jump set, which involves jumping prior to setting the ball [27].

The attack serves as the cornerstone of offensive strategy in volleyball, unfolding in three critical phases: approach, jump, and spike [28]. This sequence encapsulates the attacker's movement and technique, culminating in the attempt to score. The approach is tailored to the attacker's style and the required distance, varying from a quick one-step for fast-tempo plays to a more measured two- or three-step for slower attacks. The pivotal moment, often termed the plant, hop, or step close, is crucial for converting forward momentum into vertical lift [28]. This final step, characterized by a longer and more rapid stride, involves a nearly simultaneous placement of both feet, setting the stage for the jump. As the attacker initiates the jump, the back leg swings forward, making contact with the ground as the arms begin their forward motion. Positioning is key, with the spiker adopting a 'coiled' stance, bending the legs to maximize jump height. The depth of the bend directly correlates with the potential elevation achieved. During the spike, the arm swing is segmented into five phases: initiation, wind-up, arm cocking, arm acceleration, and finally, ball contact and follow-through [29]. Each phase is intricately connected, starting from the preparatory movements to the explosive acceleration and the precise moment of contact with the ball, followed by a controlled follow-through to ensure optimal force and direction [29].

Blocking in volleyball is a critical defensive strategy where one to three players aim to intercept the ball at the net, redirecting it into the opponent's court [30]. Effective blocking hinges on a player's ability to quickly reach the optimal position, execute a high vertical jump, and extend laterally along the net [31]. Key to a successful block is the technique used: penetration and angulation of the hands in relation to the net plane play pivotal roles in creating an effective barrier and controlling the ball's rebound [30]. Maintaining a frontal stance to the net, with the pelvis and shoulders aligned parallel to it, enhances the ability to cover more area and manage the direction of the block. Footwork is fundamental to positioning for a block, with the "slide step" and "cross-over step" being the two main techniques [32]. The slide step involves lateral movement where the leading foot moves sideways followed closely by the trailing foot, culminating in a jump propelled by both feet [32]. The cross-over step sees the left foot crossing over the right, moving closer to the net, followed by the right foot closing the step, and then both feet push off for the jump [32]. Research has indicated gender-specific biomechanical differences in blocking, particularly noting that in women, the extension moment in the knee joint during a block jump is generally lower than in men, while the maximum standardized knee valgus moment tends to be higher [33].

2.2. Training load

Training load is a central concept in sports science that provides a framework for quantifying the demands placed on an athlete during training sessions. It combines the intensity and duration of a training session to represent what is often referred to as a "dose" of training [6]. The cumulative impact of multiple sessions over time can be monitored and adjusted to ensure that athletes are progressing effectively within their training programs [34]. First introduced by Banister and colleagues [6], this concept has evolved significantly and is now widely used to guide training prescriptions and evaluate an athlete's adaptation to training [35].

The importance of monitoring training load lies in its potential to optimize performance outcomes while minimizing risks associated with inadequate recovery, overtraining, and illness [36,37]. With advancements in wearable technologies and related devices, training load can now be recorded with remarkable precision, offering coaches and practitioners valuable insights into an athlete's physical stress levels [38]. This data, when analysed effectively, helps tailor training programs to maximize fitness adaptations while mitigating adverse outcomes [39].

Despite its widespread application, the definition of training load remains somewhat ambiguous in the literature. Broadly, it is described as the cumulative stress placed on an athlete from one or more training sessions over a specific time frame [37]. This aligns with the idea of a training dose, where higher training loads correspond to greater levels of physiological stress. Banister's early work [6] introduced the concept of quantifying this dose through training impulses (TRIMPs), linking the measured training load to performance outcomes. While Banister himself did not use the term "training load," his methods laid the foundation for its later adoption in the field [40].

This lack of consistency in defining training load has sparked debate within the scientific community [41]. Some researchers emphasize its relationship to the volume or amount of training completed, while others focus on the stress or physiological impact that arises from each session [41]. Nevertheless, the concept remains a cornerstone of modern athlete monitoring, enabling practitioners to strike a balance between pushing athletes to achieve their performance potential and safeguarding their overall well-being.

2.2.1. Internal and external training load

Training load is often categorized into two distinct components: ETL and ITL [42]. These classifications help distinguish between the physical demands imposed on the athlete and the physiological responses generated by the body to meet those demands [42].

ETL refers to the measurable physical work prescribed in a training program [42,43]. It is shaped by the organization, quality, and quantity of the exercises outlined by the coach. The specific metrics used to quantify external training load depend on the nature of the activity. For instance, in resistance training, it might be represented by the weight lifted, the total work performed, or even the velocity of the lift [44]. In team sports, ETL is often assessed through metrics like total distance covered, distances run at varying speeds, accelerations, or metabolic power outputs [45]. Regardless of the specific measure, ETL is strategically designed to provoke a desired psychophysiological reaction, which is captured by ITL [7].

ITL reflects the body's actual physiological and psychological responses to the demands of the ETL [46]. These responses include the various systems and processes that the body activates to handle the stresses imposed by the prescribed exercise. Measures of ITL provide insights into how the body copes with and adapts to these demands [46].

Neither ETL nor ITL has a universally accepted method of measurement, as their assessment is context-dependent and varies across sports and activities [7]. For example, in endurance training, heart rate is a commonly used and valid indicator of ITL, while it may not be appropriate for resistance training [7]. Even within the same context, the validity of a measure can differ; heart rate, for instance, is a less reliable indicator of internal load during short, high-intensity intermittent efforts compared to longer-duration or steady-state activities [7].

2.2.2. Relationship between internal and external measures of training load

The relationship between ITL and ETL has been a focal point of research in sports science, particularly in team sports [47]. A recent meta-analysis revealed that total distance, a common ETL measure, exhibits some of the strongest associations with ITL indicators [47].

This relationship is logical, as the physiological demands of running—such as sustaining muscle contractions and maintaining oxygen delivery to working muscles—are closely tied to increases in oxygen consumption and cardiac output [45]. Additionally, the central motor commands required for locomotion contribute to perceptions of effort, further linking the physical work performed to internal psychophysiological responses [48].

Other ETL metrics, such as distances covered at high speeds, accelerations, and impacts, also show correlations with internal load indicators [49,50]. However, their relationships are often less robust compared to total distance [47]. This may be due to increased measurement errors from devices like global positioning systems (GPS) at higher velocities [51,52], individual differences in running capabilities, or the non-linear association between running velocity and internal intensity [53]. For instance, accelerometer-derived measures of impacts and loads might be influenced by activities beyond running, such as jumping, static exertions, or collisions, which are common in team sports [49]. These activities may not directly correspond to ITL measures such as session rating of perceived exertion (sRPE) or TRIMP.

Although measures like sRPE and TRIMP are widely used to capture ITL, their sensitivity to the diverse physical demands of team sports remains a subject of discussion [54]. A global sRPE score, for example, may not accurately represent the full spectrum of physiological and biomechanical exertion experienced during exercise [55]. This is because such measures often reflect the most dominant psychophysiological sensation—such as breathlessness or muscle fatigue—while overlooking subtler or more localized stressors [56]. To address this limitation, differential ratings of perceived exertion have been proposed [56]. By separately evaluating factors like breathlessness, leg muscle exertion, and upper-body effort, practitioners can gain a more nuanced understanding of internal load and its relationship with external load metrics [47].

The variance between internal and external training load measures highlights the complexity of their interaction. Individual differences, biological variation, and measurement noise all contribute to unexplained variance in their relationships. This underscores the importance of using multiple complementary metrics to capture both constructs accurately [47]. Collecting and integrating a variety of measures can provide a more holistic view of training demands, enabling practitioners to better understand the dose-response nature of training and competition [46]. Ultimately, this approach facilitates more precise adjustments to training programs, optimizing performance and recovery in elite team sports.

2.3. Fatigue

Fatigue is a complex and multifaceted concept with various definitions depending on the context in which it is studied. The Oxford Dictionaries define fatigue as "extreme tiredness resulting from mental or physical exertion or illness," a term originating from the Latin word *fatigare*, meaning "to weary" or "to tire out". While the term is widely used across different fields, its interpretation and application vary significantly, leading to challenges in establishing a universally accepted definition.

In clinical settings, fatigue often refers to a symptom associated with underlying pathophysiological conditions or treatments, assessed through psychometric tools such as self-report questionnaires and scales [57]. These subjective measures are critical in evaluating the impact of fatigue on quality of life and physical functioning, particularly when fatigue is chronic or debilitating. Conversely, in exercise science, fatigue is primarily linked to a decline in performance induced by physical activity, where exercise is defined broadly as muscle activity capable of disrupting homeostasis [58]. For over a century, exercise physiologists have sought to understand fatigue as a limitation to performance, focusing on its physiological and psychological dimensions [59].

The multidimensional nature of fatigue makes it difficult to encapsulate with a single definition. Researchers often distinguish between two key domains: perceptions of fatigue and performance fatigability [60]. Perceptions of fatigue refer to the subjective experience of tiredness or effort, while performance fatigability describes the measurable decline in motor performance, such as a reduction in force production or power output [61]. These two domains are interrelated but not always directly proportional; for example, an athlete may perceive high levels of fatigue without experiencing a significant decline in performance, or vice versa.

The models used to study fatigue often reflect this duality. Some researchers view fatigue as a purely physiological phenomenon, encompassing the increased effort required to produce a desired force and the eventual inability to sustain that force [62]. Others propose that fatigue is an emotion, shaped by the brain as a regulatory mechanism to manage exercise performance [63]. These differing perspectives underline the complexity of fatigue, suggesting it is not merely a physical event but also a psychological construct influenced by central and peripheral mechanisms.

The context in which fatigue is studied determines the approach used to measure it. In clinical populations, where fatigue may significantly impact daily life, a multidimensional framework that incorporates both objective and subjective measures is essential. In contrast, research focused on the mechanisms of exercise-induced fatigue often relies on physiological assessments to evaluate changes in performance and effort [64]. This distinction highlights the importance of explicitly defining fatigue and recognizing its multifactorial nature, particularly when studying its impact on exercise and performance.

2.3.1. Neuromuscular fatigue

Neuromuscular fatigue refers to an exercise-induced reduction in a muscle's ability to generate force or power, which is reversible with rest [65]. This definition distinguishes fatigue from other conditions such as muscle damage or weakness, which may persist for extended periods and are not necessarily alleviated by rest [66]. Historically, fatigue was described as the failure to maintain the force required to complete a task [67]. However, this perspective is now considered overly simplistic, as fatigue develops gradually during sustained activity rather than appearing solely at the point of task failure [68]. A more nuanced definition recognizes fatigue as a progressive decline in muscle contractile properties, where the expected response diminishes even if maximal force output remains initially intact [69].

A common approach to quantifying neuromuscular fatigue involves measuring the decline in maximal voluntary contraction (MVC) force before and after a fatiguing task [66]. An MVC is a short-duration, maximal-effort contraction performed with continuous feedback and encouragement to ensure peak effort [70]. This method helps evaluate the extent to which force generation capabilities are compromised by a fatiguing activity. Importantly, the sensations associated with fatigue are closely linked to the neuromuscular adjustments required to sustain effort [71]. Disengagement from a task, often seen as volitional exhaustion, involves complex regulatory processes within the central nervous system (CNS) that interact with peripheral factors [72,73].

Fatigue is broadly categorized into two components: peripheral fatigue and central fatigue, both of which contribute to reduced force generation and are deeply interconnected [62]. Peripheral fatigue refers to impairments within the muscle itself, including diminished contractile function due to metabolic byproducts or changes in ion concentrations [68]. Central fatigue, on the other hand, originates in the CNS, involving a reduction in the neural drive from the brain or spinal cord to the muscle [68]. Research increasingly acknowledges the critical role of the CNS in regulating exercise performance, highlighting that fatigue is not merely a mechanical or physiological phenomenon but also a behaviour influenced by complex neural processes [61].

Stimulation techniques applied before and after fatiguing tasks can provide insight into specific points along the neuromuscular pathway where fatigue arises, from the primary motor cortex to the muscle fibers [74]. These methods allow researchers to differentiate between central and peripheral contributions to fatigue, offering a more comprehensive understanding of how the neuromuscular system responds to sustained activity.

2.3.2. Neuromuscular fatigue assessments in team sports: questionnaires

Neuromuscular fatigue is influenced not only by physical exertion but also by the psychobiological state of the athlete, particularly during periods of prolonged cognitive demands, which can lead to mental fatigue [75]. This mental fatigue plays a critical role in shaping an athlete’s perception of their physical capabilities, often resulting in a downregulation of exercise capacity—the maximum effort an individual can sustain. To gain a more comprehensive understanding of neuromuscular fatigue and recovery, it is essential to assess subjective markers of fatigue, as they provide valuable insights into the athlete's psychophysiological state [76].

Self-report questionnaires are widely accepted tools in high-performance team sports for monitoring overall well-being and fatigue [77]. These questionnaires, which are often validated and customized for specific contexts, have been used across various disciplines and competition levels. Instruments like the Profile of Mood States (POMS) and the Recovery-Stress Questionnaire for Athletes (RESTQ-Sport) are among the most commonly utilized [76]. These tools help practitioners monitor the complex interactions between psychophysiological stress, high levels of fatigue, and suboptimal recovery, enabling them to tailor interventions accordingly [76].

One of the most frequently employed subjective measures is the RPE. RPE reflects a psychophysical process that combines an athlete’s sensations of physical stress, discomfort, and fatigue experienced during exercise [78]. Research has shown strong correlations between RPE and other methods of determining ITL, highlighting its utility as a reliable indicator [79]. By using RPE, coaches and practitioners can develop individualized periodization strategies that account for the specific needs of athletes and teams.

When implementing questionnaires in daily monitoring programs, their practicality is an important consideration. Practitioners often prefer shorter, simpler forms to minimize the time burden on athletes, especially when the questionnaires need to be completed daily [76,80]. For example, customized wellness questionnaires covering aspects like sleep quality, fatigue, muscle soreness, and mood on a Likert scale have demonstrated good reliability, with a coefficient of variation of 6.9% [81]. These shorter formats provide an efficient way to gather actionable data without imposing excessive demands on athletes' time.

However, subjective measures like questionnaires are not without limitations. Coaches and practitioners occasionally express concerns about the potential for athletes to manipulate their responses to influence outcomes or reduce training demands [76]. Additionally, the inherently individual nature of perceptions of fatigue means that these measures may not always fully capture the broader dimensions of neuromuscular fatigue [82].

2.3.3. Neuromuscular fatigue assessments in team sports: biochemical markers

Biochemical, hormonal, and immunological markers provide valuable insights into the acute responses and recovery times following training and competition [76]. These markers, which can be measured from blood or saliva, offer a window into the athlete's internal physiological state [76]. The endocrine system, in particular, plays a vital role in managing workloads by optimizing training adaptations while minimizing the risk of prolonged fatigue [83].

Among the most commonly used markers for monitoring training responses and recovery are testosterone and cortisol [81]. Testosterone, an anabolic hormone, is critical for muscle hypertrophy, glycogen synthesis, and neural facilitation, which can influence motor unit excitability [84]. Cortisol, on the other hand, is a stress hormone that reflects the endocrine system's response to exercise [83]. The balance between these hormones is often examined through the testosterone-to-cortisol (T:C) ratio, a widely used indicator of the anabolic and catabolic states in athletes [85]. A lowered T:C ratio is associated with periods of increased training load, signalling a shift toward a catabolic state [86]. Significant reductions in this ratio, typically 30% or more, have been linked to overreaching, with athletes experiencing an imbalance in their recovery and adaptation processes [85].

Another important marker for assessing fatigue is creatine kinase (CK), an enzyme stored within muscle cells and released into the bloodstream following intense exercise [87]. Elevated CK levels indicate muscle damage, making it a useful tool for monitoring the physical toll of training and competition [87]. However, CK levels are subject to substantial individual variability, with resting levels differing widely between athletes and day-to-day variations reaching up to 27% [76]. This variability complicates the interpretation of CK measurements as a reliable fatigue-monitoring tool.

Overall, despite their potential value, biochemical markers present several practical challenges in high-performance environments. Collecting and analysing these markers requires significant time, financial resources, and expertise. Invasive procedures like venipuncture blood sampling can deter athlete compliance, while factors such as prior exercise, time of day, dietary intake, and existing injuries further complicate the accuracy and reliability of results [88]. Additionally, there is often a delay in obtaining feedback, reducing the utility of these markers for real-time fatigue management.

2.3.4. Neuromuscular fatigue assessments in team sports: sprint tests

Sprint tests are widely used to assess neuromuscular fatigue and athletic performance across various sports, such as soccer [89], rugby [76], and Australian football [90]. These tests typically involve sprint distances such as 5, 10, and 20 meters, which are common benchmarks for evaluating fatigue responses. Research has demonstrated strong correlations between speed loss during sprints and metabolic markers like lactate ($r = 0.83$) and ammonia ($r = 0.86$), highlighting their alignment with physiological gold-standard measures [91]. This makes sprint tests a reliable tool for assessing fatigue, as they provide insights into both metabolic and neuromuscular responses to exertion.

The design of sprint tests, including factors such as sprint type (e.g., running, rowing, cycling), the number and duration of sprints, recovery intervals, and work-to-rest ratios, can influence performance outcomes and the interpretation of neuromuscular fatigue. Using task-specific parameters tailored to the sport enhances the understanding of fatigue development in response to repeated sprint activities [92]. Many researchers consider sprint tests to be one of the most task-specific measures of neuromuscular fatigue in team sports, given their alignment with the movement patterns and energy demands of various disciplines [90,93,94].

For example, in sports like rugby sevens, sprint accelerations and decelerations occur more frequently than vertical jump actions, making sprint tests particularly relevant for evaluating neuromuscular fatigue in these contexts [93]. Unlike vertical jumps, which rely on the stretch-shortening cycle (SSC), sprint tests predominantly involve concentric muscle actions [94]. As a result, sprint tests may offer greater sensitivity to changes in neuromuscular status, especially in sports where running is the dominant activity. This trend was observed in Australian football, where sprint tests demonstrated similar reliability to vertical jump tests for assessing neuromuscular fatigue, providing an alternative method for monitoring fatigue in high-performance athletes [90].

One of the significant advantages of sprint tests is their ease of administration. These tests do not induce excessive fatigue, making them suitable for inclusion in warm-up routines [90]. They can be performed in various environments, such as indoors or outdoors, and allow for concurrent testing of large groups of athletes [90]. This versatility enhances their ecological validity and practical application in high-performance sports settings, providing coaches with a straightforward yet effective method for monitoring fatigue and neuromuscular status.

2.3.5. Neuromuscular fatigue assessments in team sports: vertical jump tests

Vertical jump tests are widely regarded as a practical and effective method for assessing neuromuscular fatigue in high-performance sports. Their popularity stems from their ease of implementation, high level of acceptance among elite athletes, and their validity and reliability in detecting and quantifying fatigue under field conditions [93]. These tests have been extensively used to evaluate recovery times following intense training sessions or competitions, offering a valuable tool for monitoring athlete readiness and fatigue [77].

One key advantage of vertical jump tests is their sensitivity to changes in neuromuscular function, particularly in assessing the SSC capability of the lower-limb muscles

[81]. This sensitivity makes them well-suited for evaluating muscular fatigue and performance under conditions of altered neuromuscular function. Additionally, vertical jump tests are quick to administer, require minimal additional fatigue, and are supported by reliable technologies. These attributes make them a practical choice for use in both training and competition environments.

Sports like volleyball, where athletes frequently perform movements involving accelerations, decelerations, and jumps, rely heavily on the transition between eccentric and concentric contractions, a fundamental component of the SSC [95]. The repeated execution of these movements during games and practices can lead to diminished efficiency due to neuromuscular fatigue. Vertical jump tests provide a means of detecting such fatigue-related declines in movement performance, offering insights into an athlete's neuromuscular status.

A recent survey found that 54% of S&C coaches and sports scientists used vertical jump tests as part of their performance assessments, further emphasizing their widespread adoption [77]. Among the various vertical jump tests available, the squat jump, CMJ, and drop jump are the most commonly utilized in the literature [77,96]. Of these, the CMJ is particularly favoured by practitioners for assessing neuromuscular fatigue. A previous meta-analysis evaluating the CMJ's efficacy in detecting neuromuscular fatigue across 151 studies identified 63 different metrics, with jump height and peak power being the most frequently reported [96]. Despite their popularity and strong associations with independent physical performance measures, these metrics demonstrated limited sensitivity to fatigue-induced changes, with effect sizes (ES) of -0.04 for both jump height and peak power [96]. This suggests that while these metrics are valuable for general performance assessments, they may not be the most effective indicators of neuromuscular fatigue.

Time-based CMJ metrics have emerged as more sensitive alternatives for monitoring neuromuscular fatigue. Metrics such as relative net impulse (ES = -0.69) and flight time (ES = -1.4) have shown significant changes immediately following intense exercise. Over longer recovery periods, such as 24–72 hours post-exercise, metrics including time to peak power (ES = 0.41 to 1.5) and the flight time-to-contraction time ratio (ES = -0.44 to -1.6) have proven more responsive to fatigue [97,98]. These findings suggest that time-related metrics are particularly useful for detecting subtle changes in neuromuscular function, as they capture adjustments in jump strategies. Athletes may compensate for fatigue by altering their movement patterns to achieve similar jump heights, masking declines in performance when only traditional metrics like jump height are assessed [97].

A study by Gathercole and colleagues [99] further demonstrated the sensitivity of CMJ metrics to acute and chronic changes in neuromuscular fatigue. Following an acute repeated stair-climbing protocol, athletes exhibited reduced CMJ performance, with lower forces being applied and longer durations required to execute jumps. These acute declines contrast with chronic adaptations observed after a structured 19-week training program, where athletes demonstrated increases in peak force and decreases in duration-based metrics (e.g., eccentric, concentric, and total durations). These chronic improvements reflect positive adaptations, with athletes generating greater force in shorter time frames. However, the acute reductions highlight the value of time-based metrics in detecting fatigue-induced changes.

When considering these findings collectively, it becomes clear that while traditional metrics like jump height and peak power are valuable for general performance evaluations, they may be less effective for monitoring neuromuscular fatigue. Time-based metrics, including time to peak power, flight time-to-contraction time ratio, and total phase duration, offer greater sensitivity to fatigue and are therefore more appropriate for practitioners seeking to assess neuromuscular fatigue using the CMJ. These metrics provide critical insights into the neuromuscular adjustments that occur in response to fatigue, allowing for more precise monitoring and intervention strategies.

2.4. Recovery

Recovery is a multifaceted process encompassing physiological, psychological, and social dimensions, aimed at restoring balance and counteracting fatigue caused by physical and mental exertion [100]. Fatigue arises when an individual's biopsychosocial equilibrium is disrupted by internal or external factors [34]. Recovery facilitates the re-establishment of this balance, often referred to as allostatic balance, by replenishing the resources expended during training or competition on both physical and psychological levels [101].

The term "recovery" serves as an umbrella concept, encompassing various modalities tailored to address specific aspects of fatigue. Regeneration refers specifically to the physiological side of recovery and is typically applied after training or competition to mitigate physical fatigue [102]. Common regeneration strategies include cold-water immersion and sleep, which have been extensively studied for their effectiveness in enhancing recovery [103]. On the other hand, psychological fatigue, often manifesting as cognitive exhaustion, is addressed through strategies such as cognitive self-regulation, resource activation, and relaxation techniques [101].

Kellmann [101] proposes three distinct approaches to recovery: passive, active, and proactive. Passive recovery involves rest or external interventions such as massage, where the athlete remains inactive. Active recovery includes light physical activities like cool-down exercises designed to alleviate the metabolic effects of physical fatigue. Proactive recovery emphasizes self-determined activities tailored to individual preferences, such as engaging in social interactions or leisure pursuits, which promote overall well-being.

A certain degree of fatigue, known as functional overreaching (FO), is a necessary component of performance enhancement, as it reflects a short-term performance decrement without signs of maladaptation. However, if recovery is insufficient or not individualized, FO may progress into non-functional overreaching (NFO), characterized by negative psychological and hormonal changes and a subsequent decline in performance [104]. Prolonged underrecovery, along with NFO, can lead to overtraining syndrome (OTS), a severe condition marked by persistent fatigue, muscle soreness, and endocrinological disturbances [105]. While early-stage underrecovery and NFO can often be mitigated through systematic recovery strategies, recovering from OTS requires long periods of rest and recovery, potentially lasting weeks or months, during which performance remains impaired [105].

Performance itself is a multidimensional concept influenced by both physiological and psychological factors [106]. Physiologically, attributes such as strength, endurance, speed, and flexibility contribute to an athlete's ability to perform [34]. Psychologically, factors like concentration, motivation, and volition also play critical roles. Recovery and fatigue exist on a continuum, where insufficient recovery in the face of prolonged fatigue disrupts this balance, leading to declines in both performance and well-being [104].

2.4.1. Biological approaches to monitoring recovery in athletes

Biological parameters, alongside performance-based tests, are commonly regarded as objective indicators of fatigue in sports settings. These parameters provide critical insights into an athlete's recovery status, reflecting the physiological and biochemical responses to intense training sessions. When resources are depleted due to high physical demands, biological indicators can signal the need for recovery, making them a vital component of athlete monitoring systems [107]. Among the wide array of biological measures available, this section focuses on selected strategies that demonstrate both practicality and feasibility in sports contexts.

One key area of focus is the monitoring of cardiac variables, which can be used to assess the recovery status of athletes by evaluating the physiological processes influenced by training load and volume. Modern heart rate (HR) monitoring systems provide a non-invasive and practical tool for continuous tracking of cardiac activity over extended periods, including during training sessions and subsequent recovery phases. These systems enable the analysis of various cardiac parameters, such as exercise HR, heart rate variability (HRV), and heart rate recovery (HRR) [34]. HRV refers to the variation in time between consecutive heartbeats, while HRR measures the speed at which the heart returns to its normal rate after exercise [34].

Research suggests that combining resting HRV measurements with submaximal exercise HR offers a robust approach to monitoring recovery [108,109]. For example, a 5-minute resting HRV measurement, alongside the final minute of a 4- to 5-minute submaximal training bout, has been shown to provide valuable insights into both acute and chronic training responses [108,109]. Resting HRV is particularly useful in capturing the athlete’s physiological adaptation, with changes reflecting both positive and negative responses to training. However, interpreting HRV in the context of underrecovery is challenging due to the influence of variables such as the athlete's sport, environmental conditions, and individual characteristics.

In general, prolonged underrecovery is associated with a higher resting HR, reduced HRV, and increased blood pressure, signalling chronic stress and psychophysical overload [110]. These changes are indicative of sustained activation of the sympathetic nervous system, a hallmark of stress response [110]. HRR, which measures the adaptation of HR post-exercise, is another critical parameter. Delayed HRR may point to compromised recovery, highlighting the importance of assessing this metric in relation to overall recovery status. Despite their utility, cardiac parameters must be interpreted with caution and within the context of the athlete's training phase, workload, and individual baseline values. Factors such as hydration, circadian rhythm, environmental conditions, and medication can act as confounders and should be accounted for during data interpretation [108].

2.4.2. Psychological approaches to monitoring recovery in athletes

Psychological monitoring provides a valuable perspective on the recovery process by assessing the mental and emotional consequences of training-induced fatigue. These tools primarily involve subjective self-report measures, allowing athletes to reflect their perceived recovery status and offering insights into changes in psychological states such as mood, stress, and fatigue [100]. By identifying gradual negative developments in health—such as underrecovery or NFO—psychological assessments help practitioners prevent more severe outcomes like OTS [107].

A variety of psychometric questionnaires have been developed based on robust theoretical models and are widely applied in sports practice [107]. These tools vary in purpose, with some focusing on general well-being and others offering sport-specific insights. They can assess single constructs, like stress, or multiple dimensions, such as mood, vigour, and fatigue. Comprehensive psychological assessments are particularly valuable in identifying subtle shifts in an athlete's mental and emotional state before symptoms manifest, enabling a proactive approach to managing recovery [111].

Three prominent instruments used in monitoring psychological recovery in sports include the Multicomponent Training Distress Scale (MTDS) [112], the POMS [113], and the RESTQ-Sport [114].

The MTDS is a multidimensional self-report measure designed to assess psychological and behavioural responses to intense training, such as training camps [112]. It evaluates three key domains: stress, mood, and physical or behavioural symptoms, through six broader symptom clusters—Depression, Vigor, Physical Symptoms, Sleep Disturbances, Perceived Stress, and Fatigue. Using 22 items, the MTDS combines intensity and frequency scales to capture both mood and stress levels. Its compact format makes it a cost-effective and practical option for monitoring athletes in various sports contexts [112].

The POMS is a pioneer in overtraining research and remains a popular instrument for monitoring mood states in athletes [113]. It assesses six mood dimensions: Tension, Depression, Anger, Fatigue, Confusion, and Vigor. The POMS global score is calculated by subtracting Vigor from the sum of the five negative scales and adding a constant of 100, providing a comprehensive picture of mood disturbances. An "iceberg profile," where Vigor is elevated relative to other dimensions, is considered a favourable indicator. For practical applications, the shorter Brunel Mood Scale is often used as an alternative, maintaining the core functionality of the POMS while being more time-efficient [115].

The RESTQ-Sport is a comprehensive tool for assessing recovery and stress over the preceding three days and nights [114]. It includes 19 scales, each composed of four items, covering both general and sport-specific factors. Recovery dimensions encompass aspects like Social Recovery, General Well-Being, Sleep Quality, and Personal Accomplishment, while stress dimensions evaluate General Stress, Social Stress, Emotional Exhaustion, and Injury. The RESTQ-Sport is particularly effective in identifying chronic underrecovery and NFO [102], and its abbreviated version (RESTQ-Sport-36) offers a more user-friendly alternative for practical use [114].

These psychological instruments not only help track recovery but also provide actionable data for designing interventions, such as relaxation techniques or adjusted training loads [107]. They can be used individually or in combination with biological and performance-based measures to offer a holistic view of an athlete's recovery status. This integrated approach ensures that psychological well-being is prioritized alongside physiological restoration, supporting optimal performance and long-term athlete development.

2.4.3. Social approaches to monitoring recovery in athletes

While social monitoring often receives less attention in athletic contexts compared to biological and psychological approaches, evidence underscores the significant influence of social factors—such as interactions with coaches, teammates, and family—on performance [116]. A supportive social environment can act as a buffer against stress, enhance recovery, and foster sustained high-level performance [117]. Positive communication and opportunities for athletes to maintain regular interactions with their social networks contribute meaningfully to their overall performance [118].

Clear guidelines for monitoring social factors in sports are not yet well-established. However, tools like validated psychometric instruments, combined with open communication, can help identify and address social obstacles to performance [119]. One such tool is the Daily Analysis of Life Demands for Athletes (DALDA) [120], which assesses an individual's stress state, including psychophysiological and social stress, in response to changes in training load [121]. The DALDA consists of 34 items divided into two sections. Part A identifies nine sources of stress, such as home life or work, while Part B evaluates 25 stressors, including recovery time and irritability. Athletes rate each item as "normal," "worse than normal," or "better than normal," offering a clear and accessible format for data collection. Responses are displayed graphically over time, allowing practitioners to identify trends and patterns. For instance, if an athlete reports an increasing number of "worse than normal" responses over three consecutive days, this may signal an unfavourable stress state that requires intervention or training adjustments [120].

One of the DALDA's strengths lies in its inclusion of both sport-related and nonsport-related stressors. This holistic approach enables the identification of social stressors that might otherwise go unnoticed, providing a platform for discussions about potential issues affecting recovery and performance. Similarly, the RESTQ-Sport includes specific scales for social factors, such as Social Stress, Conflicts/Pressure, and Social Recovery, offering additional insights into an athlete's social functioning [114]. Persistent deficits in these areas, highlighted through RESTQ-Sport scores, can act as early warning signs of social conflicts that may warrant resolution through open dialogue.

Monitoring social processes is ideally achieved through a combination of psychometric assessments and direct communication. Personal interactions with athletes complement questionnaire data, providing a deeper understanding of the social dynamics that influence recovery. Social monitoring helps uncover dimensions of fatigue and recovery that are not fully captured by biological or psychological measures, broadening the scope of athlete recovery management.

Chapter III – Methods

"It's not the load that breaks you down, it's the way you carry it."

Lena Horne

Given the nature of this type of research and the complexity involved, this chapter aims to present the diverse methods utilized in the development of the seven studies included in this thesis. While a coherent framework underpins the methodological approach, there are naturally differences between studies that require clarification and justification. These explanations are essential to ensure a comprehensive understanding of the choices made and their potential implications for the interpretation of the results. The approval from the ethics committee for the doctoral project is provided in Appendix I. Additionally, all references throughout this thesis have been formatted according to the Vancouver referencing style

3.1. Types of review studies included

The studies presented in this thesis encompass a range of review methodologies, each serving a distinct purpose in synthesizing and analysing existing evidence. The methodological approaches include a narrative review, scoping reviews, and systematic reviews. Below, it is provided an overview of these types of reviews and their specific applications in the context of this research.

3.1.1. Narrative reviews

Narrative reviews, unlike systematic and scoping reviews, provide a broader and more flexible approach to synthesizing evidence [122]. They allow for the exploration of multiple questions, often without rigid inclusion criteria, and are well-suited to tracing the development of concepts or principles [122]. While they may lack the methodological rigor of systematic reviews, narrative reviews are valuable for contextualizing evidence within a historical or conceptual framework [123].

Study I (Strength and Conditioning for Volleyball: A Review) exemplifies the narrative review approach, synthesizing a broad range of topics related to S&C practices in volleyball. This review offers a conceptual overview, integrating diverse evidence to provide practical recommendations for improving athlete performance and mitigating injury risks.

3.1.2. Scoping reviews

Scoping reviews share similarities with systematic reviews in their structured methodology but are designed for different purposes. They aim to map the scope and coverage of a body of literature, often addressing broader research questions where evidence is emerging or fragmented [124]. Scoping reviews are particularly useful for [124]:

- Identifying the types and characteristics of available evidence.
- Clarifying key concepts or definitions.
- Highlighting knowledge gaps and guiding future systematic reviews.

Study II (Beyond the Jump: A Scoping Review of External Training Load Metrics in Volleyball) serves as an example of this methodology. This review provides a comprehensive overview of the ETL metrics used in volleyball, offering a foundation for understanding the field and identifying areas where more precise or in-depth research is required.

3.1.3. Systematic reviews

Systematic reviews are structured research syntheses designed to minimize bias and ensure reliable findings [125]. They follow rigorous pre-defined methods to identify, appraise, and synthesize evidence relevant to specific research questions. Emerging in the 1970s and gaining prominence through initiatives like Cochrane and the Joanna Briggs Institute in the 1990s [126], systematic reviews are considered a cornerstone of evidence-based practice [127]. These reviews are particularly valuable for [124]:

- Assessing the quality and reliability of existing evidence.
- Identifying gaps and variations in current practices.

- Producing evidence-based statements to inform decision-making.

Studies III (Rating of Perceived Exertion in Professional Volleyball: A Systematic Review) and IV (Training Stress, Neuromuscular Fatigue, and Well-Being in Volleyball: A Systematic Review) exemplify this approach, providing detailed analyses of specific aspects of training load and fatigue in volleyball. By synthesizing evidence from a wide range of studies, these reviews offer actionable insights into established practices and areas for future research.

By employing these three types of reviews—narrative, scoping, and systematic—the thesis provides a thorough examination of the evidence base surrounding training load, neuromuscular fatigue, and recovery in elite volleyball. Each approach was chosen to align with the specific objectives of the respective studies, ensuring that the evidence synthesis is both methodologically sound and relevant to the overarching research questions. Together, these studies contribute to a deeper understanding of how training load and recovery can be optimized for performance in high-performance sports contexts.

3.2. Types of longitudinal studies included

In addition to the review studies, this thesis includes three cohort studies, each designed to explore critical aspects of training load, neuromuscular fatigue, and recovery in elite volleyball players. These studies adopt a longitudinal approach, enabling the investigation of dynamic relationships between training variables and performance outcomes. Below, it is provided an overview of cohort studies as a methodology, followed by a detailed explanation of their applications in Studies V, VI, and VII.

3.2.1. Cohort studies

Cohort studies are a form of longitudinal research that follows a group of participants who share a common characteristic, such as being elite athletes, over a period of time [128]. In sports contexts, these studies allow researchers to investigate how certain exposures, like training loads or competition schedules, influence outcomes such as performance, recovery, or fatigue. By observing changes over time, cohort studies can provide valuable insights into cause-and-effect relationships, particularly regarding how specific training or recovery strategies impact athletic performance.

The strength of cohort studies lies in their ability to link exposures to outcomes with greater confidence, making them a robust method for examining causal relationships [128]. For instance, by tracking athletes across a competitive season, researchers can evaluate how varying training loads influence neuromuscular fatigue or recovery. These studies often involve large sample sizes and long follow-up periods, enhancing their reliability and generalizability [128].

However, cohort studies also present challenges. Collecting data prospectively over extended periods can be time-consuming, resource-intensive, and susceptible to participant dropout, which increases the risk of bias. In the context of sports science, where athletes may alter their behaviours due to their awareness of being observed, maintaining ecological validity becomes critical. Additionally, analysing the complex data generated from these studies requires sophisticated statistical methods to account for confounding variables.

To ensure the quality and reliability of cohort studies, researchers are encouraged to adhere to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines [129]. These guidelines provide a structured framework for designing, conducting, and reporting cohort studies, enhancing their transparency and reproducibility.

3.3. Participants

Studies I (Strength and Conditioning for Volleyball: A Review), II (Beyond the Jump: A Scoping Review of External Training Load Metrics in Volleyball), III (Rating of Perceived Exertion in Professional Volleyball: A Systematic Review), and IV (Training Stress, Neuromuscular Fatigue, and Well-Being in Volleyball: A Systematic Review) did not involve primary data collection from participants, as they were review studies. However, while Study I was a narrative review and did not require inclusion or exclusion criteria, Studies II, III, and IV adhered to specific criteria to ensure methodological rigor and relevance to the research objectives. In addition to the review studies, this thesis incorporates three cohort studies designed to investigate key aspects of training load, neuromuscular fatigue, and recovery in elite volleyball players – Studies V (Training Load, Neuromuscular Fatigue, and Well-Being of Elite Male Volleyball Athletes During an In-Season Mesocycle), VI (Impact of Congested

Match Schedules on Countermovement Jump Metrics in Elite Volleyball Players), and VII (Optimizing Recovery: The Impact of Training Load in Elite Volleyball Players). These studies follow participants longitudinally, enabling a detailed examination of the dynamic interactions between training demands, physical performance, and recovery processes.

3.3.1. Study II

The scoping review in Study II was designed to map the available literature on ETL in volleyball. The following inclusion criteria were applied:

- Population: Studies involving volleyball players of any age or performance level.
- Focus on ETL: Articles that reported on ETL measurements, including how ETL relates to player performance, injury rates, or other relevant outcomes.
- Specificity of ETL Metrics: Studies measuring ETL beyond movements in the sagittal plane or explicitly stating a sagittal-plane-only focus.
- Study Design: Both observational and interventional studies were included.

These criteria ensured a broad scope, allowing for the identification of gaps in the current literature and providing an overview of ETL measurement in volleyball.

3.3.2. Study III

Study III systematically reviewed the use of RPE in professional volleyball. The inclusion and exclusion criteria were as follows:

Inclusion Criteria:

- Articles that examined professional volleyball athletes.
- Studies reporting RPE outcomes during at least one phase of the season (off-season, pre-season, or competitive period).
- Cross-sectional or longitudinal observational studies.

Exclusion Criteria:

- Studies involving collegiate or young volleyball athletes.
- Experimental studies implementing an intervention, as these could misrepresent natural workload patterns.
- Studies reporting player monitoring data only during competitive games or a partial phase of the season, as they did not represent the full workload experienced by players over a season.

These criteria focused the review on professional volleyball and provided insights into the practical application of RPE in this population.

3.3.3. Study IV

Study IV focused on training stress, neuromuscular fatigue, and well-being in volleyball athletes. Its inclusion and exclusion criteria were as follows:

Inclusion Criteria:

- Original research published in peer-reviewed journals in English, French, Spanish, or Portuguese.
- Studies involving volleyball athletes of any age group, including youth, collegiate, and adult players.
- Research with at least two evaluation points, such as baseline and post-intervention measurements.

Exclusion Criteria:

- Studies not involving human participants.
- Research not specifically addressing volleyball training or competition.
- Studies lacking empirical data or a clear methodological description.

3.3.4. Study V

Study V included 15 professional male volleyball players competing in the first Portuguese Volleyball Division—Liga UNA Seguros. The participants had an average age of 28.51 years (SD: 5.39), a mean height of 193.19 cm (SD: 9.87), and a mean body mass of 88.46 kg (SD: 13.18). These athletes provided data on training load, neuromuscular fatigue, and well-being over an in-season mesocycle, ensuring insights into performance and recovery within a high-performance environment.

3.3.5. Study VI

Participants in Study VI were required to meet a classification framework for elite-level players, which was based on their involvement in national and international competitions and their professional status within the sport. Eligibility criteria included being 18 years or older, actively competing during a congested match period, and consistently participating in team training sessions and matches without any injuries or conditions impairing their ability to perform jump tests.

The final sample consisted of 14 elite male volleyball players with a mean age of 28.94 years (SD: 4.99), a mean body mass of 90.84 kg (SD: 10.57), and a mean height of 194 cm (SD: 0.09). The positional breakdown included two liberos, four middle blockers, four outside hitters, two setters, and two opposite hitters. No participants were excluded during the study, and complete data were obtained for all primary variables of interest, ensuring a robust dataset for analysis.

3.3.6. Study VII

Study VII involved 14 elite volleyball players, classified using the same framework as in Study VI. Participants had a mean age of 28.59 years (SD: 4.99), a mean height of 193.93 cm (SD: 9.38), and a mean body mass of 90.88 kg (SD: 10.56). The sample included four outside hitters, two setters, two opposite hitters, four middle blockers, and two liberos. The study focused on examining the impact of training load on recovery during a competitive season.

3.4. Data sources and measurement

As a narrative review, Study I (Strength and Conditioning for Volleyball: A Review) did not adhere to a structured methodology for data sources. Instead, it synthesized evidence from a broad range of available literature, offering a conceptual overview of S&C practices in volleyball.

Studies II, III, and IV, data sources were rigorously selected through structured database searches.

- Study II (Beyond the Jump: A Scoping Review of External Training Load Metrics in Volleyball) utilized electronic databases including PubMed/Medline, Scopus, Web of Science, and SPORTDiscus. The final literature search was conducted on June 26, 2023. Additionally, reference lists of identified articles and relevant reviews were manually screened to ensure comprehensive coverage.
- Study III (Rating of Perceived Exertion in Professional Volleyball: A Systematic Review) systematically identified relevant articles from PubMed, SPORTDiscus, Scopus, and Web of Science. The search spanned from database inception to July 2022.
- Study IV (Training Stress, Neuromuscular Fatigue, and Well-Being in Volleyball: A Systematic Review) conducted its literature search from database inception to March 2023 across PsycINFO, MEDLINE/PubMed, SPORTDiscus, Web of Science, and Scopus.

In Study V (Training Load, Neuromuscular Fatigue, and Well-Being of Elite Male Volleyball Athletes During an In-Season Mesocycle), ITL was quantified using the sRPE method. Approximately 15 minutes after each training session, players rated the difficulty of the session using the BORG-CR10 scale. ITL was calculated by multiplying the sRPE value by the session duration in minutes. ETL was measured using inertial measurement units (IMUs) equipped with 3-axis gyroscopes, 3-axis magnetometers, and 3-axis accelerometers (Vert® Classic, MyVert, Florida, FL, USA). Neuromuscular fatigue was assessed through CMJ tests performed on a contact platform (Chronojump Boscosystem, Barcelona, Spain).

In Study VI (Impact of Congested Match Schedules on Countermovement Jump Metrics in Elite Volleyball Players), neuromuscular fatigue was assessed exclusively through CMJ tests. These tests were conducted on two portable adjacent force plates (Hawkin Dynamics, Westbrook, Maine, USA), with data collected at a sampling rate of 1000 Hz, ensuring precision and reliability in neuromuscular performance measurements.

Study VII (Optimizing Recovery: The Impact of Training Load in Elite Volleyball Players) used a combination of methods to assess ITL and ETL, as well as recovery. ITL was measured using the sRPE method, following the same protocol as in Study V. ETL was also assessed using Vert® Classic IMUs. Neuromuscular fatigue was monitored through CMJ tests conducted on portable adjacent force plates (Hawkin Dynamics, Westbrook, Maine, USA). Additionally, psychological and social recovery metrics were evaluated using the 36-item version of the Recovery Stress Questionnaire for Athletes (RESTQ-Sport-36). This questionnaire measured 12 factors across recovery and stress dimensions using a 7-point Likert scale, providing insights into the athletes' recovery processes.

3.5. Procedures

This section is divided into two sub-sections: operational procedures and statistical procedures. The operational sub-section outlines the methodological steps taken in the development of each study, detailing the processes involved in data collection and analysis. The statistical sub-section describes the analytical approaches employed to interpret the data and derive meaningful insights. For a more detailed explanation of the procedures used in each study, readers are encouraged to refer to Chapter IV.

3.5.1. Operational

As a narrative review, Study I (Strength and Conditioning for Volleyball: A Review) did not follow standardized procedures. The authors relied on their experience in the field to curate and synthesize relevant evidence, providing an overview of S&C practices in volleyball.

Study II (Beyond the Jump: A Scoping Review of External Training Load Metrics in Volleyball) followed a protocol aligned with the Preferred Reporting Items for Systematic

Reviews and Meta-Analyses extension for scoping reviews guidelines [130]. The protocol was registered on the International Platform of Registered Systematic Review and Meta-analysis Protocols [131] and made publicly accessible. The search strategy, developed by the primary researcher with input from the research team, adhered to the Peer Review of Electronic Search Strategies checklist [132]. Both controlled vocabulary (e.g., MeSH terms in PubMed/Medline) and free-text terms were employed, including key terms such as "volleyball," "external training load," "physical demands," and "measurement." The search was tailored to the syntax and subject headings of each database, ensuring thoroughness and reproducibility. After executing the search across multiple electronic databases, all identified citations were imported into CADIMA software to facilitate screening and data extraction [133]. Duplicate citations were automatically removed, and the screening process was systematically conducted to ensure a structured review.

Study III (Rating of Perceived Exertion in Professional Volleyball: A Systematic Review) followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines [134]. The study protocol was registered with International Platform of Registered Systematic Review and Meta-analysis Protocols to ensure transparency and replicability. The screening of abstracts was independently conducted by two authors against pre-defined selection criteria. Disagreements were resolved through discussion or, when necessary, consultation with a third author. Full-text copies of eligible articles were obtained, and full-text screening was performed by the same two authors. Methodological quality was assessed using a modified version of the Downs and Black checklist for evaluating healthcare interventions [135].

Study IV (Training Stress, Neuromuscular Fatigue, and Well-Being in Volleyball: A Systematic Review) adhered to Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2020 guidelines [136]. The search strategy incorporated terms related to volleyball training, matches, and key concepts such as "training load," "rating of perceived exertion," "well-being," and "fatigue." Searches were conducted across five electronic databases, and retrieved papers were exported to CADIMA software for efficient evidence synthesis. Duplicate records were removed automatically. Screening was conducted in two stages: title/abstract and full-text screening. Both steps were independently performed by two authors, with discrepancies resolved through discussion or involvement of additional authors when necessary. Methodological quality was evaluated using a modified version of the Downs and Black checklist [135].

Study V (Training Load, Neuromuscular Fatigue, and Well-Being of Elite Male Volleyball Athletes During an In-Season Mesocycle) utilized a non-interventional design to capture real-world data over a 5-week competitive phase during the 2021–2022 annual season. This phase included five microcycles, each culminating in a weekend match, for a total of five matches. Data collection encompassed volleyball training sessions and matches.Training data were analysed relative to the number of days away from the match day (MD). In weeks with only one match, the team typically trained five or six days per week (e.g., MD-6 to MD-1) and conducted one post-match recovery session (MD+1). This design provided a view of training load distribution and its relationship with neuromuscular fatigue and perceptual well-being across the competitive phase.

Study VI (Impact of Congested Match Schedules on Countermovement Jump Metrics in Elite Volleyball Players) monitored athletes during the final mesocycle of the competitive season, spanning March 12 to May 4, 2024. This period included 11 matches—one game from the second phase of the championship, two Portuguese Cup matches, and eight matches from the championship finals (three semi-final matches and five final matches). In addition to matches, 34 training sessions were conducted, with one session held on each non-match day, except MD+1, where no training took place. Microcycles were structured based on the match schedule, typically ending on MD+1. For microcycles with multiple matches (e.g., Microcycles 4, 6, and 7), the microcycle extended until MD+1 of the last match. An exception was Microcycle 2, which featured consecutive match days, necessitating a shift in the schedule after the first MD+1. CMJ assessments were performed 14 times throughout the study period, providing a detailed timeline of neuromuscular fatigue in response to a congested match schedule. The study adhered to the STROBE guidelines to ensure methodological rigor and transparency.

Study VII (Optimizing Recovery: The Impact of Training Load in Elite Volleyball Players) followed the STROBE guidelines. The study was conducted with a professional volleyball team competing in Portugal’s highest division, Liga UNA Seguros, over 105 days between December 2023 and March 2024. This period encompassed the second phase of the national championship, involving the top eight teams competing in home-and-away matches to qualify for the playoffs. This accounted for 14 matches, alongside two domestic cup matches and the final two games of the first championship phase, where 14 teams played against each other once. In total, 18 matches were included in the study period. Recruitment and exposure periods coincided with the competitive season, ensuring that training load and recovery data accurately reflected real-world conditions. Data collection was conducted continuously, providing insights into the interplay between training demands, recovery strategies, and performance outcomes during the critical phases of the season.

3.5.2. Statistical

Study I, being a narrative review, did not involve any statistical analyses. Instead, it relied on qualitative synthesis. Studies II (Beyond the Jump: A Scoping Review of External Training Load Metrics in Volleyball), III (Rating of Perceived Exertion in Professional Volleyball: A Systematic Review), and IV (Training Stress, Neuromuscular Fatigue, and Well-Being in Volleyball: A Systematic Review) did not conduct meta-analyses. The extracted data were processed systematically to generate a narrative synthesis, which involved iterative exploration, pattern recognition, and thematic identification. Insights were derived descriptively, focusing on the body of literature's overall characteristics, study designs, and participant profiles.

In Study V (Training Load, Neuromuscular Fatigue, and Well-Being of Elite Male Volleyball Athletes During an In-Season Mesocycle), all statistical analyses were performed using SPSS (Version 27.0). Descriptive statistics characterized the sample. The Shapiro-Wilk and Levene tests assessed normality and homoscedasticity, respectively. When variables demonstrated normal distribution (Shapiro-Wilk > 0.05), repeated-measures analysis of variance with Bonferroni post hoc adjustments was used to compare the five microcycles and match-day intervals. ES were calculated to standardize coefficients using between-subjects standard deviation. Pearson product-moment correlations tested relationships between continuous variables, while Spearman correlations were used for ordinal or mixed continuous-ordinal variables. Statistical significance was set at an alpha level of 0.05.

Study VI (Impact of Congested Match Schedules on Countermovement Jump Metrics in Elite Volleyball Players) followed a detailed statistical protocol. A priori power analysis using G*Power (v. 3.1.9.7) determined that a sample size of 7 participants would be sufficient to achieve a power of 0.975, based on preliminary data ($\eta p^2 = 0.225$, Cohen's $f = 0.54$). CMJ metrics were transformed into standardized z-scores (0–100 scale) to allow for meaningful comparisons. Repeated-measures ANOVA was conducted separately for comparisons across microcycles and between match-day intervals (e.g., MD-5 and MD-1). Mauchly's test of sphericity was used, and when its assumption was violated ($p < 0.05$), the Greenhouse-Geisser correction was applied. Effect sizes were measured using partial eta squared (ηp^2), and Bonferroni corrections were applied for post hoc analyses. Additionally, coefficients of variation were calculated to assess the variability of CMJ metrics across microcycles and match days.

In Study VII (Optimizing Recovery: The Impact of Training Load in Elite Volleyball Players), sample size calculations using G*Power (v. 3.1.9.7) indicated that 96 observations were required to achieve a power of 0.851 for a two-tailed test with an expected medium effect size ($\rho = 0.30$). The relationships between training load metrics and various dimensions of recovery were analysed using a General Linear Model to account for repeated measures across 18 time points for 14 elite volleyball players. The dependent variables included six biological recovery metrics derived from CMJ measurements and six psychological and social recovery metrics derived from the RESTQ-36 questionnaire. The independent variables consisted of ITL and ETL measures. An alpha level of 0.05 was used to determine statistical significance.

Chapter IV – Studies Developed

"Nothing's ever going to be given to you. Everything is going to be earned. If you don't go out there and put in the work, if you don't put in the effort, one you're not going to get the results, but two, most importantly, you don't deserve it. You didn't earn it."

Tiger Woods

This chapter presents the seven studies developed as part of this thesis, each contributing to the overarching goal of understanding training load, fatigue, and recovery in elite volleyball players. The studies span a range of methodologies, including narrative, scoping, and systematic reviews, as well as empirical cohort studies, providing a broad perspective on the topic. Each study is included alongside the journal in which it was published, reflecting their contribution to the scientific community and their relevance in advancing volleyball performance research.

4.1. Study I – Strength and Conditioning for Volleyball: A Review

Rebelo, A., Valente-Dos-Santos, J., Pires, I. G., Arrais, I., Pereira, J. R., & Turner, A. N. (2025). Strength and Conditioning for Volleyball: A Review. *Strength and Conditioning Journal*. Published ahead of print. https://doi.org/ 10.1519/SSC.0000000000000895.

4.1.1. Abstract

Volleyball, with its global popularity and rigorous competition schedules, presents unique challenges in athlete conditioning and injury prevention. This narrative review synthesizes the current understanding of the physical demands and injury risks associated with elite volleyball play, offering a detailed analysis of match play dynamics and prevalent injury mechanisms. It emphasizes the important role of strength and conditioning (S&C) coaches in developing training programs to enhance performance and mitigate injury risks through strategic exercise selection and periodization. The review provides a thorough needs analysis, highlighting specific conditioning requirements for different player positions and detailing effective physical testing protocols. Recommendations are made for implementing structured S&C programs, which are vital for preparing athletes for the physical challenges of competitive volleyball. Practical guidelines are outlined for S&C coaches to optimize training outcomes, including suggestions for drill sequences and conditioning routines that reflect the sport-specific demands of volleyball. Thus, this review aims to equip coaches, trainers, and athletes with the knowledge and tools necessary to elevate their performance and safeguard against injuries, thereby contributing to the advancement and sustainability of volleyball as a high-intensity competitive sport.

Key Words: injury prevention; program design; resistance training; speed; power; team sports.

4.1.2. Introduction

With more than 500 million players worldwide and representation in over 220 countries, volleyball has firmly established itself as a global sport [1]. Notably, volleyball ranks among the top five most popular sports globally, particularly resonating in Brazil, Italy, Russia, and the United States of America (USA). In the USA alone, the sport boasts over six million participants annually [2]. This popularity is not limited to professional players, as volleyball's younger generations are also rising. A prime example of this can be seen at the high school level, where volleyball is the second-highest sport for female participation [3].

In volleyball, the central goal is to win points by skillfully maneuvering the ball over the net into the opponent's court, making it unreturnable or inducing faults. This objective is pursued through tactical skills, strategic play, and cohesive team effort, where roles like passing, setting, spiking, blocking, and serving are decisive [4] (Table IV-1). Five primary positions, each with specific functions, are central to the sport. The setter, akin to a quarterback in other sports, is the strategic heart of the team. Tasked with setting up the ball for attackers, they require excellent ball-handling and decision-making abilities [5]. The opposite hitter, positioned on the right side, is the primary attacker. They play an important role in both offensive spikes and defensive blocks, especially against the opponent's outside hitters [6]. The outside hitter, often stationed on the left side, is another key attacker, known for taking numerous swings at the ball. This position demands versatility, as they must excel in attacking and defensive skills like blocking and digging [7]. Middle blockers, positioned centrally, form the core of the team's defense. Their job is to block opponent attacks, especially rapid middle strikes, while executing quick offensive moves [8]. The libero, a defensive specialist, is unique in being restricted from serving, spiking, or rotating into the front row. Their primary role is to bolster the team's defense through exceptional passing and digging skills [9].

Elite volleyball athletes face demanding schedules, particularly those competing for club and national teams. For example, in the 2022/2023 season—an intense year due to the upcoming 2024 Olympic Games—top European men's national teams, like Italy, Poland, and France, faced an extended calendar of competitions. These included friendly matches in May and June, the FIVB Volleyball Nations League until the end of July, the CEV European Volleyball Championship until mid-September, and finally, the FIVB Men's Road to Paris Olympic Volleyball Qualifier in October. While this schedule is unique to Olympic participation, even in non-Olympic years, national team-level competitive seasons span until

August-September. Female elite athletes, such as those on the USA Women's National Team, experience similar demands. For players not involved in national teams, a typical off-season of approximately three months (from May to August) is relatively long compared to other team sports, reflecting the unique scheduling structure of professional volleyball.

Table IV-1: Definitions of key volleyball terms.

Term	Definition
Digging	A defensive action where a player prevents the ball from hitting the court by using their forearms to deflect an opponent's attack or spike.
Setting	A strategic pass where a player uses their fingertips to position the ball for an attacker, enabling a teammate to perform an offensive play, such as a spike.
Spiking	An aggressive, downward hit of the ball into the opponent's court, typically executed at the net with high force to score a point or force an error.
Blocking	A defensive action performed at the net to intercept or deflect the opponent's attack by using the hands and arms to prevent the ball from crossing into one's court.
Serving	The act of initiating play by hitting the ball from behind the end line over the net to the opponent's side, starting each point.

Despite the relatively longer off-season for some players, the continuous cycle of training and competition—especially for those balancing club and national team commitments—places significant physical demands on elite volleyball athletes, driving an increasing focus on physical development [10-12] and injury risk reduction [13-15]. The continuous cycle of training and competition, with minimal rest, can significantly tax an athlete's body [16]. The strength and conditioning (S&C) coach is tasked with enhancing athletic performance and implementing strategies to mitigate injury risks [17]. Their work involves developing tailored training programs that address the specific physical demands of volleyball, considering the unique needs of players in different positions [18]. This nuanced understanding of position-specific requirements is vital for S&C coaches, as it allows them to effectively prepare players for the physical challenges of their roles.

4.1.3. Positional load analysis in match play

For male volleyball players, research examining external load during matches is sparse, predominantly focusing on metrics associated with jumping [19,20]. Analysis reveals that male setters tend to execute the highest number of vertical jumps compared to other positions [21-23]. Notably, most of these jumps are executed during setting actions and are typically of lower intensity than those performed during blocking and attacking [21]. In contrast, male middle blockers are recorded to have the highest number of block jumps, followed closely by outside hitters [21]. When considering jump height, it is observed that jumps performed during attacks, especially by outside hitters, generally approach their maximum jump height more closely than those performed during blocks [21].

Research on the external load of female volleyball players during match play is even more limited than that for their male counterparts, with only a handful of studies focusing on jump-related metrics [14,24]. The available data shows that female setters experience the highest number of jumps per game, followed by middle blockers and outside hitters [14,24]. The data also shows that the average jump height for outside hitters is substantially higher than for other positions [24]. The disparity in jump heights can be attributed to the different jump types involved; blocking primarily requires a concentric-only squat jump, whereas attacking spikes typically involve an approach jump with multiple rapid steps. This biomechanical distinction is responsible for the higher jump heights seen in attacking actions, underscoring the importance of conditioning programs that target both concentric power and impulse and approach-based power and impulse to meet the varied demands of each position.

The external load for male and female players is presented in Table IV-2. It should be acknowledged, however, that limited studies have investigated this, with the variability in league and team strategies influencing results. This underscores the need for more extensive research to comprehensively analyze jump-related metrics with greater certainty and applicability across different competitive environments. The dominant technology used across studies to measure jump metrics was an inertial measurement unit (IMU), which consists of 3-axis gyroscopes, magnetometers, and accelerometers. IMUs were generally placed on a belt secured to the athlete's hip, transmitting data via Bluetooth. A validation study has shown high correlations between IMUs and laboratory-standard three-dimensional motion analysis systems, though there is a minor bias, with IMUs slightly overestimating vertical displacement by approximately 3.5–4.3 cm [25].

Table IV-2: Analysis of position-specific jump metrics in male and female volleyball players during official matches.

Male players						
Position	**Number of jumps (per set)**	**Number of spike jumps (per set)**	**Number of block jumps (per set)**	**Average jump height (m, per set)**	**Average spike jump height (m, per set)**	**Average block jump height (m, per set)**
Outside hitter	13.3-17.6	8.9	10.3	0.58 ± 0.12	0.68 ± 0.12	0.58 ± 0.12
Opposite	23	No data	No data	No data	No data	No data
Middle blocker	20.7-24.3	4.3	11.0	0.55 ± 0.15	0.65 ± 0.12	0.53 ± 0.12
Setter	11.9-31.7	0.6	6.8	0.45 ± 0.14	0.55 ± 0.07	0.58 ± 0.01
Female players						
Position	**Number of jumps (per game)**			**Average jump height (m, per game)**		
Outside hitter	72.8 ± 22.8			0.52 ± 0.2		
Opposite	50.3 ± 22.1			0.45 ± 0.11		
Middle blocker	89.2 ± 30.7			0.47 ± 0.5		
Setter	136.7 ± 36.8			0.27 ± 0.3		

Although jumping remains an important component of volleyball, accelerations, decelerations, and changes of direction also play an essential role, particularly for certain positions. In a 4-set Women's CEV Champions League match, data showed that outside hitters and opposite hitters engage most frequently in forward or backward linear transitions, with approximately 40% of their movements involving a run-up jump [26]. The remaining 60% of their acceleration and deceleration movements are split between lateral and backward directions over short distances of 1–2 meters. Liberos, in contrast, tend to focus 65% of their movements on forward and left directions, with only 35% allocated to backward and right transitions [26]. Findings from a separate study on elite female players in the Turkish League highlighted that setters cover greater total distances than other positions, while outside and opposite hitters exhibit the highest acceleration and deceleration values, reinforcing the importance of agility and direction change for these roles [27]. Interestingly, explosive player load data (acceleration counts >3.5 m/s²) reveal that liberos, who perform extensive lateral movements, record the highest counts, whereas opposite hitters show the lowest, underscoring the necessity of rapid changes of direction throughout court transitions for the liberos [28].

From a load management perspective, differences in playing time also impact physical demands. Liberos and middle blockers do not participate in all rallies, with liberos involved in approximately 80% of rallies and middle blockers in about 60%, leading to rest periods over 20% longer than other players [28]. These findings indicate that the dynamic physical requirements of volleyball extend well beyond vertical jumps, emphasizing accelerative and decelerative movements as significant to gameplay. The limitations of current IMU-based data collection further underscore the need for technologies like local positioning systems (LPS), which could offer more comprehensive tracking of volleyball's multidirectional demands, especially for positions like liberos who rely less on jumping and more on agility and court coverage.

4.1.4. Injuries: prevalence, risk factors, and mitigation strategies

In volleyball, injuries are a significant concern, affecting players' performance and career longevity. A detailed analysis highlights the prevalence and severity of injuries in different anatomical locations (Table IV-3). To reduce the occurrence of injuries, this section aligns with a three-phase cycle previously proposed in the literature: assessing the current injury situation, identifying risk factors and mechanisms, and informing preventative strategies [29].

Among the most frequent acute injuries encountered are ankle sprains, constituting up to 60% of all reported injuries [30,31]. Such injuries predominantly occur during landing phases, either from blocking attempts or less frequently from spiking. The typical scenario involves a player landing on another player's foot, leading to an inversion sprain affecting the lateral collateral ligaments [30,32]. The dynamics of blocking, with its abrupt landings, particularly predispose front-row players (e.g., middle blockers and opposites) to such injuries. A risk factor for ankle injuries in volleyball often reported is gender with previous results showing that adult men have a higher risk for ankle injuries compared to adult women (risk ratio of 3.2) [1]. The same authors also found a higher risk during matches for ankle injuries (risk ratio of 2.1) [1]. Preventing ankle sprains involves a combination of equipment use and training techniques. Employing ankle taping or wearing high-top shoes can limit unwanted inversion movements that lead to sprains [33]. Semi-rigid ankle supports effectively reduce the active inversion range of motion and are preferable to taping as they maintain their supportive properties even after repeated jumping [33]. Neuromuscular and proprioceptive training programs are safe and effective components of ankle rehabilitation that should be introduced as soon as an athlete can tolerate them post-injury. Following an ankle injury, altered neuromuscular activation patterns often lead to functional instability and gait alterations, increasing the likelihood of recurrent injuries [34]. Neuromuscular retraining programs have been shown to reduce the prevalence of recurrent injuries and issues related to functional instability [35]. Additionally, coaching strategies to correct players' approach, particularly for those who tend to jump forward during spikes, can significantly reduce the risk of landing injuries [36]. Encouraging players to adjust their jumping technique to minimize forward motion can help avoid scenarios where the foot lands under the net.

Table IV-3: Common injuries sustained during volleyball.

Location		Incidence			Type		Most common injury	Most common cause
		Match	Training	Total	Contact	Non-contact		
Ankle	Men	2.6	0.8	1.0	47.7%-59%	25.4%-35%	Ankle sprains	Landing from blocking
	Women	0.7	0.9	0.8				
Knee		0.0-0.25	0.0-2.54	0.3	19.4%	23.9%	Patellar tendonitis	High frequency of jumping
Shoulder		0.0	0.16-0.32	0.2	No data		Rotator cuff or biceps tendons tendonitis	High frequency of spiking actions
Overall	Men	2.3-3.9	1.5-3.8	1.7-11.2				
	Women	1.5-3.0	1.6-4.2	1.7-10.3				

Injury incidence is defined as the equivalent to injuries incurred by each player every 1000 h played by them.

Patellar tendonitis, often termed "jumper's knee", emerges as one of the predominant overuse injuries due to the sport's repetitive jumping actions [30,37]. Its prevalence among players, particularly those engaging in the sport more frequently and between 20 and 25 years old, underscores the importance of conditioning the leg extensors [38]. In examining the impact of volleyball on knee health, studies have found that athletes with jumper's knee often achieve greater jump heights compared to asymptomatic athletes, particularly in male players [39]. This phenomenon, often referred to as the "jumper's knee paradox", suggests that athletes with superior jumping ability place higher mechanical demands on the patellar tendon, increasing the risk of overuse injuries [40]. Knee joint dynamics studies highlight that rapid force development, significant tibial external torsion at spike jump take-off, and deep knee flexion angles predict developing symptoms [41]. Players most at risk are those in positions demanding frequent and powerful jumps, such as middle blockers and outside hitters, who rely heavily on these movements for effective play. To mitigate the risk of patellar tendonitis, careful management of training volume is important, especially during the transition to senior levels [42]. Gradual adaptation to increased training demands can help young athletes avoid sudden overuse. Additionally, diverse exercise regimens that promote tendon health, including metabolic activity enhancement, collagen synthesis, and improvements in tendon mechanical properties, are beneficial [43]. Implementing a combination of these exercises—from isometric strength exercises to plyometrics and eccentric load exercises—within regular training sessions has shown promise in reducing knee pain [44].

Accounting for a notable fraction of injuries (i.e., total incidence of 0.2 per 1000 hours of play), shoulder issues primarily manifest as tendonitis of the rotator cuff or biceps tendons, driven by the repeated overhead motions inherent in spiking and serving [30,37]. Studies have indicated that top-level volleyball players often exhibit a disproportionately high strength ratio between the internal and external rotators of the shoulder, coupled with a diminished range of motion for internal shoulder rotation (known as glenohumeral internal rotation deficiency, or GIRD) on their dominant side [45,46]. This condition is accompanied by an increased capacity for external rotation [45,46]. An interesting finding among elite players is the occurrence of suprascapular neuropathy, a condition often asymptomatic yet characterized by a significant reduction in external rotation strength [47]. To prevent shoulder injuries, incorporating stretching and strengthening exercises is essential. Focusing on elongating shortened dorsal muscles and bolstering scapular stabilizers can aid in prevention and symptom alleviation [48]. Addressing the imbalance between internal and external rotator strength and improving the flexibility of internal rotation is important [45]. Training programs should aim to maintain an optimal strength balance and enhance internal rotation flexibility [45]. Additionally, refining techniques to reduce shoulder stress, such as adjusting the backswing in spikes, can mitigate injury risks while potentially improving performance [49].

Though less common and seldom leading to prolonged absences from play, hand injuries, including sprains, fractures, and contusions, predominantly affect the fingers. Injuries to the fingers predominantly occur due to the ball's impact, representing approximately three-quarters of such incidents [50]. In contrast, collisions with other players are relatively less common, contributing to about one-seventh of finger injuries [50].

4.1.5. Athlete assessment

Jump height is an important performance indicator in volleyball, significantly influencing match outcomes [51]. In men’s volleyball, winning teams have been shown to demonstrate significantly higher jump values during serves, attacks, and blocks compared to losing teams. Notably, jump height during both the serve and block phases was found to be statistically significant ($p < 0.05$) in influencing match outcomes [51]. Research has demonstrated significant relationships between the force-time characteristics from isometric tests and various jumping tasks, highlighting their relevance in volleyball. The isometric mid-thigh pull (IMTP) and the isometric squat test, conducted at different knee angles, show varied correlations with jump performance. Based on the data presented in Table IV-4, we recommend the isometric squat performed at a 90° knee angle as a more suitable method for testing maximal strength in volleyball athletes. Research has shown that variables obtained from the 90° isometric squat demonstrate stronger correlations with jump height in the countermovement jump (CMJ) compared to those from the IMTP or isometric squats performed at different knee angles [52]. The isometric squat at 90° can be reliably performed for multiple maximal attempts (typically 2–3) without compromising the accuracy of results, as evidenced by strong intrasession reliability in peak force measures [53]. This test thus provides a consistent and effective indicator of strength and rapid force production, making it well-suited to monitor training adaptations in volleyball athletes.

The spike and the block are two of the most important actions in volleyball, responsible for generating the majority of points during a game [54]. In line with the principle of specificity in sports training, previous research has already suggested some specific movements be tested, such as the spike jump and block jump, and measured using devices like the Vertec [55]. The effectiveness of a spike relies heavily on factors such as contact height, which was already discussed in relation to jump height, ball direction, and ball speed. Ball speed is important as it affects the opponent's ability to react and defend. Monitoring spike speed typically involves assessing upper-body strength and throwing ability through general tests. Commonly, this includes measuring the three-repetition maximum (3RM) for exercises like the pullover or bench press [56,57]. While these tests are fundamental in evaluating upper-body strength, they fail to determine how effectively volleyball players can translate their strength into game-like situations. For instance, one study observed that despite significant increases in bench press and pullover one-repetition maximum (1RM), there was no corresponding improvement in spike ball speed among female players over an entire season [58]. Therefore, while this data may be tracked as part of their S&C program, it may be wise to omit it when physically profiling the athlete as part of a fitness testing battery.

Table IV-4: Correlation coefficients between isometric mid-thigh pull and isometric squat test, and countermovement jump and squat jump heights.

Isometric test	Knee angle	Countermovement jump height	Squat jump height
Mid-thigh pull	140º	Peak force, $r = 0.276$	
		Relative peak force, $r = 0.588$	
	120º-135º	Peak force, $r = 0.36$	Peak force, $r = 0.40$
		Relative peak force, $r = 0.45$	Relative peak force, $r = 0.47$
		Peak RFD, $r = 0.39$	Peak RFD, $r = 0.48$
Squat	90º	Peak force, $r = 0.79$	Peak force, $r = 0.79$
	120º	Relative peak force, $r = 0.33$	
	140º	Relative peak force, $r = 0.276$	

RFD = rate of force development.

To bridge this gap, Palao and Valades developed a spike and serve speed protocol consisting of six tests that ranged from general to specific in terms of strength/power application [59]. The protocol starts with a standing spike where players hit the ball from a self-toss without any restrictions related to time or space which assesses the players' capacity to exert power in a non-game-specific action. The second test introduces a spatial constraint by requiring players to spike while standing at the net, at a height equivalent to their typical jumping spike position. In the third test, players execute a spike from a ball tossed by a coach or teammate at the net, tossed to a height between two and three meters, a scenario more reflective of a game situation. The fourth and fifth tests are variations of the third, with the only difference being the direction of the spike—diagonally across the court in the fourth and directly down the line in the fifth. The sixth and final test in the protocol evaluates the players' serving technique. While the comprehensiveness of this protocol allows for a detailed assessment of skills directly relevant to volleyball performance, it is important to consider the time and resources required to implement such extensive testing. Moreover, the skill-based nature of this protocol means that the results may reflect technical proficiency as much as physical capacity, posing challenges in isolating constraints in physical capacity. Given these considerations, integrating the spike and serve protocol may be more effective during technical training sessions, conducted in collaboration with volleyball coaches.

As an alternative to the skill-intensive spike and serve speed protocol, the bench press throw – performed on the Smith machine – emerges as a valuable in-gym exercise for assessing upper-body ballistic performance, important for the high arm acceleration required during the spike [60]. Research indicates that the peak force from the force-velocity profile of the bench press throw correlates with both spike and serve speeds ($r \geq 0.53$) [61]. This correlation underscores the significance of evaluating and enhancing upper-body ballistic performance through exercises like the bench press throw. This exercise provides a reliable measure of the physical attributes essential for elite volleyball players. It directly impacts their ability to effectively transmit force to the ball during spikes and serves, making it a practical choice for integration into regular S&C assessment routines. This test is also a direct measure of physical capacity, thus making it actionable by S&C coaches.

Counterattack skills such as blocking, digging, and attacking are essential for team success in volleyball [54]. While attacking and blocking have already been discussed, it is equally important to focus on digging, as this skill is important for effective defense and transitioning to offense. The digging agility test (DAT), which includes visual stimuli, specifically assesses a volleyball player's digging agility [62]. This test replicates the lateral digs performed in actual games, requiring athletes to respond to visual cues and move quickly from a stationary position to designated targets. However, considering the complexity of setting up the DAT and the current lack of widespread validation within the S&C community, we recommend a cautious approach to its use. While the DAT could offer insights into sport-specific agility under game-like conditions, its practical application is currently limited by uncertainties regarding its reliability and the scarcity of implementation in routine training assessments. Equally, separating skill from physical capacity is hard, meaning actionable constraints are harder to decipher. Therefore, until further research can establish its efficacy and reliability, it may be prudent to prioritize more established agility tests that have been proven effective and are easier to administer, like the T-Test or the Illinois agility test [63,64].

Sheppard et al. developed the repeated-effort test that accurately simulates volleyball's front-row demands [65]. This test utilizes a vertical jump and reach testing device (e.g., Vertec), an adjustable block jump apparatus set to sport-specific heights, and timing gates [65]. Athletes perform four repeated efforts encompassing jumping movements, including spike jumps and block jumps, combined with lateral movements typical of front-row offensive and defensive play [65]. Structured on a fixed 20-second interval with brief rests tailored to the speed of each repetition, this test measures jump and movement times, block jump task errors, and a performance decrement percentage, indicating the difference between ideal and actual performance times [65]. This provides a detailed measure of fatigue resistance and jumping reserve, aligning well with the sport-specific conditioning needs of volleyball players.

4.1.6. Periodization

Periodization has been a cornerstone in athletic training, designed to enhance fitness and performance over a structured timeline. Traditional long-term periodization models, such as classic or linear periodization, typically start with high-volume, low-intensity training, gradually shifting towards lower-volume, high-intensity sessions over several months [66]. This approach, which cycles back to high-volume, low-intensity phases at the end of each cycle, organizes training blocks around distinct goals (e.g., hypertrophy, strength, strength/power, and power), usually lasting 4–6 weeks each. The overarching aim in these linear programs is often to reach peak strength or power by the end of the final phase, frequently called the power phase [67].

However, in volleyball, where club seasons run almost uninterrupted from September through April and national team duties occupy April to August, this tapering approach proves less suitable. A traditional linear model would significantly reduce training intensity during competition, hindering performance levels for elite and professional volleyball players [68]. While classic periodization may still have limited application during certain phases, such as the extended off-season for players not engaged in national team activities (which can span up to three months), a more adaptable model is often preferred for volleyball. Nonlinear periodization, specifically a flexible nonlinear approach, offers a practical solution. This method adheres to the principles of nonlinear training but allows adjustments to session intensity based on an athlete's readiness [69]. For example, assessing readiness through pre-session tests, like a CMJ, or monitoring the early sets velocity in a workout can guide coaches in tailoring the day's focus to the athlete's current physical state, ensuring optimal training effectiveness.

Training Zones

Building on the principles of flexible nonlinear periodization, each athlete's training load can be adjusted daily based on their current readiness, placing them in an appropriate training zone to maximize effectiveness and minimize unnecessary strain (Figure IV-1).

• Training Zone 1: This zone focuses on low-intensity, low-volume recovery sessions. These lighter workouts aim to accelerate recovery, especially following intense match days classified as Training Zone 4. Typical activities include low-intensity aerobic exercises or mobility circuits, often scheduled for the day after a match (MD+1) to aid athletes in quickly recovering from high exertion.

• Training Zone 2: Characterized by high volume and low intensity, this zone emphasizes exercises that increase time under tension, supporting goals like muscle hypertrophy or tendon resilience [70]. It is especially beneficial for athletes requiring enhanced tendon health due to volleyball-specific injury risks discussed previously. Training here typically takes place during the off-season or early in the competitive week, away from match days, as these methods can induce fatigue and muscle soreness [71]. Alongside high-repetition isotonic exercises, holding isometric muscle actions (HIMA) are also effective in this zone, with recommended durations of 30 to 45 seconds at sport-specific joint angles [72]. For example, front-row players can perform single-leg ankle HIMA to strengthen the Achilles tendon.

• Training Zone 3: This zone is intended for low-volume, high-intensity days, commonly scheduled right before matches (MD-1). Volleyball coaches often use this time for brief, game-like training drills that mirror competitive scenarios, such as 6 vs. 6 scrimmages starting at a score of 19-19, so only a few points and rallies are played. From an S&C perspective, this zone focuses on training rate of force development (RFD), power, and reactive strength. Recommended methods include high-intensity power lifts at low volumes (>75% 1-RM), isotonic high-load and moderate-velocity repetitions for strength-speed and speed-strength, brief pushing isometric muscle actions (PIMA), Olympic lifts and derivatives, and sprinting and plyometric exercises that stimulate the central nervous system without inducing fatigue. These training methods will be discussed in the following section.

• Training Zone 4: Representing the highest volume and intensity, this zone aligns with match days, pre-season training camps, or scrimmage days with high-intensity 6 vs. 6 play. Athletes typically report high perceived exertion in this zone, often monitored using session rating of perceived exertion (RPE) [73]. With increased intensity (higher %1RM), there's a corresponding rise in RPE during resistance training, making this zone ideal for focusing on maximal strength development. Common methods include isotonic high-load, low-velocity repetitions (absolute and accelerative strength, <0.75 m/s) [74] and PIMA at joint angles specific to volleyball movements. For instance, a middle blocker might perform a single-leg knee PIMA at an angle similar to their position during a block jump.

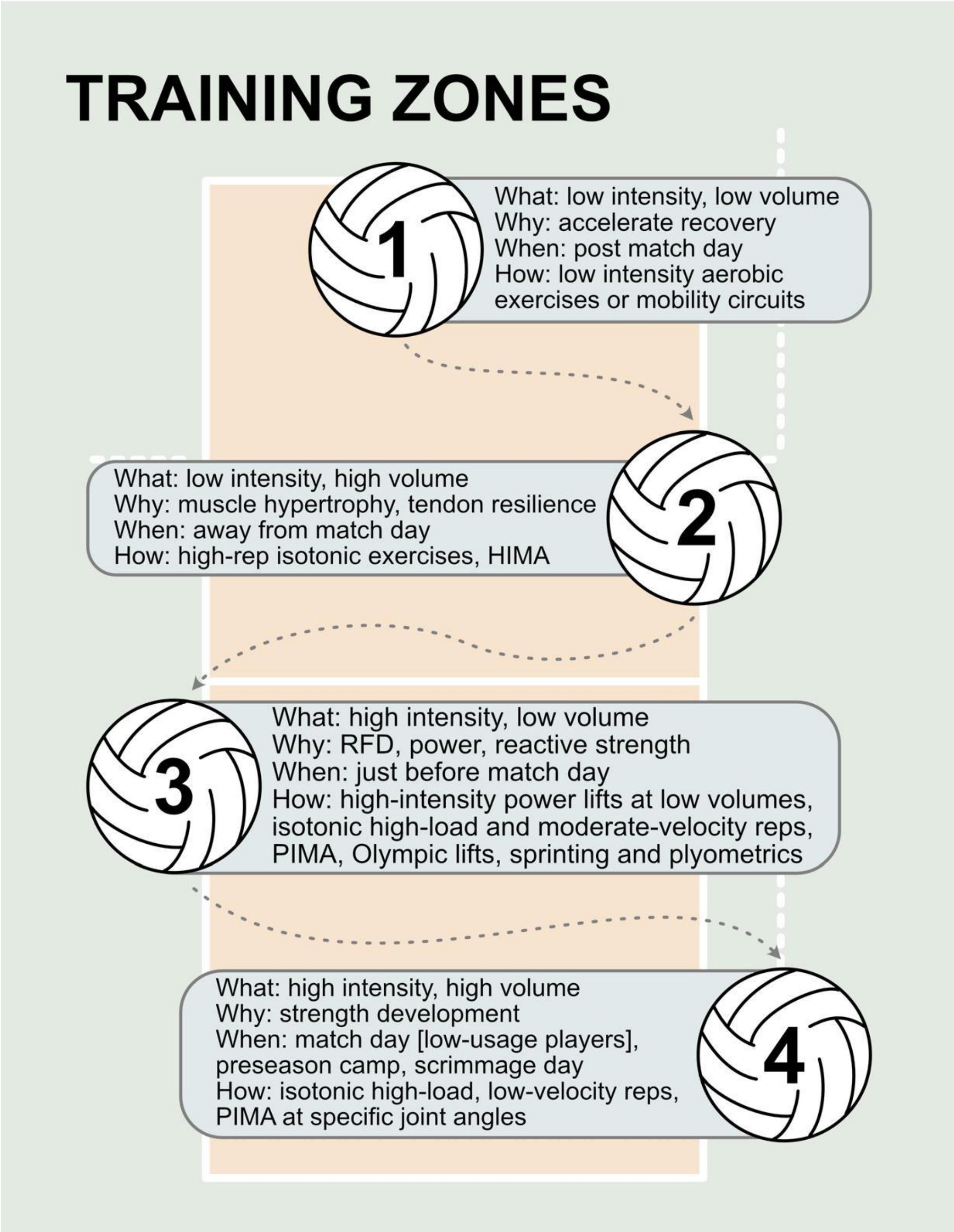

Figure IV-1: Flexible training zones for volleyball athletes: intensity, volume, and methods.

Preparatory Phase

The pre-season, or preparatory phase, begins with a period focused on building physical readiness before any competitive matches take place. During the initial weeks, also known as the general preparatory phase, athletes are expected to experience a degree of fatigue as training volume remains high. This period allows S&C coaches to build on the accumulation work established during the off-season, with the goal of maintaining training volume while progressively increasing intensity. For instance, athletes may lift heavier loads for the same number of repetitions or perform movements with greater speed using the same weight, thus enhancing both strength and power output.

As the pre-season progresses, friendly matches begin to be incorporated, marking the shift to the specific preparatory phase. At this point, reducing the physical training volume becomes crucial to accommodate the added workload from these matches. Training in this phase increasingly resembles that of the competitive season, gradually conditioning athletes to manage both training and match demands. This phase may even conclude with a taper, especially for elite clubs that start their season with a domestic Supercup or similar competitive event, ensuring athletes are physically primed for peak performance (discussed afterwards).

Competitive Phase

When planning microcycles and mesocycles, professional volleyball schedules can vary depending on competition frequency. At the club level, official games are often spaced 7 days apart for teams competing only in domestic leagues, while clubs engaged in both domestic and international competitions may face a more condensed schedule, with games separated by 3 days. Additionally, many leagues feature a “final four” tournament format for domestic cup semi-finals and finals, where games occur within 24 hours of each other. Each of these formats demands specific adjustments to training, with the S&C coach using flexible nonlinear periodization principles to adapt intensity and volume based on athlete readiness assessments conducted before each session. Figure IV-2 provides an overview of the tailored microcycle structures for each schedule type, outlining optimal training zones and methods based on athlete readiness and competition demands.

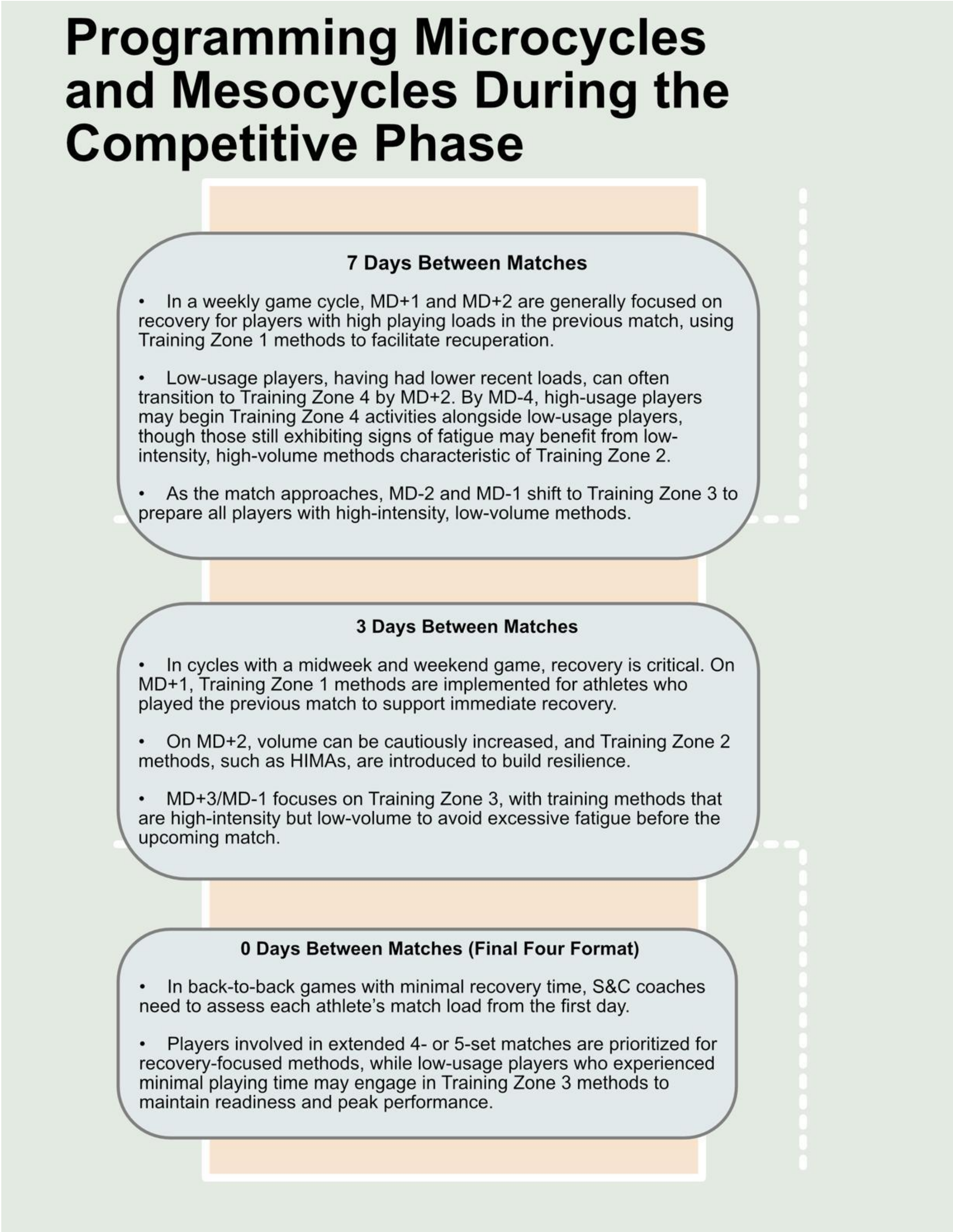

Figure IV-2: Flexible periodization for competitive phases in volleyball: microcycle strategies by match frequency.

During the competitive phase, careful mesocycle planning is essential for ensuring athletes peak at decisive points in the season. Collaboration between S&C and volleyball coaches is necessary to identify the most important matches, whether for playoff qualification or title contention. With these key games or periods highlighted, a structured approach to tapering and peaking can be established. Tapering, defined as "a progressive, nonlinear reduction of training load over a variable period to reduce the physiological and psychological strain of training while enhancing performance" [75], can be effectively applied to volleyball, even though much of the tapering research traditionally focuses on individual sports [76]. In professional and elite volleyball, once priority matches are identified, S&C coaches can create short, intensive training blocks lasting 1 to 3 weeks (i.e., shock microcycle or mesocycle) to build the necessary performance stimulus, followed by a taper. In these targeted blocks, a strategy of microdosing—distributing total training volume across a microcycle in frequent, short, repeated bouts—can optimize performance gains without overloading the athletes [77]. Table IV-5 shows an example of a tapering phase with a duration of three weeks for two types of exercises used for Training Zone 3 (power clean) and Training Zone 4 (trap bar deadlift).

Table IV-5: Example of a 3-week taper period for volleyball players.

Training Zone	Week 1	Week 2	Week 3
3	Power Clean 5x3 @80% (>2.40 m/s)	Power Clean 4x3 @80% (>2.40 m/s)	Power Clean 3x3 @80% (>2.40 m/s)
4	Trap Bar Deadlift 5x3 @80-85% (<0.75 m/s)	Trap Bar Deadlift 4x3 @80-85% (<0.75 m/s)	Trap Bar Deadlift 3x3 @80-85% (<0.75 m/s)

Note: peak velocity values should be used for power exercises like the power clean, whereas mean velocity values should be used for the trap bar deadlift.

Transition Phase

The transition phase, often called the off-season, offers volleyball athletes a unique period to focus exclusively on physical development without the immediate demands of match play. For players not involved in national team activities, this phase can extend up to three months, providing an ideal opportunity to address specific physical attributes with minimal concern for fatigue management. With no competitive games on the horizon, athletes can engage in up to five training sessions per week focusing on Training Zones 2, 3, or 4, complemented by two lower-intensity days employing methods from Training Zone 1 for recovery.

As previously discussed, the off-season's extended timeframe allows for applying linear periodization models, as athletes can progress through structured training blocks without interruptions from matches [68]. For example, an opposite hitter working to increase maximal strength might start with a block that prioritizes methods from Training Zone 4. Furthermore, due to the limited or nonexistent volleyball practices during this period, athletes can increase plyometric volume in the gym, which is essential for developing reactive strength. This concentrated plyometric work in the off-season prepares athletes for the high jumping demands of the upcoming pre-season and competitive phases, where practice and game loads will limit the room for intense plyometric training. Additionally, the off-season is an ideal time to incorporate change of direction and acceleration drills, particularly for liberos, who rely heavily on these skills. Training Zone 3 methods, focusing on these agility and speed elements, can be implemented consistently to enhance movement efficiency and agility on the court. Finally, if the training goal is to build foundational strength to handle the demands of later phases and to lessen injury risk as training becomes more intense, S&C coaches might incorporate HIMA (and the remaining Training Zone 2 methods). This approach enhances activation of synergist muscles, which plays a key role in preserving joint stability during high-intensity movements, thereby reducing the likelihood of injuries [78].

The off-season may conclude with a 3- to 4-week accumulation block to establish a robust foundation for the season ahead [79]. Unlike most team sports, which incorporate this block into the pre-season, volleyball's relatively long off-season allows S&C coaches to introduce this phase earlier. By increasing the number of sets while maintaining intensity, athletes can gradually adapt to the increased workload, ensuring they enter the pre-season well-prepared for the demands of competitive play.

4.1.7. Training physical fitness attributes

The subsequent sections explore essential physical fitness attributes for volleyball athletes, including maximal strength, RFD, muscular power, reactive strength, agility, and conditioning. This guidance is supplemented with a selection of exercises designed to cultivate the necessary physical capacities and refine athletic prowess, ensuring athletes are fully equipped to thrive in high-performance volleyball settings.

Maximal Strength

Maximal strength is important for athletes, reflecting the highest force muscles can produce during concentric, eccentric, or isometric contractions or within a specific movement [80]. This attribute is particularly valued for its direct impact on a player's capacity to execute specific physical tasks demanding high power outputs and RFD. For instance, in volleyball, maximal strength is essential, as it underpins the ability to perform powerful actions such as spikes and blocks [10]. Moreover, it supports landing mechanics, mitigating injury risks [81].

Training for maximal strength typically involves high loads (≥80% of 1RM) and thus low repetitions (1-6 reps per set) to stimulate significant strength gains [82,83]. The training frequency for maximal strength sessions ranges from two to four times per week, depending on the athlete's recovery and the training cycle's phase [82,83]. The off-season, which can last up to three months for players not involved in national team duties, provides a valuable window for more frequent maximal strength development training. For athletes involved with national teams, the off-season can be significantly shorter or even non-existent, making a nonlinear periodization approach more suitable for in-season strength training. Nonlinear periodization offers flexibility, allowing for varying training intensities and loads within shorter cycles, which can help athletes continue to make strength gains without accumulating excessive fatigue [69]. For instance, the initial in-season mesocycle could still emphasize maximal strength development through high-intensity, low-volume sessions, but these efforts could be strategically alternated with moderate- and lower-intensity sessions to facilitate recovery and adaptation. Opportunities for more intensive strength training may arise during scheduled breaks, such as the Christmas and New Year periods, which can provide up to two weeks without matches. During these times, mini (1 to 2 weeks) shock microcycles can be implemented to boost strength gains [68]. This approach ensures athletes can improve strength without compromising their recovery or risking injury during the busy competitive season.

In addition to the traditional maximal strength training methods discussed earlier, alternative approaches can further support maximal strength development in volleyball players. These methods provide unique benefits and can be tailored to meet the specific needs and competitive demands of the sport. Examples of such training methods include the following:

• Accentuated eccentric loading: This training technique involves using additional weight during the eccentric phase of a movement, which is then reduced for the concentric phase [84]. One practical application for volleyball players is using weight-release devices, which attach extra resistance to a barbell or machine during the eccentric portion of the lift. For example, to enhance maximal strength in knee and hip extension, S&C coaches can implement back squats with an eccentric load of 120% of the athlete's 1-RM, followed by a concentric phase performed with 80% of their 1-RM. This approach effectively targets the muscles involved in vertical force production.

• Isometric strength training: Isometric strength training offers a unique advantage for athletes due to its lower energy demands compared to dynamic muscle contractions [85]. This characteristic is particularly valuable as it helps players start games without high levels of fatigue. Research suggests that isometric training performed at intensities ranging from 80–100% of an athlete's maximum voluntary contraction, with each contraction sustained for 1–5 seconds and totaling 30–90 seconds per session, is optimal for developing maximal strength [86]. For volleyball players, specific exercises such as the knee isometric push or ankle isometric push can be particularly beneficial. These exercises not only enhance the strength of key muscle groups but also allow players to maintain performance levels without adding excessive fatigue, making them ideal for integration into in-season training programs.

Rate of Force Development, Muscular Power and Reactive Strength

RFD is pivotal in defining an athlete's capability to rapidly generate force, commonly referred to as explosive strength [87]. In volleyball, for example, this includes jumping for a spike or block and quick directional changes [88,89]. Muscular power in sports science is defined by the quantity of work performed per unit of time and is a product of both force and velocity. Reactive strength, often encapsulated under the umbrella term "plyometrics," is integral for volleyball players due to the plyometric nature of many actions, such as rebound jumping and executing rapid accelerations [88]. Plyometric training exploits the stretch-shortening cycle (SSC) properties, categorizing exercises into those with fast SSC (e.g., sprinting, drop jumps, bounding) and slow SSC (e.g., changes of direction, depth jumps) movement times [90].

In analyzing the mechanics of the CMJ, researchers have identified five primary phases that occur before landing: unweighting, braking, transfer, propulsive, and flight [91]. These phases can be translated to the approach jump used in volleyball, particularly for the spike, where each phase of the CMJ corresponds to a specific action within the spike jump's mechanics (Figure IV-3). By identifying and training these distinct phases, S&C coaches can help athletes optimize each part of the jump for improved performance on the court.

Figure IV-3: Volleyball approach jump (panel A represents the unweighting phase, panel B shows the braking phase, panel C captures the propulsive phase, and panel D depicts the flight phase).

Similarly to the lower body phases, the spike and jump serve can also be analyzed through distinct phases of upper body mechanics, which impact performance. In volleyball, both actions—spiking and serving—follow a five-phase motor pattern that includes approach, takeoff, arm cocking, arm acceleration, and follow-through [60]. Therefore, as with the lower body's SSC use in the approach jump phases, each phase of the upper body movement can be trained and optimized to enhance RFD, power, and reactive strength during important game actions like spiking and serving.

To enhance performance in the unweighting and braking phases, training methods can focus on increasing the momentum (i.e., mass × velocity) at the end of the unweighting phase and improving the force generated during braking. These methods are key for optimizing the SSC in the subsequent phases. Effective training techniques for these initial phases include:

• Accentuated eccentric loading: Using loads up to 130% of concentric maximum for controlled eccentric contractions develops braking force [92]. Only 1-3 reps per set are needed, with concentric loads adjusted to 80-90% or 50-60% of 1-RM.

• Weighted jumps and upper body throws: To maximize power, athletes can perform throws and jumps that project the body or a weighted object into the air, minimizing deceleration [93].

• Inertial flywheel training: This method, which offers variable resistance and eccentric overload, enhances power, especially in trained athletes [94]. It also improves horizontal displacement [94], which is valuable for liberos who perform more lateral movements. High-speed, maximum-intensity reps (3-5 per set) are recommended for optimal adaptation.

Once athletes reach the lowest point in the countermovement, their velocity is momentarily zero [91]. As they begin the upward movement, velocity increases, typically while force decreases. Right before takeoff, velocity reaches its peak [95]. The takeoff velocity (a crucial determinant of jump height) depends on the total impulse generated during the propulsive phase in proportion to the athlete's body mass [95]. Therefore, achieving a high takeoff velocity requires the athlete to produce substantial vertical power, maintaining force application throughout the ascent from the point of zero velocity onward. Training for power and RFD during this phase is thus focused on maximizing the force an athlete can exert starting from the bottom position.

• Box squat and seated box squat jump: The box squat, in which athletes sit back onto a box before driving upward, is commonly used to strengthen the squat pattern and develop power [96] and RFD [97]. When performed with a brief pause at the bottom position (replicating the zero-velocity point in a countermovement), the exercise minimizes elastic energy contributions, requiring the muscle groups involved in the propulsive phase to generate force independently [96]. The concentric phase should be executed as explosively as possible, using a load where the athlete's power output is maximized. Similarly, the seated box squat jump closely simulates the block jump seen in volleyball and can be performed with body weight or light dumbbells, emphasizing rapid concentric force production without relying on stored elastic energy.

• Accommodating resistance (bands and chains): This method adjusts the force-velocity curve by adding resistance (through rubber bands or chains) during the concentric phase [98]. As the athlete pushes through the movement, additional resistance increases, particularly in biomechanically challenging positions known as "sticking points." This increases acceleration and velocity during the lift's concentric phase, optimizing power output [98]. For peak power gains, total loads of 60-90% of 1-RM are ideal, with approximately 80-85% of resistance coming from free weights and 15-20% from chains [98]. For band resistance, the setup should comprise 20-35% band tension with 65-80% free weight, depending on the athlete's needs [98].

• Pneumatic resistance training: Pneumatic resistance, which uses air resistance to create external loads with minimal inertia, is another effective method for boosting power and velocity [99]. Unlike traditional weights, pneumatic resistance systems generate less momentum, allowing athletes to focus on maintaining high speeds throughout the movement.

Research suggests that using lighter loads (30-45% of 1-RM) with pneumatic resistance training can enhance velocity and power in trained athletes [99].

• Olympic-style weightlifting movements: Olympic lifts generate some of the highest power outputs in resistance training [100]. Exercises such as the clean and jerk or snatch should be programmed at around 80% of an athlete's 1-RM to optimize power output [101]. For best results, S&C coaches should tailor loads based on each athlete’s power output profile, assessing individual responses to the loading to ensure maximal adaptation.

Agility

Agility encompasses an athlete's ability to swiftly decelerate, change direction, and accelerate again, reacting adeptly to situational cues [102]. Agility training should be characterized by its emphasis on high-intensity drills that mimic the pace and energy demands of volleyball, incorporating game-like scenarios to foster athletes' ability to anticipate and react to opponents' actions. To effectively train agility in volleyball athletes, it is important for S&C coaches to identify the movement patterns characteristic of the sport. Volleyball requires a combination of retreating and forward patterns during play. For instance, retreating patterns are often observed when back-row players track and dig balls traveling toward the rear court, while forward patterns are prevalent when athletes move quickly to intercept or defend balls dropping between front and back rows. These patterns frequently occur in combination, forming the basis of agility drills tailored to volleyball's specific demands.

One essential movement pattern in volleyball agility training is the drop step. This involves transitioning from a parallel stance to a rapid forward movement. Back-row players commonly execute this movement when defending balls that bypass the block and fall between the front and back rows. For optimal performance, players must take a step backward to generate the necessary push-off force for an explosive forward movement:

• Tennis ball drill: The S&C coach tosses a tennis ball onto the ground. As soon as the ball touches the ground, the athlete performs a drop step, moving quickly forward to catch it before it touches the ground again.

• Reactive cone drill: Set up two cones, one on each side of the athlete. On the coach's command, the player executes a drop step toward the designated cone, simulating a reactive defensive scenario.

Another fundamental movement pattern in volleyball agility training is the lateral shuffle, a side-to-side motion that enables players to quickly cover ground without crossing their legs. This pattern is frequently observed in back-row players when defending opposition spikes directed toward the backcourt. Defensive players often execute a lateral shuffle to position themselves to dig the ball using one or both arms:

• Multi-repetition lateral shuffle: Athletes perform three continuous lateral shuffles in one direction and then repeat the same movement to the opposite side. This drill emphasizes repeated, explosive push-offs from the outside leg combined with efficient pulling from the inside leg.

• Tennis ball lateral shuffle drill: Incorporate a tennis ball into the drill by having the S&C coach toss the ball onto the ground. Athletes must execute the prescribed number of lateral shuffles and catch the ball before it touches the ground again.

• Reactive agility lateral shuffle drill: Introduce a reactive component by using visual cues. For instance, the S&C coach raises one arm to indicate the direction in which the athlete should shuffle.

The hip turn is an essential movement pattern for volleyball players, particularly when retreating to defend balls redirected behind their initial position. This commonly occurs when back-row players, initially positioned to defend an opposition spike, must quickly retreat after the spike is deflected by the block and redirected over their heads. For an efficient hip turn, the movement should begin with a strong push from the front foot, avoiding simultaneous pivoting of both feet. This ensures a quick and efficient transition into the retreat:

• 90-degree hip turn to sprint drill: Athletes begin facing forward, perform a 90-degree hip turn, and sprint directly in a straight line. The goal is to avoid curvilinear initial steps, which indicates insufficient hip opening during the turn. Drills should emphasize practicing the movement in both directions to build symmetry in movement proficiency.

• 45-degree hip turn to lateral shuffle drill: Athletes initiate a 45-degree hip turn followed by a short sprint and transition seamlessly into a lateral shuffle. This drill simulates game situations where a teammate’s defensive touch redirects the ball unexpectedly, requiring immediate directional changes.

• Reactive hip turn drill: Introduce reactive elements where the S&C coach provides auditory or visual cues to dictate the direction of the hip turn. For instance, a whistle can signal the athlete to execute a hip turn to the left or right before running toward a specific marker.

Conditioning

Conditioning for volleyball players is tailored to meet the sport's unique demands, blending the development of explosive power and speed with the stamina to sustain these efforts throughout the match. The sport's energetic demands predominantly hinge on the ATP-CP and aerobic pathways, with a lesser but still significant reliance on the anaerobic glycolytic system [103]. This energetic profile underscores the necessity for volleyball players to cultivate a multifaceted conditioning approach that enhances their ability to repeatedly execute high-intensity actions interspersed with periods of lower-intensity activity and rest.

Volleyball matches, typically lasting about 100 minutes, are characterized by intense activity bursts followed by shorter rest or low-intensity periods [65]. An average rally lasts about 12 seconds, during which front-row players might execute up to three approach jumps and four block jumps, along with extensive lateral movements across the court [55,65]. Occasionally, rallies can extend up to 40 seconds, with players covering distances that vary significantly based on their role—middle blockers often move about 788 m, whereas setters can cover up to 1,630 m throughout a match [65,104].

To target these specific needs, conditioning programs incorporate high-intensity interval training to engage both the anaerobic and aerobic systems, along with sport-specific drills that replicate the rhythm and intensity of actual match play. For instance, drills tailored for outside hitters may involve a sequence of a block jump, retreating 4 meters, a swift approach to a spike, and a concluding spike jump [105]. Defensive specialists like liberos might engage in drills involving lateral moves over 3 meters, a forward sprint of the same distance, followed by a dive and roll, and a backpedal to the initial position. Setters' drills could include sprinting from the backline to the net for a jump set, followed by a block jump and a return sprint to the starting position [105]. Small-sided games can also help improve volleyball-specific conditioning. Various studies, such as those by have shown that skill-based conditioning training in formats like 3 vs. 3 and 4 vs. 4 players can lead to such improvements in elite female volleyball players [106,107].

In addition to the sport-specific conditioning drills previously described, it might be prudent to incorporate off-feet conditioning methods to target energy systems without the high musculoskeletal load associated with typical volleyball movements [108]. Off-feet conditioning modalities, such as cycling, rowing, and using battle ropes, provide valuable aerobic and anaerobic stimuli. These activities are particularly beneficial during periods requiring careful load management, such as post-match recovery or during rehabilitation from injury [109].

Figure IV-4 provides a visual summary of the topics discussed in this paper, serving as a quick-reference tool for S&C practitioners to design training programs tailored to volleyball's unique demands.

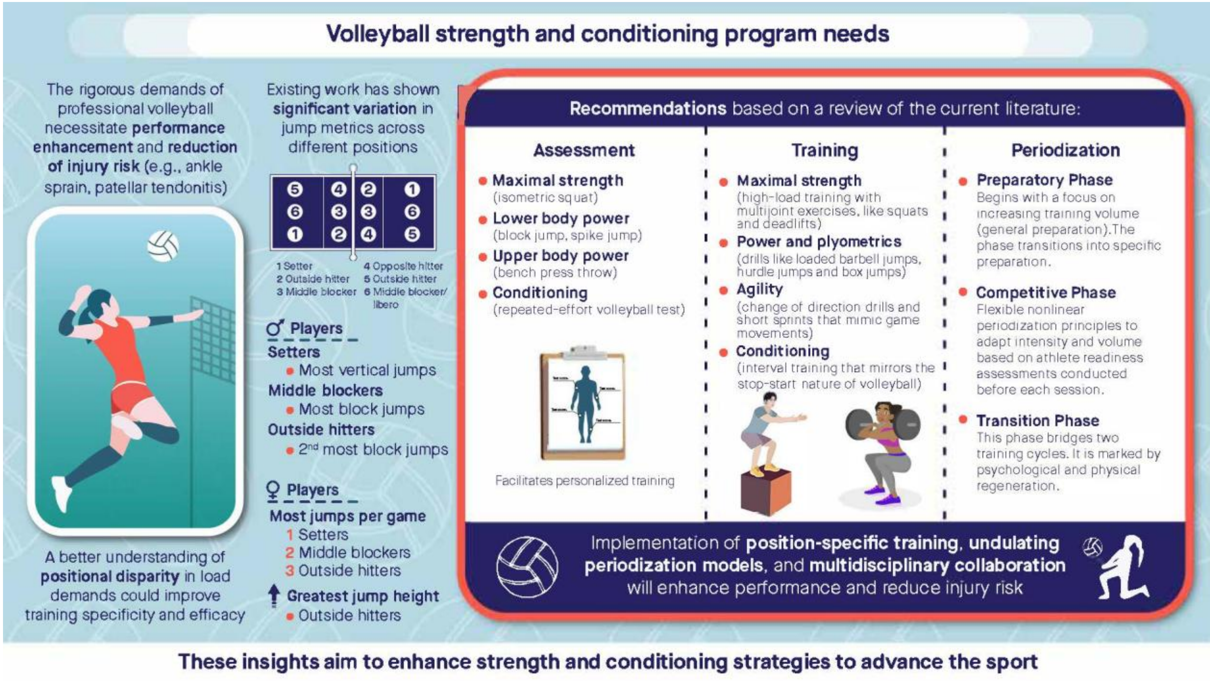

Figure IV-4: Volleyball strength and conditioning program needs.

4.1.8. Practical applications

In designing effective S&C programs for volleyball, it is essential to adapt training plans to the unique demands of each phase of the season. Tables IV-6, IV-7, and IV-8 provide structured examples for each phase—transition, preparatory, and competitive—demonstrating how training zones can be adjusted across the weekly schedule. These sample programs illustrate how volume and intensity are managed through the use of Training Zones 1-4, allowing S&C coaches to tailor sessions based on the timing within the season and the proximity to matches. By providing a clear framework for each phase, the table aims to offer practical insights for S&C practitioners looking to maximize athletic performance and readiness across the volleyball season.

Table IV-6: Example programming across the transition phase for volleyball.

Transition Phase							
Day of the Week	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Training Zone	3	2	3	2	4	1	1
Lower Body Option	N/A	Week 1: Calf Isometric Hold 2x45 sec Week 2: Calf Isometric Hold 3x45 sec Week 3: Calf Isometric Hold 4x45 sec	N/A	Week 1: Leg Curl 3x12 @65% Week 2: Leg Curl 4x12 @65% Week 3: Leg Curl 5x12 @65%	Week 1: Trap Bar Deadlift 3x5 @80% Week 2: Trap Bar Deadlift 4x5 @80% Week 3: Trap Bar Deadlift 5x5 @80%	Rest	Rest
Upper Body Option	N/A	Week 1: Lat Pulldown 3x12 @65% Week 2: Lat Pulldown 4x12 @65% Week 3: Lat Pulldown 5x12 @65%	N/A	Week 1: Bench Press 3x12 @65% Week 2: Bench Press 4x12 @65% Week 3: Bench Press 5x12 @65%	Week 1: Seal Row 3x5 @80% Week 2: Seal Row 4x5 @80% Week 3: Seal Row 5x5 @80%	Rest	Rest
Power Option	Week 1: Spike Jump to a Target 4x2 Week 2: Spike Jump to a Target 5x2 Week 3: Spike Jump to a Target 6x2	N/A	Week 1: Jammer Arm Throw 3x3 @40-60% Week 2: Jammer Arm Throw 4x3 @40-60% Week 3: Jammer Arm Throw 5x3 @40-60%	N/A	N/A	Rest	Rest

Table IV-7: Example programming across the preparatory phase for volleyball.

Preparatory Phase							
Day of the Week	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Training Zone	3	2	1	3	4	1	1
Lower Body Option	N/A	Week 1: Romanian Deadlift 3x12 @65% Week 2: Romanian Deadlift 3x13 @65% Week 3: Romanian Deadlift 3x14 @65%	Rest	N/A	Week 1: Back Squat 3x5 @80% Week 2: Back Squat 4x5 @80% Week 3: Back Squat 5x5 @80%	Rest	Rest
Upper Body Option	N/A	Week 1: Pullover 3x10 @70% Week 2: Pullover 3x11 @70% Week 3: Pullover 3x12 @70%	Rest	N/A	Week 1: Bench Press 3x5 @80% Week 2: Bench Press 4x5 @80% Week 3: Bench Press 5x5 @80%	Rest	Rest
Power Option	Week 1: Clean High Pull 3x2 @85% Week 2: Clean High Pull 4x2 @85% Week 3: Clean High Pull 5x2 @85%	N/A	Rest	Week 1: Push Jerk 3x3 @60-80% Week 2: Push Jerk 4x3 @60-80% Week 3: Push Jerk 5x3 @60-80%	N/A	Rest	Rest

Table IV-8: Example programming across the competitive phase for volleyball.

Competitive Phase (7-day Cycle with a Match on Saturday)							
Day of the Week	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Training Zone	3	4	1	2	3	4	1/2
Lower Body Option	N/A	Week 1: Knee Isometric Push 3x (3x2 sec) @95% Week 2: Knee Isometric Push 4x (3x2 sec) @95% Week 3: Knee Isometric Push 5x (3x2 sec) @95%	Rest	Week 1: Standing Calf Raise 3x10 @70% Week 2: Standing Calf Raise 3x11 @70% Week 3: Standing Calf Raise 3x12 @70%	N/A	Matchday Consider Training Zone 4 methods for players that did not play	Rest or mobility circuit for players that play on the day before. Consider Training Zone 2 methods for players that did not play
Upper Body Option	N/A	Week 1: Pull-Up 3x5 @80% Week 2: Pull-Up 4x5 @80% Week 3: Pull-Up 5x5 @80%	Rest	Week 1: Shoulder Press 3x10 @70% Week 2: Shoulder Press 3x11 @70% Week 3: Shoulder Press 3x12 @70%	N/A		
Power Option	Week 1: Bench Press Throw 3x3 @40-60% Week 2: Bench Press Throw 4x3 @40-60% Week 3: Bench Press Throw 5x3 @40-60%	N/A	Rest	N/A	Week 1: Power Clean 2x3 @60-80% Week 2: Power Clean 3x3 @60-80% Week 3: Power Clean 4x3 @60-80%		

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4.2. Study II – Beyond the Jump: A Scoping Review of External Training Load Metrics in Volleyball

Rebelo, A., Pereira, J. R., Nakamura, F. Y., & Valente-Dos-Santos, J. (2025). Beyond the Jump: A Scoping Review of External Training Load Metrics in Volleyball. *Sports Health*, *17*(1), 111–125. https://doi.org/10.1177/19417381241237738.

4.2.1. Abstract

Context: Volleyball is a complex sport involving multifaceted movements and high-velocity actions, leading to diverse external training loads that have profound implications for player performance and injury risk.

Objective: To provide a comprehensive overview of the measurement of external training load in volleyball, identify gaps in current understanding, and offer valuable insights for stakeholders in the field.

Data Sources: The literature search was conducted across the following electronic databases: PubMed/Medline, Scopus, Web of Science, and SPORTDiscus.

Study Selection: Studies were selected based on their relevance to the measurement of external training load in volleyball.

Study Design: A scoping review methodology was chosen to map and summarize the broad body of literature related to external training load measurement in volleyball.

Level of Evidence: Level 4

Data Extraction: Data related to external training load measurements in volleyball were extracted and analysed from the selected studies, focusing on metrics utilized, player positions examined, and technologies employed.

Results: A total of 18 studies related to external training load in volleyball were identified and examined for this review. Despite the importance of sagittal plane movements in volleyball, the review identified a substantial research gap regarding external training load measurements beyond this plane, as well as a lack of focus on the unique demands of different player positions like the liberos. The use of technologies such as inertial measurement units was prevalent, but more comprehensive measurement methods are needed.

Conclusions: There is a critical need for diversified external training load metrics in volleyball, extending beyond the conventional sagittal plane measurements. The findings highlight a substantial research gap in addressing the unique demands of different player positions, notably the liberos. This study underscores the importance of incorporating multi-planar movement data, player-specific roles, and advanced measurement technologies to develop more tailored training programs and injury prevention strategies.

Key Words: multidimensional analysis, measurement technologies, athletic performance, player positions, movement planes.

4.2.2. Introduction

Volleyball is a sport rich in multifaceted movements, strategic planning, and high-velocity actions, leading to varied and often intense external training loads (ETLs) [1,2]. External training loads, encompassing the volume, intensity, and type of physical work performed by an athlete during training or competition, have profound implications for players' performance, injury risk, and recovery needs [3]. These loads are especially variable in volleyball due to the sport's inherent dynamic nature, marked by unpredictable gameplay and player-specific roles [1,4].

These roles, such as that of the libero, highlight the complexity and unique demands of volleyball. The libero, known for their defensive mastery, often engages in quick, low-to-ground movements, requiring rapid acceleration, deceleration, and changes in direction [5]. Unlike other players who frequently jump for attacks or blocks, the libero's performance predominantly involves lateral and diagonal maneuvers, pointing to a unique ETL profile. Middle blockers also need to move laterally along the net to block attacks from different zones of the court, thereby involving significant transverse and frontal plane actions [6,7]. Like liberos, outside hitters also perform lateral and diagonal movements during defence, especially when transitioning from backcourt to the attack line [8,9]. Additionally, outside hitters' rotational movements while spiking can generate significant torsional loads on the body, emphasizing the necessity of a triaxial ETL measurement [10]. Setters frequently perform rapid changes of direction, and their hands-on role in ball distribution involves substantial rotations, highlighting the relevance of the transverse plane [11]. Such positional nuances accentuate the need for a thorough, multidimensional understanding of ETL in volleyball.

Advanced technologies like accelerometers, inertial measurement units (IMUs), and global positioning system (GPS) devices have revolutionized the way ETL is quantified and interpreted [12,13]. Despite these technological advances, the focus of ETL measurement in volleyball has been skewed towards movements in the sagittal plane, such as jump count and jump height [14]. This approach overlooks the vast range of motions that volleyball players, particularly liberos, undertake on the court.

In parallel, there is a growing body of research exploring the internal training load (ITL) - the individual physiological and psychological response to ETL [3]. While these studies have provided valuable insights into players' loading patterns [15], the need to complement this understanding with a comprehensive analysis of ETL, extending beyond sagittal plane movements, is becoming increasingly apparent. Given the fast-paced, demanding, and position-specific nature of volleyball, gaining a holistic perspective on ETL is crucial. This involves not only exploring the range of ETL metrics used across different studies but also identifying the measurement tools and technologies employed, and the player positions and levels of play considered in the research. Such a comprehensive overview would not only enhance our understanding of volleyball's physical demands but also assist in developing tailored training programs and injury prevention strategies. This can be important in recognizing the intensity and volume of training that is most effective for enhancing specific skills or physical attributes. This means that training can be aligned more precisely with the demands of specific playing positions or individual weaknesses and strengths, including in volleyball [16]. Furthermore, through ongoing assessment of ETL, coaches can identify signs of fatigue or overtraining, allowing them to adjust training loads and incorporate appropriate rest and recovery protocols [17,18]. This ensures that athletes remain fresh and responsive to training stimuli. By understanding the specific physical demands during games, training programs can be designed to mimic these demands, ensuring that players are conditioned to meet the specific challenges they will face in matches.

Given the exploratory nature of the present research, a scoping review was deemed an ideal approach to gather and present the breadth of information related to ETL measurement in volleyball [19]. The objective of this review was therefore to provide a clear and nuanced overview of the measurement of ETL in volleyball, to identify gaps in the current understanding, and to offer valuable insights for researchers, practitioners, and stakeholders in the field.

4.2.3. Methods

Protocol and registration

This review protocol was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for scoping reviews (PRISMA-ScR) guidelines [19]. All aspects of the PRISMA-ScR checklist are available in Appendix II. The scoping review protocol was developed and registered on the International

Platform of Registered Systematic Review and Meta-analysis Protocols (INPLASY) [20]. The protocol was compiled to provide comprehensive information and ensure transparency and replicability of the planned research. Methodological decisions, inclusion and exclusion criteria, the search strategy, and the approach to data extraction and synthesis were all outlined within this protocol.

To ensure accessibility and transparency, the protocol has been made publicly available on the INPLASY platform. It was published on 19 June 2023 and can be accessed via the direct link: https://inplasy.com/inplasy-2023-6-0059/. Its unique digital object identifier (DOI) is 10.37766/inplasy2023.6.0059, and the INPLASY registration number is INPLASY202360059.

Eligibility criteria

Studies were included based on the following criteria: (1) the study involves volleyball players of any age and performance level; (2) the study must report on ETL, how it is measured, and ideally, how it relates to player performance, injury rates, or other relevant outcomes; (3) the study must report on ETL measurements that extend beyond movements in the sagittal plane or clearly state that only sagittal plane movements are considered; (4) both observational and interventional studies were included.

These criteria are selected to capture a broad range of studies that examine ETL in volleyball. By including players of all ages and performance levels, the review can provide a comprehensive understanding of ETL measurement across diverse populations.

Restrictions were applied based on the language of publication. Only studies published in English were considered to ensure that the research team can accurately interpret and synthesize the findings. There were no restrictions on the date of publication to ensure a comprehensive overview of all relevant research.

Information sources

The literature search was conducted across the following electronic databases: PubMed/Medline, Scopus, Web of Science, and SPORTDiscus. The date of the last literature search was on 26 of June of 2023. In addition to the database searches, reference lists of identified articles and relevant reviews were manually scanned for additional studies. Similarly, key journals in the field were hand-searched for relevant articles.

Search

The search strategy was developed and executed by the primary researcher, with input from the entire research team. The strategy conducted was in accordance with the Peer Review of Electronic Search Strategies (PRESS) checklist to ensure its robustness and comprehensiveness [21].

The search strategy encompasses both controlled vocabulary (such as MeSH terms in PubMed/Medline) and free-text terms to capture all relevant literature. The key search terms were: "volleyball", "external training load", "physical demands", "measurement", and "libero", along with their synonyms, related terms, and any appropriate variations. To ensure thoroughness and reproducibility, the search strategy was adapted to the syntax and subject headings of each database. For instance, in PubMed/Medline, the search looked like this: ("volleyball"[MeSH Terms] OR "volleyball"[All Fields]) AND ("training load"[All Fields] OR "physical demands"[All Fields]) AND "measurement"[All Fields]. The comprehensive search terms and strategy for each database is reported in Appendix II to allow for easy replication.

Selection of sources of evidence

The selection process for included sources of evidence was undertaken in several steps. Initially, after executing the search strategy across the electronic databases, all identified citations were imported into the CADIMA software. This platform was chosen for its ability to facilitate the screening and data extraction processes and to ensure a structured and systematic approach to the review [22]. It also facilitated the removal of duplicate citations, which was the first step in the screening process.

Subsequently, a standardized form was developed to guide the screening of titles and abstracts. This form included questions related to the eligibility criteria, such as whether the study involved volleyball players, whether it reported on external training load, and whether it reported measurements beyond the sagittal plane. The form was tested by the four authors of the review on a small subset of 10 citations. This calibration exercise helped ensure that all authors had a clear understanding of the eligibility criteria and could apply them consistently.

Discrepancies were discussed and resolved through consensus, leading to a refinement of the form and a clearer shared understanding of the eligibility criteria.

Following the calibration exercise, each title and abstract was screened by two authors, with conflicts resolved by a third author. This double screening approach was adopted to minimize the risk of bias and to ensure no relevant studies were missed. A similar approach was used for the full-text screening of articles identified as potentially eligible during the title and abstract screening stage. For the full-text screening, a more detailed form was used, capturing information related to study design, participant characteristics, and outcome measures.

In the event of disagreements that couldn't be resolved by discussion, a third author acted as a mediator to achieve consensus. The CADIMA software facilitated the management of this process, including tracking which authors screened each article and recording decisions about study inclusion and reasons for exclusion.

Data charting

A data charting form was developed to standardize the extraction of relevant information from each included study. This form was designed to capture a range of information pertinent to the research question, including study characteristics (such as author, year, and study design), participant characteristics (such as age, performance level, and player position), and details about ETL measurement (including the specific metrics used, any measurement tools or technologies, and key findings).

The selection of items for charting was informed by the research question and the principles of a scoping review. To ensure consistency and reliability in data charting, the team carried out a calibration exercise, similar to the one performed during the study selection process. A subset of five included studies was used for this exercise. Each author independently charted the data from these studies, and then the team compared and discussed their charting to identify and resolve discrepancies.

Once the charting form was finalized, the data extraction process was initiated. Each included study was independently charted by two authors using the CADIMA software. This tool was particularly useful in managing the extraction process and facilitating collaboration among the team. When inconsistencies arose, these were discussed and resolved through consensus, with the involvement of a third author if required. To further ensure accuracy, a 10% random sample of the charted data was verified by a third author, checking for any errors or omissions in the data extracted.

During the charting process, the team maintained an iterative approach, revising the charting form as necessary. These changes were primarily based on emerging insights from the data and were made to improve the clarity and relevance of the extracted information. If necessary, authors of the original studies were contacted for clarification or additional information to ensure accurate data extraction.

Data items

In this scoping review, the data charting form was designed to extract a combination of qualitative and quantitative information from each of the included studies. We began by recording study identification details including the author(s), the year of publication, and the country where the study was conducted. We also captured information about the study design, detailing the methodology used, such as whether it was a cross-sectional, longitudinal, case study, or another design.

The characteristics of the participants in each study were also documented, with information regarding age, sex, level of play (which could range from youth/high school to collegiate to professional), and their specific player position. To understand the metrics used in the studies, we extracted specific ETL metrics, which could include total distance covered, number of accelerations or decelerations, number of jumps, among others. The measurement tools or technologies used to gather these metrics were also recorded, and these could range from local positioning systems (LPS) to video analysis or to other wearable devices.

An important part of the charting process was extracting key findings of each study related to the measurement of ETL in volleyball players. The findings, along with any limitations or challenges reported by the authors in relation to measuring ETL, were synthesized into concise statements.

Each item in the data charting form was clearly defined to ensure a consistent understanding and application among all authors. The systematic capture of this wide range of information facilitated a comprehensive understanding of the existing body of evidence regarding the measurement of ETL in volleyball players, thereby highlighting the current gaps and potential areas for future research.

Critical appraisal of individual sources of evidence

Given that the objective of this scoping review is to identify and map the approaches used to measure ETL in volleyball players, a critical appraisal step may not be necessary [19]. The main goal is to provide an overview of the existing research and highlight gaps and opportunities for further investigation. Therefore, the present scoping review did not include a formal critical appraisal of the individual sources of evidence.

Synthesis of results

The synthesis of the results aimed to create a comprehensive overview of the range of evidence included in this review, aligned with the research questions and objectives. To facilitate this, the extracted data were processed in a structured manner to generate a narrative synthesis. This process involved an iterative exploration of the data, identification of patterns and themes, and generation of insights relevant to the measurement of ETL in volleyball players.

The synthesis of results primarily took a descriptive approach, characterizing the overall body of literature and detailing the key findings across studies. This included information on the study designs employed, the characteristics of the participant populations, the ETL metrics reported, the measurement tools and technologies used, and the key findings of each study. This allowed the current review to provide a comprehensive and nuanced picture of the research landscape.

The findings from the synthesis were presented in several ways to cater to diverse information needs and to enhance accessibility and understanding of the results. A narrative summary was provided, detailing the key insights and trends across the studies. In addition, the data were presented visually using tables to illustrate the range and distribution of the studies, the participant characteristics, the ETL metrics used, and other relevant aspects. These visual representations complemented the narrative synthesis, providing an at-a-glance understanding of the key aspects of the evidence base.

4.2.4. Results

Selection of sources of evidence

The search for sources of evidence in the literature resulted in the identification of 157 records across four major databases: PubMed/Medline (43 records), Scopus (24 records), SPORTDiscus (21 records), and Web of Science (69 records). Before initiating the screening process, 44 duplicate records were meticulously identified and eliminated, reducing the total number of unique records to 113. Following the removal of duplicates, all 113 records were thoroughly screened for relevance to the research objectives. This initial screening process led to the exclusion of 92 records, primarily due to reasons such as mismatch with the study focus, lack of pertinent data, or studies not focused on volleyball players. The remaining 21 records were then earmarked for more detailed evaluation. These records were retrieved for a more in-depth review and assessment against the inclusion and exclusion criteria. Out of these, three records were excluded: two were identified as not having any ETL data, and one was a conference proceeding which did not meet the inclusion criteria. Ultimately, 18 studies met all the stipulated criteria and were included in the final scoping review. The process of record identification, screening, eligibility, and inclusion in the study is presented in a flow diagram in Figure IV-5.

Characteristics of sources of evidence

The 18 studies included in this review present a range of participant characteristics, reflecting diverse contexts of volleyball training and performance. The studies varied in terms of sample size, ranging from a minimum of 5 participants [23,24] to a maximum of 24 participants [25]. The participants represented both male [4,14,23,26-33] and female [24,25,34-38] volleyball players. Age ranges were also quite diverse across studies, with the youngest participants being 16-18 years old [37] and the oldest participants up to 30.5 years old [14]. In terms of player positions, most of the studies reported on outside hitters, setters, middle blockers, and opposites (n = 7; 39%) [4,14,26,27,30-32]. A smaller number of studies also reported on liberos (n = 4; 22%) [28,33,34,38]. The level of play was predominantly at the elite level (n = 12; 67%) [4,14,23,26-33,36], but there were also studies involving collegiate (n = 4;

22%) [24,34,35,38] and youth (n = 2; 11%) [25,37] players. In terms of physical characteristics, the studies reporting these data showed variations in height and weight across different player positions and levels of play. However, some studies did not report these data (n = 4; 22%) [4,25,27,35].

Further details about the individual studies, including specific participant characteristics, level of play, and player positions, are provided in Table IV-9. These findings present a broad overview of the populations involved in research on the measurement of ETL in volleyball, highlighting the variability across studies and the diverse contexts in which this research has been conducted.

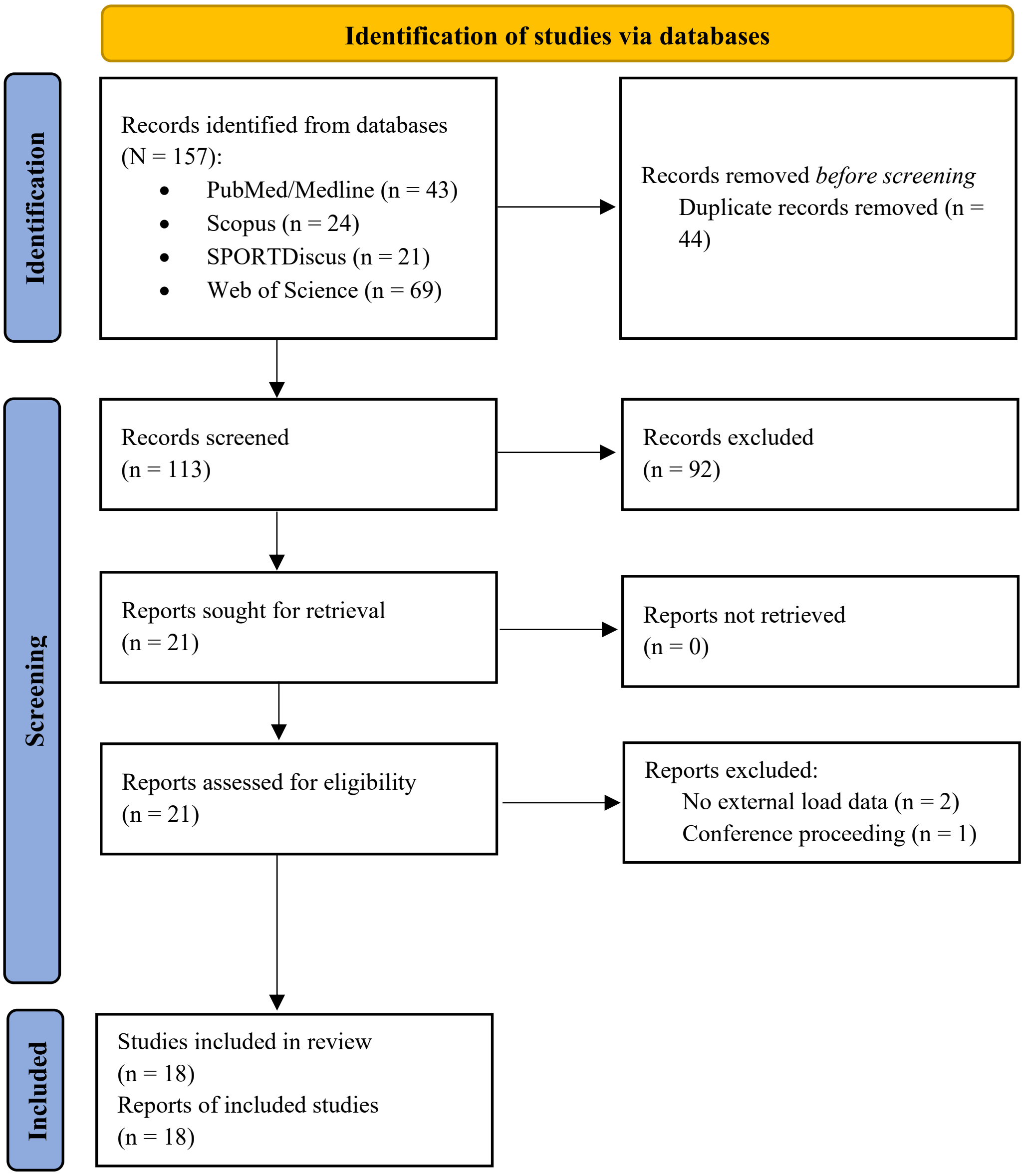

Figure IV-5: PRISMA 2020 flow diagram for the present review.

Table IV-9: Descriptive data of the included studies.

Study	N	Sex (M/F)	Age (years)	Height (cm)	Weight (kg)	Level	Players' positions
Lima et al, 2023	7	M	30.5 ± 3.5	200.2 ± 6.3	93.0 ± 8.1	Elite	Outside hitter, setter, middle blocker, and opposite
Schumann et al., 2023	24	F	Not reported	Not reported	Not reported	Youth	Not reported
Rebelo et al, 2023	15	M	28.51 ± 5.39	193.19 ± 9.87	88.46 ± 13.18	Elite	Outside hitter, setter, middle blocker, and opposite
Taylor et al., 2022	16	F	19.6 ± 1.1	178 ± 7.0	75.9 ± 9.3	Collegiate	Libero, outside hitter, setter, middle blocker, and opposite
Piatti et al., 2022	12	M	25.8 ± 2.37	201.1 ± 0.05	Not reported	Elite	Outside hitter, setter, middle blocker, and opposite
de Leeuw et al., 2022	17	M	27.0 ± 3.0	200 ± 10.0	91.2 ± 6.4	Elite	Libero, outside hitter, setter, middle blocker, and opposite
Herring & Fukuda, 2022	9	F	Not reported	Not reported	Not reported	Collegiate	Outside hitter, middle blocker, and opposite
Altundag et al., 2022	14	F	22 ± 0.9	195.1 ± 7.6	71.4 ± 6.3	Elite	Not reported
Lima et al., 2022	14	M	21.7 ± 4.19	192.4 ± 6.25	85.7 ± 8.69	Elite	Outside hitter, setter, middle blocker, and opposite
Pawlik & Mroczek, 2022	11	F	16-18	172.42 ± 7.3	63.54 ± 8.36	Youth	Not reported
de Leeuw et al., 2022	14	M	27 ± 3	197 ± 7.0	90.5 ± 6.3	Elite	Not reported
Lima et al., 2021	10	M	21.7 ± 4.19	192.4 ± 6.25	85.7 ± 8.69	Elite	Outside hitter, setter, middle blocker, and opposite
Kupperman et al., 2021	11	F	19.36 ± 1.27	64.04 ± 7.08	69.91 ± 3.88	Collegiate	Libero, outside hitter, setter, middle blocker, and opposite
García-de-Alcaraz et al., 2020	11	M	28.0 ± 6.12	197.2 ± 6.93	87.9 ± 6.41	Elite	Outside hitter, setter, middle blocker, and opposite
Ness et al., 2019	5	F	19.6 ± 1.1	180 ± 1.0	79.4 ± 6.6	Collegiate	Not reported
Rabello et al., 2019	18	M	23.0 ± 4.3	190 ± 0.0	89.8 ± 9.6	Elite	Libero, outside hitter, setter, middle blocker, and opposite
Lima et al., 2019	5	M	26.7 ± 7.2	193 ± 8.0	86.5 ± 6.3	Elite	Outside hitter, setter, middle blocker

Skazalski et al., 2018	14	M	Not reported	Not reported	Not reported	Elite	Outside hitter, setter, middle blocker, and opposite

Results of individual sources of evidence

The 18 studies reviewed utilized varying methods and technologies for measuring ETLs in volleyball, with durations ranging from short-term, five-day studies [37] to long-term studies spanning over two full competitive seasons [35].

The dominant technology used across studies was the IMU equipped with 3-axis gyroscopes, magnetometers, and accelerometers [4,14,23,25-31,34]. This device was commonly placed on a belt secured to the athletes' hips, transmitting data via Bluetooth. The validity of the IMU device was typically reported according to the work of Charlton et al. (2017) [39], specifically the Vert® Classic model (MyVert, Florida, USA). Notably, Pawlik & Mroczek (2022) utilized the ClearSky Vector S7 (Catapult Innovations, Melbourne, Australia) [37], while Kupperman et al. (2021) used the ClearSky T6 (Catapult Innovations, Melbourne, Australia) [38]. In a departure from the IMU method, Altundag et al. (2022) [36] used a LPS (KINEXON, GMBH, Precision Technologies, KINEXON ONE, Munich, Germany), and the validity of this method was reported according to Fleureau et al. (2020) [40]. Both García-de-Alcaraz et al. (2020) and Ness et al. (2019) utilized video camera methods [24,32], and Rabello et al. (2019) [33] used a combination of 3-axis accelerometers and video camera to measure the ETL. The methodological considerations varied across the studies, with many describing the placement of the device, the rate of data sampling, or specific details about how the data was collected or processed.

In terms of the training phase during which these studies were conducted, a large number of the studies collected data during both the preparatory (pre-season) and competitive (in-season) phases (n = 9; 50%) [4,24,25,28,29,31,32,34,36,38], while others focused solely on the competitive phase (n = 7; 39%) [14,23,26,27,30,35,37].

Every detailed information regarding the results of individual sources of evidence is in Table IV-10. The collective evidence reflects a strong interest in the use of IMU technology to measure ETL in volleyball, with a specific preference for devices equipped with 3-axis gyroscopes, magnetometers, and accelerometers.

Table IV-10: Study settings and methodological considerations of the included studies.

Study	Duration of the study	Training phase	Type of device(s)	Validity and reliability of device reported	Methodological considerations
Lima et al, 2023	3 weeks	Competitive (in-season)	IMU with 3-axis gyroscopes, 3-axis magnetometers, and 3-axis accelerometers (Vert® Classic, MyVert, Florida, FL, USA)	Validity reported according to Charlton et al., 2017	The IMU was placed on a belt secured to athletes' hips. The data were transmitted via Bluetooth
Schumann et al., 2023	20 weeks	Preparatory (pre-season) and competitive (in-season)	IMU with 3-axis gyroscopes, 3-axis magnetometers, and 3-axis accelerometers (Vert® Classic, MyVert, Florida, FL, USA)	Validity reported according to Benson et al., 2020	The IMU was placed on a belt secured to athletes' hips. The data were transmitted via Bluetooth
Rebelo et al, 2023	5 weeks	Competitive (in-season)	IMU with 3-axis gyroscopes, 3-axis magnetometers, and 3-axis accelerometers (Vert® Classic, MyVert, Florida, FL, USA)	Validity reported according to Charlton et al., 2017	The IMU was placed on a belt secured to athletes' hips. The data were transmitted via Bluetooth
Taylor et al., 2022	17 weeks	Preparatory (pre-season) and competitive (in-season)	IMU with 3-axis gyroscopes, 3-axis magnetometers, and 3-axis accelerometers (Vert® Classic, MyVert, Florida, FL, USA)	Validity reported according to Charlton et al., 2017	The IMU was placed on a belt secured to athletes' hips. The data were transmitted via Bluetooth
Piatti et al., 2022	One competitive season	Competitive (in-season)	IMU with 3-axis gyroscopes, 3-axis magnetometers, and 3-axis accelerometers (Vert® Classic, MyVert, Florida, FL, USA)	Validity reported according to Charlton et al., 2017	The IMU was placed on a belt secured to athletes' hips. The data were transmitted via Bluetooth
de Leeuw et al., 2022	24 weeks	Preparatory (pre-season) and competitive (in-season)	IMU with 3-axis gyroscopes, 3-axis magnetometers, and 3-axis accelerometers (Vert® Classic, MyVert, Florida, FL, USA)	Validity reported according to Charlton et al., 2017	The IMU was placed on a belt secured to athletes' hips. The data were transmitted via Bluetooth
Herring & Fukuda, 2022	Two competitive seasons	Competitive (in-season)	IMU with 3-axis gyroscopes, 3-axis magnetometers, and 3-axis accelerometers (Vert® Classic, MyVert, Florida, FL, USA)	Validity reported according to Charlton et al., 2017	The IMU was placed on a belt secured to athletes' hips. The data were transmitted via Bluetooth
Altundag et al., 2022	10 months	Preparatory (pre-season) and	Local positioning system (KINEXON, GMBH, Precision Technologies,	Validity reported according to	External load data were collected at 20Hz and

		competitive (in-season)	KINEXON ONE Munich, Germany)	Fleureau et al., 2020	processed using specific Kinexon Software. The system used in this study consisted of 12 antennas positioned at three different distances around the volleyball court. The data acquisition sensor was placed in the middle of each athlete's upper back using a vest. Signals in the frequency range of 4.25–7.25GHz were transmitted to antennas using UWB technology.
Lima et al., 2022	8 months	Preparatory (pre-season) and competitive (in-season)	IMU with 3-axis gyroscopes, 3-axis magnetometers, and 3-axis accelerometers (Vert® Classic, MyVert, Florida, FL, USA)	Validity reported according to Charlton et al., 2017	The IMU was placed on a belt secured to athletes' hips. The data were transmitted via Bluetooth
Pawlik & Mroczek, 2022	5 days	Competitive (in-season)	IMU with 3-axis gyroscopes, 3-axis magnetometers, and 3-axis accelerometers (ClearSky Vector S7; Catapult Innovations, Melbourne, Australia)	Not reported	Accelerometer sampled at 1kHz, provided at 100 Hz
de Leeuw et al., 2022	24 weeks	Preparatory (pre-season) and competitive (in-season)	IMU with 3-axis gyroscopes, 3-axis magnetometers, and 3-axis accelerometers (Vert® Classic, MyVert, Florida, FL, USA)	Validity reported according to Charlton et al., 2017	The IMU was placed on a belt secured to athletes' hips. The data were transmitted via Bluetooth
Lima et al., 2021	10 weeks	Competitive (in-season)	IMU with 3-axis gyroscopes, 3-axis magnetometers, and 3-axis accelerometers (Vert® Classic, MyVert, Florida, FL, USA)	Validity reported according to Charlton et al., 2017	The IMU was placed on a belt secured to athletes' hips. The data were transmitted via Bluetooth
Kupperman et al., 2021	18 weeks	Preparatory (pre-season) and competitive (in-season)	IMU with 3-axis gyroscopes, 3-axis magnetometers, and 3-axis accelerometers (ClearSky T6; Catapult Innovations, Melbourne, Australia)	Reliability reported according to Nicolella et al., 2018	The units were placed on the back of players (between the scapulae) in a pocket sewn into a fitted Catapult Sports harness. The units were

					sampled at a rate of 100Hz
García-de-Alcaraz et al., 2020	32 weeks	Preparatory (pre-season) and competitive (in-season)	Video camera (Sony Handycam HDR-CX240)	Not reported	A Sony Handycam HDR-CX240 (30 Hz) video camera, located at the end of the court and at a height greater than the official volleyball net height, was used to record all in-court training sessions.
Ness et al., 2019	22 weeks	Preparatory (pre-season) and competitive (in-season)	Video camera	Not reported	Practices were viewed by two researchers collaboratively in an environment with minimal distractions. An upper extremity swing was tallied for a serve, attack, or roll shot. One researcher viewed the video footage and called out a swing along with the corresponding athlete's jersey number, while the other researcher recorded the data.
Rabello et al., 2019	7 weeks	Preparatory (pre-season)	3-axis accelerometers (Zephyr BioHarness 3TM, Zephyr Technology) and video camera	Not reported	Jumps were counted based on pattern recognition in the vertical acceleration data (100Hz)
Lima et al., 2019	4 weeks	Competitive (in-season)	IMU with 3-axis gyroscopes, 3-axis magnetometers, and 3-axis accelerometers (Vert® Classic, MyVert, Florida, FL, USA)	Validity reported according to Charlton et al., 2017	The IMU was placed on a belt secured to athletes' hips. The data were transmitted via Bluetooth
Skazalski et al., 2018	One full season	Preparatory (pre-season) and competitive (in-season)	IMU with 3-axis gyroscopes, 3-axis magnetometers, and 3-axis accelerometers (Vert® Classic, MyVert, Florida, FL, USA)	Validity reported according to Charlton et al., 2017	The IMU was placed on a belt secured to athletes' hips. The data were transmitted via Bluetooth

IMU = inertial measurement unit.

Synthesis of results

According to the data presented in Table IV-11, the majority of studies focused on variables measured in the sagittal plane, specifically relating to jumps (n = 17; 94%). Variables included the count, height (including maximum, minimum, average, and range), and load of jumps, in addition to factors such as the jump rate and height over 50 cm. Lima et al. (2023) highlighted the role of jump count, maximum, and average jump height, finding that a higher number of jumps corresponded to greater jump height [14]. Meanwhile, Piatti et al. (2022) highlighted the specific case of middle blockers, who presented the highest jump load and second highest number of jumps, despite not jumping as frequently as setters [27]. Taylor et al. (2023) tied these variables to injury, noting that injured athletes performed fewer jumps and had larger variation in external training loads before their injury [34].

Altundag et al. (2022) [36] and Pawlik & Mroczek (2022) [37] expanded their measurement to the frontal and transverse planes, exploring variables like total distance, accelerations, decelerations, metabolic load, speed, and player load. These variables demonstrated a strong correlation between training loads and competition performance.

Ness et al. (2019) took a unique approach by focusing on upper extremity arm swing, suggesting that monitoring changes in this metric may have implications for injury prevention [24].

Table IV-11: Variables measured and main results of the included studies.

Study	Variables measured	Main results
Lima et al, 2023	Sagittal plane: jump count, maximum jump height, and average jump height	It was observed a similar density of jumps during the week. However, when comparing MD-1 to MD-2, a more significant average number of jumps per minute was observed in MD-1. Additionally, a positive, large, and significant correlation was registered between the number of jumps and the height of the jump.
Schumann et al., 2023	Sagittal plane: jump count, jumps greater than 50 cm, maximum jump height, and stress upon landing. Frontal and transverse planes: movements per minute	The club elite sample of players had greater weekly variations throughout the season and many weeks were outside of the optimal ACWR range. The collegiate data showed spikes in ACWR at the onset of the season.

	All planes: kinetic energy	
Rebelo et al, 2023	Sagittal plane: jump count, average jump height, and kinetic energy	Sleep quality and fatigue were negatively associated with weekly kinetic energy.
Taylor et al., 2023	Sagittal plane: jump count, average jump height, maximum jump height, and jump load	Those athletes who were injured performed significantly fewer jumps per athletic exposure and had larger variation in external training loads before their injury.
Piatti et al., 2022	Sagittal plane: jump count and jump height	Middle blockers present the highest jump load; they have a median number of jumps of 126 (second only to the 147 of setters) and have the highest number of jumps higher than 50 cm. Setters present the highest number of jumps per game and the lowest jump height.
de Leeuw et al., 2022	Sagittal plane: jump count, and average jump height	Worse attack performance is linked to low jump heights and small variations in the number of high jumps in the four weeks prior to competition. Lower passing performance was associated with small variations in the number of high jumps in the preceding week and an excessive number of high jumps performed, on average, in the two weeks prior to competition.
Herring & Fukuda, 2022	Sagittal plane: jump count, jump rate, and average jump height	Outside hitters had the highest average jump height followed by middle blockers then opposites. Middle blockers had higher jump count and jump rate compared to outside hitters.
Altundag et al., 2022	Sagittal plane: jump count. Frontal and transverse plane: total distance, accelerations, decelerations, metabolic load, and speed	As the metabolic load, jumps, accelerations, and decelerations values obtained during training increase, the values obtained in competitions also increase.
Lima et al., 2022	Sagittal plane: jump count, minimum jump height, maximal jump height, range jump height, and average jump height	There was a negative correlation between the maximum jump height and the range jump height with the internal training load. Higher internal intensities are correlated with lower external intensities in sessions further away from the game day.
Pawlik & Mroczek, 2022	Sagittal plane: jump count and jump height. Frontal and transverse planes: accelerations and decelerations All planes: Player Load	There is a relationship between internal training load and the number of total accelerations. It was reported that on the training days of the same well-being level, the jump number values were significantly different.
de Leeuw et al., 2022	Sagittal plane: jump count and jump height.	Jump load is an important predictor for overuse injuries in volleyball.
Lima et al., 2021	Sagittal plane: jump count and jump height.	Congested features did not interfere with the players' external training load.
Kupperman et al., 2021	Sagittal plane: jump count and jump height. Frontal and transverse planes: changes of direction, repeated high-intensity efforts,	Setters accrued over twice as many jumps in a practice than during a game and had similar overall jump counts in practice to attacking positions. Middle blockers had a greater number of repeated high-intensity efforts for both games and practice compared to other positions.

	accelerations, and decelerations All planes: Player Load	
García-de-Alcaraz et al., 2020	Sagittal plane: jump count	The middle blockers showed the greatest jump count regardless of the season period, while the setters performed the smallest. Similar jump count was found in opposites and outside hitters.
Ness et al., 2019	Upper extremity arm swing	Monitoring upper extremity performance changes and swing count volume may have implications for injury prevention
Rabello et al., 2019	Sagittal plane: jump count	At the dominant side, higher cumulative weekly jump count was related to a significant decrease of echo type I percentage
Lima et al., 2019	Sagittal plane: jump count and jump height	Setters made a significantly greater number of jumps than middle blockers and outside hitters, with similar height. However, middle blockers and outside hitters accumulated their jumps in specific moments (frontcourt).
Skazalski et al., 2018	Sagittal plane: jump count and jump height	Setters performed the greatest number of jumps. Opposites jumped higher than their teammates.

4.2.5. Discussion

Summary of evidence

The primary objective of this scoping review was to provide a comprehensive overview of the measurement of ETL in volleyball and identify any gaps in current knowledge. As evidenced from the 18 studies reviewed, research on ETL measurement has predominantly focused on sagittal plane movements, particularly involving jumps. While the importance of jumps in volleyball is undeniable, the emphasis on this single aspect leaves other crucial dimensions underexplored, potentially compromising the development of holistic training and injury prevention strategies.

Jump-related metrics, such as jump count, height, and load, were consistently used across the studies to assess the players’ external load. Lima et al. (2023) found that a higher number of jumps corresponded to greater jump height, indicating a potential strain on the player's physical performance [14]. Similarly, Taylor et al. (2023) linked fewer jumps and larger variations in ETLs to an increased risk of injuries [34]. In contrast, Piatti et al. (2022) identified middle blockers as having the highest jump load, despite not jumping as frequently as setters, which points to the position-specific demands within the sport [27].

While the focus on jumping metrics in volleyball research is pervasive due to the sport's inherent vertical demands, other non-jumping variables also play a pivotal role in defining the ETL for players. Essential parameters such as total distance covered, changes in direction, accelerations, decelerations, metabolic load, speed, player load, and upper extremity movement metrics, particularly the arm swing characteristics, are indispensable in offering a holistic perspective [36,37]. Especially in positions like libero, which involve minimal jumps, these metrics become paramount. Additionally, factors such as kinetic energy in the sagittal plane, lateral movements in the frontal plane, and complex rotational movements in the transverse plane, associated with different player positions, significantly contribute to the overall external load. Hence, to craft a complete narrative of a player's exertion and the sport's physical demands, it's imperative to incorporate and emphasize these non-jumping metrics.

Importantly, the position of the libero was notably absent in most studies, perhaps because of the traditional focus on sagittal plane movements. Given that liberos are less involved in jumping activities and have unique role-specific movements [5], this omission suggests a substantial area of underrepresentation. In addition, setters often perform complex rotational movements in the transverse plane when setting the ball, and these movements are vital to their performance yet often overlooked in research [11]. Moreover, the dynamic lateral movements, characteristic of outside hitters when they approach for a spike or adjust their position for blocking, also constitute significant load in the frontal plane [1]. Understanding these movements in detail could provide unique insights into the physical demands of these positions and could inform training and injury prevention strategies accordingly. By isolating the unique physical demands of each position, coaches can design training programs that focus on strengthening the relevant muscles, enhancing the necessary energy systems, and honing the requisite coordination patterns. This targeted approach ensures that athletes' training time is spent more efficiently, developing the exact strengths and skills that will be most frequently used in matches. This could be a game-changer, allowing the development of position-specific programs that cater to the unique demands of each role and potentially enhancing performance and reducing injury risk.

Notably, Ness et al. (2019) introduced the upper extremity arm swing as a significant metric, suggesting that changes in this measure could have implications for injury prevention [24]. Understanding upper extremity movement is indeed critical when considering the ETL of volleyball players, particularly given the sport's heavy reliance on upper body actions such as serving, spiking, and blocking [1,41]. Technologies such as wearable IMUs, that can accurately capture 3D movement data, are well-suited for this purpose. Metrics derived from such data, including arm swing velocity, frequency, and range of motion, can provide nuanced insight into the demands placed on the upper body during different phases of play. While these measures have broad applicability across all positions due to the integral role of upper body movements in volleyball, they may be particularly valuable for outside hitters, opposites, and middle blockers, who frequently perform high-intensity, upper body dominant actions [1].

While these studies have made valuable contributions to our understanding of ETL in volleyball, the concentration of research on sagittal plane measurements, particularly those related to jumping, indicates a substantial gap in current knowledge. The complexity and fast-paced nature of volleyball necessitate a broader examination of ETL that encompasses multiple planes of movement, various player positions, and different levels of play. Such a holistic approach would not only enhance our understanding of volleyball's physical demands but also aid in the development of tailored training programs and injury prevention strategies.

As it was previously highlighted, a thorough understanding of ETL is vital for coaches, athletes, and stakeholders involved in the sport, informing the creation of individualized training regimes and injury prevention strategies. Policymakers and healthcare providers could also benefit from this comprehensive overview, allowing them to make informed decisions about volleyball training, competition policies, and player health and safety protocols.

Limitations

Despite efforts to be comprehensive, only English language articles were included, potentially excluding significant research conducted in other languages. Furthermore, this review did not assess the methodological quality of the included studies, as is typical in a scoping review [19]. Although this approach allows for the inclusion of a wide range of studies to provide a broad overview of the field, it also means that the strength of the evidence presented cannot be definitively appraised. Consequently, readers should interpret these findings with an understanding of this inherent limitation.

While our primary focus was on examining the methodologies used for measuring ETL in volleyball, we recognize certain intrinsic factors that can influence workload. These factors include potential differences in workload by sex, level of play, and specific type of play (e.g., indoor vs. beach). The present scoping review did not delve into these variations, as the current objective was more methodologically oriented.

Conclusions

A key finding is that the majority of the studies focused on sagittal plane measurements, particularly those related to jumping, due to the critical role these actions play in the sport. However, this reveals a gap in the research where other planes and variables, including the frontal and transverse planes, and factors such as kinetic energy, changes of direction, and repeated high-intensity efforts, are often overlooked. Moreover, while it is clear that the measurement of ETL is well-explored for some positions (e.g., setters, middle blockers, and outside hitters), there is a conspicuous lack of focus on the liberos. This further highlights the need for a more holistic approach to studying external load in volleyball, taking into account the unique characteristics and demands of different player positions.

In terms of technologies used for monitoring ETL, most of the studies relied on IMUs as the primary tools of data collection. This reflects a predominant methodology in external load measurement in volleyball. The predominance of IMU technology suggests a degree of standardization in the tools used for external load measurement in volleyball, which aids in comparison and synthesis of findings across different studies. Yet, given the multidirectional nature of volleyball [42], it is vital to employ technologies capable of capturing movements across all three planes - sagittal, frontal, and transverse. Examples of such technologies include sophisticated IMUs and LPSs, which provide comprehensive movement data. When analysing this data, it is crucial to consider metrics that capture total movement load. While metrics such as PlayerLoad, which is calculated as the square root of the sum of the squared instantaneous rate of change in acceleration in all three planes, offer insights into a player's exertion, one must be cautious [43]. PlayerLoad and similar metrics are brand-specific, and their algorithms can differ significantly across brands. This can make comparisons challenging and, at times, unfeasible. Therefore, while such metrics provide a convenient tool for coaches, there is a pressing need for more standardized and universally applicable measures to ensure consistency in assessing players' exertion, taking into account not only the volume of movement but also its intensity and directionality.

For a more granular analysis, coaches can look at specific metrics within each plane. In the sagittal plane, jump count, jump height, and kinetic energy are key variables often measured in volleyball. In the frontal and transverse planes, variables such as total distance covered, changes of direction, accelerations, and decelerations can provide valuable insights into the player's lateral and rotational movements. It is important to note that while these metrics can be valuable, the accuracy of traditional GPS and accelerometery devices can be limited in indoor settings like volleyball courts. The challenges posed by indoor environments, such as interference and lack of direct GPS signal, can impact the data quality. The LPSs have emerged as potential solutions for indoor tracking, but they too have their set of challenges. Despite these current limitations, these plane-specific metrics can still offer valuable insights and help coaches design position-specific training programs and injury prevention strategies, tailored to the unique demands of each role within the team.

With regard to the existing literature, this review's findings align with the understanding that volleyball is a sport with high vertical load [14]. However, the importance of expanding the perspective beyond sagittal plane metrics and considering other positional roles like libero are novel insights. From a practice perspective, these findings underscore the need for a multidimensional approach to load monitoring in volleyball, one that accounts for the different planes of movement, role-specific demands, and the overall match and training context. This has potential implications for the design of training programs, with more nuanced and position-specific strategies likely to be more effective in enhancing performance and minimizing injury risk.

As for future research, there is a clear need for more comprehensive studies examining the external load across different player positions, especially the under-researched libero role, and including metrics beyond the sagittal plane. Such research could enable the development of a more complete picture of the physical demands of volleyball, paving the way for more effective, position-specific training programs. Also, further investigation into the different technologies used for load measurement, and perhaps the development of a standardized set of tools, could be beneficial. Furthermore, upper body metrics could be instrumental in individualizing training programs and developing targeted injury prevention strategies [44]. For instance, identifying a player with a particularly high arm swing velocity might suggest a need for increased focus on shoulder strength and stability in their training regimen. Alternatively, observing changes in arm swing characteristics over the course of a season could provide early indicators of overuse or fatigue, informing timely interventions to prevent injury [45]. Therefore, the inclusion of upper body movement metrics in future ETL research represents an important avenue for enhancing our understanding of volleyball's diverse physical demands and tailoring training interventions accordingly.

In conclusion, while this scoping review has provided valuable insights into the measurement of ETL in volleyball, it also highlights significant gaps in the current body of knowledge. Addressing these gaps could hold the key to developing more effective training methods and injury prevention strategies, ultimately elevating the level of the sport.

4.2.6. References

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4.3. Study III – Rating of Perceived Exertion in Professional Volleyball: A Systematic Review

Rebelo, A., Pereira, J. R., Martinho, D. V., & Valente-Dos-Santos, J. (2023). Rating of Perceived Exertion in Professional Volleyball: A Systematic Review. *Journal of Human Kinetics*, *87*, 143–155. https://doi.org/10.5114/jhk/161614.

4.3.1. Abstract

The rating of perceived exertion (RPE) it's a non-invasive, cost effective, and time efficient strategy to measure load. However, data can be collected without following specific procedures and across a range of methods (e.g., different RPE scales and/or different operational questions). Consequently, practitioners working in professional volleyball can use this information in various ways with different assessment standards between them. Therefore, the purpose of the current review was to systematically and critically evaluate the use of RPE-based methods in professional volleyball athletes. Electronic searches were conducted in four databases (PubMed, SPORTDiscus, Scopus, and Web of Science). The electronic search yielded 442 articles in which 14 articles were included in the systematic review. All included studies used the BORG-CR10 scale to calculate the session RPE. The main findings indicate that, to minimize the effect of the last exercise of the session, the athlete should be presented with the RPE question 10 to 30 minutes after the session is finished. Plus, in order, to evaluate the intensity of the training session, the question should be "how hard/intense was your session?", avoiding questions without these adverbs or adjectives such as "how was your training session/workout?". Future studies should analyse the collection of the localized RPE responses in professional volleyball athletes and their relationships with objective markers such as number of jumps and accelerations.

Key Words: workload; team sports; athletes; monitoring.

4.3.2. Introduction

Fatigue is a normal and desired part of the training process, and its severity can be observed as a continuum [1]. When the proper balance between training stress and recovery is ensured, athletes experience acute fatigue in response to training sessions and recover within hours or days. However, if intense training continues without an adequate recovery period, athletes may enter a state of overreaching [1]. When athletes experience a temporary reduction in performance levels as a result of training, they enter a state of functional overreaching [2]. If training continues and unplanned fatigue persists, athletes may experience non-functional overreaching that can last for several weeks. The last phase of the fatigue continuum is called overtraining syndrome, which is characterized by decreases in performance levels that are usually accompanied by psychological disturbances that can remain for long periods [2]. To prevent these maladaptations associated with excessive training loads, it is recommended that practitioners monitor training loads to ensure adequate recovery. In addition to these negative performance implications, excessive training loads increase the risk of injury and illness in high-performance athletes [3]. These heightened risks demonstrate the importance of monitoring how athletes are responding to training and competition, showing that the key for a good exercise prescription is an adequate understanding of the effect promoted by training load on the human body [4].

Monitoring athlete load is better understood through sub-dividing load into two groups – internal and external [5]. Internal training load (ITL) refers to the physiological stress that a training session induces in the athlete [6]. Rating of perceived exertion (RPE) has become the most common method of monitoring ITL as it's a non-invasive, cost effective, and time efficient strategy to measure load [5]. The RPE method was originally developed by Borg [7], and Foster et al. [8] created a simple technique to quantify ITL using a modification of this scale. This technique is known as the session RPE (sRPE) and is derived by multiplying the overall RPE obtained at the end of a training session (or match), using the Borg Category-Ratio 10 scale (BORG-CR10) by the total duration (in minutes) of the training session, to provide a modified training impulse (TRIMP) score.

Developing an understanding of the ITL response to specific mesocycles and the transition between mesocycles could inform future training prescription. However, RPE data can be collected without following specific procedures and across a range of methods (e.g., different RPE scales and/or different questions). For instance, in order to prevent that sRPE scores are overly influenced by how athletes felt at the end of the training session, the question should not be presented immediately after the session is finished [8]. Consequently, practitioners working in professional volleyball can use this information in various ways with different scales and questions to assess this information. A review of the literature specifically examining the available evidence and present suggestions to effectively monitor athletes with RPE in professional volleyball would be of interest. Such review can ensure that coaches would use quality information used to prescribe training in applied settings. Therefore, the purpose of the current review was to systematically and critically evaluate the use RPE-based methods in professional volleyball.

4.3.3. Methods

Literature Search Strategy

Articles were systematically identified via four electronic databases (PubMed, SPORTDiscus, Scopus, and Web of Science) using the search strategy presented in Appendix III. The search string for each variable (rating of perceived exertion and volleyball) was used independently, after which both were combined in the complete search strategy. The search was restricted to original peer-reviewed studies published in English, Spanish, and Portuguese with literature reviews and conference proceedings excluded. The search was developed to consider research articles published online or in print from database inception until July 2022, when the search was conducted.

Selection Criteria

The process for screening articles followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [9]. The study protocol was registered with INPLASY (INPLASY202280034). Articles considered for inclusion in the review were those examining professional volleyball athletes and reporting RPE outcomes within, at least, one phase of the season (i.e., off-season, pre-season, or competitive period). The sample of participants were made up of volleyball athletes who were part of a professional team. Therefore, collegiate and young volleyball athletes were excluded from the present systematic review. Including experimental studies that implemented an intervention may have misrepresented the results, so the review was restricted to cross-sectional or longitudinal observational study designs. Studies where player monitoring data were reported only during competitive games or during a portion of a phase of the season (e.g., one week) were excluded as they did not represent the complete workloads experienced by players during a specific period of the annual training plan.

The abstracts of all the articles identified in the search were screened independently against the pre-defined selection criteria by two authors (AR and DVM). Any disagreements between the two authors regarding article inclusion were further discussed and, if agreement was not reached, a third author (JRP) was consulted to establish consensus. Full-text copies were acquired for all papers that met title and abstract screening criteria. Full-text screening was performed by two reviewers (AR and DVM). Again, any discrepancies were discussed until the authors reached an agreement and consulted a third author (JRP) when required.

Assessment of Methodological Quality

Methodological quality was assessed using a modified version of the Downs and Black [10] checklist for assessing the methodological quality of healthcare interventions. This checklist has been validated for use with observational study designs [10] and has been previously used to assess methodological quality in systematic reviews assessing cross-sectional and longitudinal studies [11,12]. The number of items from the original checklist can be tailored to the scope and needs of the systematic review, with 10–15 items used in previous systematic reviews [11,12]. For this review, 11 items in the checklist were deemed relevant (Appendix III). Each item is scored as “1” (yes) or “0” (no/unable to determine), and the scores for each of the 11 items are summed to provide the total quality score. The quality of each included article was rated against the checklist independently by two authors (AR and DVM). Any disparity in the outcome of the quality appraisal was discussed, and a third author (JRP) was consulted if a decision could not be reached.

Data Extraction and Analysis

Data were extracted from each article by the lead author (AR). Data not provided or presented non-numerically were identified as “not reported”. The following data, where possible, were extracted from each article: (1) participants’ characteristics (sample size, sex, age, body height, and body mass); (2) monitoring period (i.e., seasonal phase(s) and duration);

(3) objective measures (e.g., heart rate, time motion analysis); (4) RPE scale methods (e.g., scale, operational question).

4.3.4. Results

Search Findings and Study Selection

The electronic search yielded 442 articles (PubMed = 56, SPORTDiscus = 123, Scopus = 143, Web of Science = 120). A total of 304 duplicate records were removed, and a further 114 irrelevant articles were excluded based on title and abstract; 24 fulltext articles were screened and 10 were removed, leaving 14 articles for inclusion in the review. Reasons for exclusion were analysis only in a part of a period of the season (N = 5), not professional athletes (N = 2), player monitoring limited to competitive games only (N = 2), duplicate data (N = 1), and conference paper (N = 1). The full results of the search are presented in Figure IV-6.

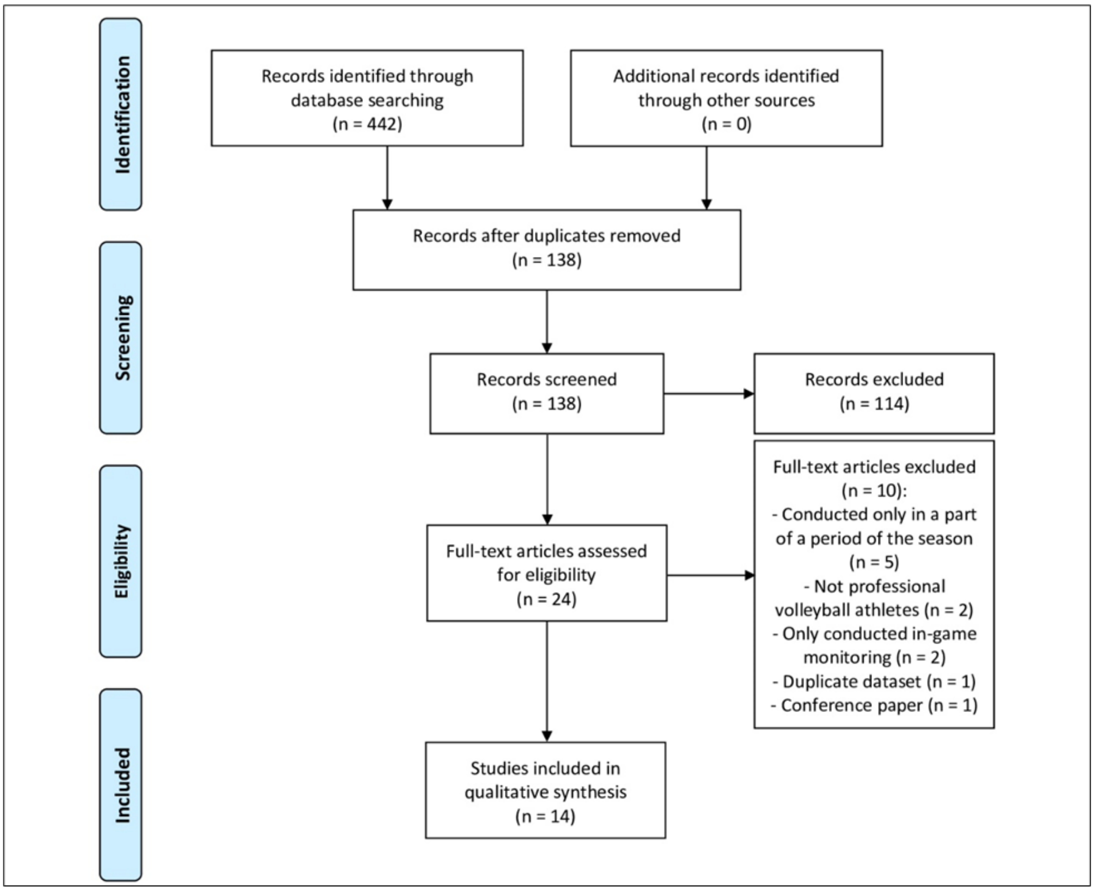

Figure IV-6: Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) flow diagram of search strategy.

Methodological Quality

The ratings from the quality appraisal for each article are presented in Appendix III. Methodological quality scores ranged from 7 to 9 out of 11. In line with previous literature using the Downs and Black checklist [11,12], no articles were excluded based on methodological quality.

Participant Characteristics

The characteristics of the participants investigated in the included articles are presented in Table IV-12. Sample sizes ranged from 8 to 16 players. In total, 12 studies monitored only males and two monitored only female athletes.

Table IV-12: Participant characteristics of the included articles.

Study, year	N	Sex (M/F)	Age (years)	Body mass (kg)	Body height (cm)
Andrade et al., 2021	15	M	24 ± 4	96.67 ± 11.33	194.30 ± 6.65
Berriel et al., 2022	16	M	23.60 ± 4.93	92.10 ± 10.26	197 ± 6.29
Brandão et al., 2018	14	M	26.7 ± 5.5	95.8 ± 8.2	197 ± 7.9
Clemente et al., 2020	13	M	31.0 ± 5.0	88.9 ± 7.6	194 ± 7
Debien et al., 2018	15	M	24.0 ± 3.6	96.7 ± 11.3	194.3 ± 6.7
Domingos et al., 2022	11	M	26.4 ± 5.7	96.6 ± 9.0	197.6 ± 7.8
Duarte et al., 2019	14	M	24.0 ± 3.59	96.87 ± 9.85	194.36 ± 6.9
Horta et al., 2019	12	M	26.9 ± 4.6	94.9 ± 11.6	194.6 ± 8
Horta et al., 2020	9	M	26.4 ± 4.0	93.9 ± 5.7	198.9 ± 9.1
Lima et al., 2020	8	M	23.0 ± 5.22	84.5 ± 7.58	193.0 ± 9.71
Mendes et al., 2018	13	M	31 ± 5.0	88.9 ± 7.6	194 ± 7
Rabbani et al., 2021	13	F	25.8 ± 3.0	69.7 ± 7.6	178.1 ± 6.7
Timoteo et al., 2021	14	M	26.7 ± 5.5	95.8 ± 8.2	197.0 ± 7.9
Ungureanu et al., 2021	12	F	22 ± 4	74.1 ± 4.3	180 ± 6

Collection of RPE Data

The duration of the selected studies lasted 6 weeks [13] to 36 weeks [14-16]. Data were predominantly collected during preparatory and competitive periods (50%) [14,16-21].

Three studies collected RPE-based data during the preparatory period only (21%) [13,22,23] and another three during the competitive period only (21%) [15,24,25]. One study reported data during the transition period between clubs and national team camps (7%) [26]. Only two studies complemented RPE-based ITL data with objective measurements such as inertial movement units [24] and heart rate [25]. A detailed description of RPE data collection procedures is reported in Table IV-13.

Table IV-13: Data collection methods adopted to monitor RPE in professional volleyball.

Study, year	Period	Duration	Objective measurements
Andrade et al., 2021	Pre + Comp	22 weeks	-
Berriel et al., 2022	Pre	10 weeks	-
Brandão et al., 2018	Pre + Comp	33 weeks	-
Clemente et al., 2020	Comp	36 weeks	-
Debien et al., 2018	Pre + Comp	36 weeks	-
Domingos et al., 2022	Pre	11 weeks	-
Duarte et al., 2019	Pre + Comp	35 weeks	-
Horta et al., 2019	Pre	6 weeks	-
Horta et al., 2020	Pre + Comp	19 weeks	-
Lima et al., 2020	Comp	15 weeks	IMU
Mendes et al., 2018	Pre + Comp	36 weeks	-
Rabbani et al., 2021	Transition	NR	-
Timoteo et al., 2021	Pre + Comp	27 weeks	-
Ungureanu et al., 2021	Comp	16 weeks	HR

Pre = preparatory period; Comp = competitive period; NR = not reported; IMU = inertial movement unit; HR = heart rate.

Characteristics and Variables of the RPE Questionnaires

All included studies used the BORG-CR10 scale to calculate the sRPE (Table IV-14). "How was your training session?" was the most used question (29%) [17-19,23], followed by "how was your workout?" (21%) [13,16,25]. Four studies (29%) did not report the question that was used [14,21,22,26]. Most studies included the weekly internal training load (wITL) to their results (79%) [13-23], while a few included derived variables such as training monotony

(21%) [15,16,21], strain (14%) [16,21], and the acute:chronic workload ratio (ACWR) (21%) [15,16,21].

Table IV-14: Operational question and variables adopted in studies monitoring RPE-derived training load in professional volleyball.

Study, year	RPE scale	Question	When was the question asked?	Daily-based variables	Weekly-based variables
Andrade et al., 2021	CR10	How was your TS?	30 min after	sRPE	wITL
Berriel et al., 2022	CR10	NR	15 min after	sRPE	wITL
Brandão et al., 2018	CR10	How was your TS?	30 min after	sRPE	wITL
Clemente et al., 2020	CR10	How hard was the TS?	30 min after	sRPE	wITL, monotony, ACWR
Debien et al., 2018	CR10	How was your workout?	30 min after	sRPE	wITL, monotony, strain, ACWR
Domingos et al., 2022	CR10	How was your TS?	30 min after	sRPE	wITL
Duarte et al., 2019	CR10	How was your TS?	30 min after	sRPE	wITL
Horta et al., 2019	CR10	How was your workout?	NR	sRPE	wITL
Horta et al., 2020	CR10	How did your training go?	30 min after	sRPE	wITL
Lima et al., 2020	CR10	How hard was the TS?	30 min after	sRPE	-
Mendes et al., 2018	CR10	NR	30 min after	sRPE	wITL
Rabbani et al., 2021	CR10	NR	30 min after	sRPE	-
Timoteo et al., 2021	CR10	NR	30 min after	sRPE	wITL, monotony, strain, ACWR
Ungureanu et al., 2021	CR10	How was your workout?	20 min after	sRPE	-

TS = training session; sRPE = session rating of perceived exertion; wITL = weekly internal training load; ACWR = acute:chronic workload ration.

4.3.5. Discussion

In the present study, the methods used to collect and interpret RPE-based ITL in professional volleyball were reviewed. Articles considered for inclusion in the review were those examining professional volleyball athletes and reporting RPE outcomes within, at least, one phase of the season (i.e., off-season, pre-season, or competitive period), which may reflect the use of RPE in practical settings. The findings of this systematic review provide the basis to establish a consensus regarding the practice adopted to collect and interpret RPE in volleyball.

Description and Quality of the Studies

The main deficiencies identified in the qualitative assessment concern the non-detailed description of estimates of the random variability in the data for the main outcomes. Moreover, all studies included had issues with their external validity. In order to reduce variations between subjects, the dataset should be organized as a whole [27] and, therefore, in this type of studies (i.e., longitudinal) the ITL data should be reported according with the total number of training sessions/matches. Only four studies [14-16,21] (29%) included match load in the ITL calculation, which represents an issue in the majority (i.e., 71%) of the studies since matchday represents the most demanding day of the week [15] and leaving it out of the analysis might skew the results. Besides that, the training prescription during the week can be supported by the matches' ITL.

Collection of RPE Data

Studies that reported results during the pre-season period showed that the loading pattern was defined by a progressive increase in the wITL between the first to the middle weeks of pre-season, followed by a recovery week. Afterwards, there was another peak in the ITL, followed by a progressive decline towards the end of the preseason [17,18,22,23]. However, in cases where the pre-season period is short it was observed that there was a progressive increase in the wITL without any recovery week in the middle of this phase [13]. This recovery week in the middle of the pre-season is often used to avoid unfavourable stress-recovery balance [28]. However, it can be observed that in every scenario (i.e., short vs long pre-season duration) it was implemented a taper in the last weeks to better prepare for the start of the competitive phase to regain the training stimuli. Also, during this period, aerobic fitness is negatively correlated with the load perceived during the weeks following the test in professional volleyball players [22]. This finding indicates that the assessment and development of the cardiorespiratory fitness can be important to allow volleyball players to better tolerate the training load and avoid excessive fatigue [29].

Studies that were conducted during the competitive period reported a wave distribution of the wITL [16,17,19]. Due to various travels made and games played against teams of different levels the number of training sessions reduce during the competitive period [30].

Therefore, this wave distribution of the training load can avoid a possible decrement in performance. This can be done by increasing training loads in weeks in which the team has a low possibility of winning or losing the game [30,31].

None of the studies included RPE collection in complementary training sessions (e.g., gym sessions). While, in the short term, this might not be that important, missing out this information in the accumulated ITL may bias some data, especially those related to spike variables, such as ACWR.

Characteristics and Variables of the RPE Questionnaires

According to this systematic review, the BORG-CR10 is the “gold standard” approach to collect RPE data in professional volleyball as every study included this scale within their methods. However, some inconsistencies have been observed in respect to RPE questions adopted, indicating the lack of a standard questionnaire. Only two studies reported the question “how hard was your training session?” [15,24]. This type of questions that include words like “hard” or “intense” is better targeted at what is intended for RPE [32] compared to most questions implemented in the included studies like “how was your training session/workout?” or “how did your training go?” [13,16-20,23,25]. Also, some problems exist in the fact that four studies did not report the question that was used to collect RPE data [14,21,22,26].

The use of sRPE is more preferred within the professional volleyball environment than the use of derived variables such as monotony, strain, and ACWR. Previous studies already showed that the TRIMP method fails in reflecting the demands of intermittent sports, the same way the mean of the heart rate in exercises of prolonged nature is impracticable and may not provide significant data, reinforcing the importance to use other methods to monitor ITL in sports like volleyball, such as the sRPE [33]. Nevertheless, since the relationship between the training session duration and the perceived exertion in volleyball was not yet investigated, practitioners should have caution when implementing the sRPE method after long training periods as athletes can adopt a pacing strategy to be fresh by the end of the session. On other hand, RPE data in short time sessions may be representative of the actual exercise intensity as opposed to objective measurements (e.g., distance covered, or number of jumps) [34] and should be used in volleyball high intensity practices.

It should also be noted that most studies (i.e., 79%) presented the RPE question to volleyball athletes 30 minutes after the training session was finished. This recommendation comes from the original concept of sRPE to prevent athletes' responses to be highly influenced by the last portion of the training practice [8]. However, this time delay required is often a limitation when working with high performance athletes as they are not always predisposed to wait that long to answer this question daily. Previous studies outside of volleyball have demonstrated that the sRPE is temporally robust, showing that there are almost no differences between answering the question 10 or 30 minutes after the training session finishes [35]. Although future research still needs to assess the effect of measurement timing on s-RPE in professional volleyball athletes, these previous results further support the practical usefulness of s-RPE to measure ITL in athletes.

Limitations and Recommendations for Future Research

Although the present study focused on RPE collection practices, other factors such as players' position, competitive schedule, and types of exercises performed might have an impact on perceptual responses of professional volleyball athletes. For instance, results from previous studies already shown that starters players presented greater ITL in comparison to nonstarters players in all periods of the season [36]. Also, during weeks were there is more than one game (i.e., congested weeks), volleyball players have a higher ITL compared to normal weeks with only one game [14,18]. Moreover, it is well reported that volleyball players from different positions have different external training load (ETL) responses (e.g., number of jumps, jumps' height) [37,38] and different perceptions of ITL across the competitive phase [25]. Therefore, in professional volleyball, players' RPE is dictated not only by match/schedule related factors but also by ETL and future reviews should have this into consideration.

Since the RPE represents the subjective perception of the effort from all organs, as well as the perception of fatigue and pain, it is sometimes insufficient to capture the whole range of exercise-related perceptual sensations, due to its generalization and oversimplification [39]. For this reason, previous studies already proposed the differentiation of muscular RPE and respiratory RPE [40,41]. However, no study in professional volleyball evaluated this localized RPE responses in these athletes and future studies should look in this direction. Also, only two studies included objective markers in their methods alongside the RPE collection [24,25]. Previous research showed that the sRPE method was correlated with several objective markers of training load. For instance, the velocity at lactate threshold and the velocity at onset of blood lactate threshold are strongly correlated to the sRPE method during soccer training sessions [42]. Plus, the number of impacts and the distance covered are also correlated to the sRPE method in rugby [43].

Research in volleyball shows promising results when using inertial movement unit technology (e.g., VERT) to monitor jumping metrics, such as jump height and jump count [24,38,44,45]. This method of monitoring ETL can be extremely useful since there are significant differences in competition and in training jump count, jump height and jump load between positions in female [44] and male volleyball athletes [37,38,46]. For example, outside hitters have the highest jump height followed by middle blockers and right-side hitters [44]. Female [44] and male [37,38] volleyball middle blockers showed a higher jump count and jump rate compared to outside hitters and right-side hitters. Therefore, future studies in professional volleyball should study the correlations between the sRPE method and different objective markers, such as jump count, jump height, number of accelerations, or number of high-speed runs. Finally, to the authors' knowledge, there is no study that collect RPE during the off-season period. This could prove to be of extreme importance, especially for the calculation of the ACWR during the first weeks of the pre-season which is often neglected since there is no previous data available for its calculation.

Among observational studies in professional volleyball, the use of RPE-based methods presents some inconsistencies. While most studies present the RPE question 30 minutes after the session is finished, the sRPE method appears to be temporally robust and, therefore, coaches can apply this method sooner if they wish to do so. Plus, in order, to evaluate the intensity of the training session, the question should be "how hard/intense was your session?", avoiding questions without these adverbs or adjectives such as "how was your training session/workout?" or "how did your training go?". Future studies should analyse the collection of the localized RPE responses in professional volleyball athletes and their relationships with objective markers such as number of jumps and accelerations. Finally, the off-season is a period that is being neglected in professional volleyball research and future studies should analyse this phase of the season so that coaches can have data from the start of the pre-season from their athletes.

4.3.6. Conclusions

This review offers a few practical implications for sports practitioners. Athletes should answer the question "how hard/intense was your session?", 10 to 30 minutes after finishing the training session, using the BORG-CR10 scale, to better target what is intended for RPE. Professionals should aim to evaluate the localized RPE responses of professional volleyball athletes, as the RPE alone is insufficient to capture the whole range of exercise-related perceptual sensations. Finally, due to the intermittent nature of professional volleyball, the sRPE method should be employed to monitor ITL over methods such as the TRIMP.

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4.4. Study IV – Training Stress, Neuromuscular Fatigue and Well-Being in Volleyball: A Systematic Review

Rebelo, A., Pereira, J. R., Cunha, P., Coelho-E-Silva, M. J., & Valente-Dos-Santos, J. (2024). Training stress, neuromuscular fatigue and well-being in volleyball: a systematic review. *BMC*

Sports Science, Medicine & Rehabilitation, *16*(1), 17. https://doi.org/10.1186/s13102-024-00807-7.

4.4.1. Abstract

Background: Volleyball, with its unique calendar structure, presents distinct challenges in training and competition scheduling. Like many team sports, volleyball features an unconventional schedule with brief off-season and pre-season phases, juxtaposed against an extensive in-season phase characterized by a high density of matches and training. This compact calendar necessitates careful management of training loads and recovery periods. The effectiveness of this management is a critical factor, influencing the overall performance and success of volleyball teams. In this review, we explore the associations between training stress measures, fatigue, and well-being assessments within this context, to better inform future research and practice. Methods: A systematic literature search was conducted in databases including PsycINFO, MEDLINE/PubMed, SPORTDiscus, Web of Science, and Scopus. Inclusion criteria were original research papers published in peer-reviewed journals involving volleyball athletes. Results: Of the 2535 studies identified, 31 were thoroughly analysed. From these 31 articles, 22 included professional athletes, seven included collegiate-level volleyball athletes, and two included young athletes. Nine studies had female volleyball players, while the remaining 22 had male volleyball athletes Conclusions: Internal training load should be collected daily after training sessions and matches with the session rating of perceived exertion method. External training load should also be measured daily according to the methods based on jump height, jump count, and kinetic energy. If force platforms are available, neuromuscular fatigue can be assessed weekly using the FT:CT ratio of a countermovement jump or, in cases where force platforms are not available, the average jump height can also be used. Finally, the Hooper Index has been shown to be a measure of overall wellness, fatigue, stress, muscle soreness, mood, and sleep quality in volleyball when used daily.

Key Words: team sports; wellbeing; health; performance analysis; time motion analysis.

4.4.2. Introduction

Monitoring athletes has become an important and present part of sport preparation. The scientific study of quantifying athletes' training began in the early 1990s with the four methods that were most used at the time: retrospective questionnaires, diaries, physiological monitoring and direct observation [1]. Nowadays, there is a plethora of athletic monitoring methods and technologies, varying from the simplest and cheapest, such as diaries [1], to the most complicated and expensive ones, such as the global positioning system (GPS) [2].

Frequently monitoring the variables related to performance can help coaches to assess the effectiveness of their training programs and update those to better meet the athletes' needs. Besides, another reason to frequently monitor athletes is to reduce the time lost to illness [3] and injury [4,5]. By monitoring the weekly training loads, coaches can make better decisions about the changes in the program to ensure that athletes are not exceeding thresholds that put them in higher risk of injury [6] and illness [7]. Furthermore, monitoring the recovery response after a training session or a competitive match can aid practitioners to balance the adaptation process and recovery. This is particularly important to understand the beginning of the period characterized by a decrease in performance in reaction to high loads (i.e., functional overreaching) [8]. Failing to monitor this response can lead to unplanned fatigue followed by a period of inadequate recovery, phenomenon designed by nonfunctional overreaching [9]. This continuum of unplanned fatigue can result in a syndrome defined by overtraining, in which large decrements in performance occur that are associated to psychological disturbances that can last for months [10].

The particularities of the variables mentioned before alongside with the complexity of the majority of team-sports calendar (e.g., short preparation periods and weeks with high volumes of matches and training sessions) can make the training process hard to monitor and prescribe [11]. The management of the balance between training loads and recovery significantly influences a team's overall fitness, which, in turn, plays a crucial role in their competitive success [4]. One of the team-sports that has a voluminous competitive calendar is professional volleyball. Volleyball is a sport characterized by a diverse range of physical demands, necessitating well-developed energy systems [12,13]. These include the phosphagen system, which provides immediate energy for high-intensity, short-duration activities like quick sprints or jumps; glycolysis, which predominates in moderate to high-intensity activities lasting from a few seconds up to a minute, contributing to sustained efforts during longer rallies; and the oxidative system, which supports prolonged, lower-intensity activities, crucial for endurance over the course of a match. The effective interplay of these energy systems is essential for optimal performance in volleyball, as players frequently transition between activities of varying intensity and duration [14,15].

Prior research in the field of volleyball has explored various aspects of athletic performance [12] and recovery [16,17]. Studies have examined internal and external training loads, investigating how these variables influence players' physiological responses and performance outcomes [18,19]. Key findings have indicated the importance of monitoring training intensity and volume to optimize player readiness and prevent overtraining [18]. Additionally, research has highlighted the role of neuromuscular fatigue assessments and well-being measures in understanding athletes' responses to training and competition demands [18,20]. In the realm of these neuromuscular assessments, the vertical jump emerges as a particularly crucial measure in volleyball. This is because the act of jumping is central to key actions such as serving, blocking, and attacking [12]. The vertical jump, therefore, is not just a frequent movement in volleyball but also a critical skill that significantly influences a team's performance and success. It underscores the importance of precisely monitoring and optimizing training loads, as these directly impact an athlete's ability to perform these jumps effectively and consistently. Despite these advancements, there remains a gap in the systematic synthesis of this literature, particularly in integrating these diverse findings to inform monitoring strategies in volleyball. This gap underscores the need for the current systematic review, aiming to consolidate existing knowledge and identify directions for future research.

Moreover, previous research has shown the importance of conducting systematic reviews about training/match monitoring with increasing attention given to the consensus as to which variables related to training load, fatigue, and well-being are most useful [21]. Therefore, the aim of this systematic review was to examine the extent, range, and nature of the evidence on the associations between training load measures, fatigue and well-being assessments used in volleyball training/match monitoring literature to aid the planning of future research.

4.4.3. Methods

Registration and Protocol

This systematic review was conducted in accordance with the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 [22]. The study protocol was registered with INPLASY (INPLASY202270059). A PRISMA checklist is provided in Appendix IV.

Eligibility Criteria

Inclusion criteria for this systematic review were as follows: (1) original research papers published in peer-reviewed journals in English, French, Spanish, or Portuguese; (2) subjects were volleyball athletes, with no restrictions on age, thereby including youth, collegiate, and adult players; (3) the study involved at least two evaluation points, encompassing a baseline and a post-intervention measurement. The exclusion criteria were: (a) studies not involving human subjects; (b) research not specifically focused on volleyball training or competition; (c) studies lacking empirical data or not presenting clear methodological descriptions. These criteria were designed to ensure an analysis across various age groups and both male and female athletes, providing a holistic understanding of volleyball training and performance.

Information Sources

The literature search was performed from database inception to March 2023 (date when the search was last conducted) in five electronic databases: PsycINFO, MEDLINE/PubMed, SPORTDiscus, Web of Science, and Scopus. The search was developed to consider research articles published online.

Search Strategy

Scientific peer-reviewed published papers written in English, Portuguese, French, and Spanish were eligible for the present systematic review. The search strategy was developed around keywords for Population (volleyball athletes), Exposure (volleyball training or matches), Country (all), and study type (longitudinal). Included terms for the searches were: ‘training load volleyball’, ‘workload volleyball’, ‘rating of perceived exertion volleyball’, ‘RPE volleyball’, ‘well-being volleyball’, ‘wellness volleyball’, ‘fatigue volleyball’, ‘sleep volleyball’, ‘training response volleyball’, ‘neuromuscular fatigue volleyball’, and ‘neuromuscular status volleyball’. The complete search strategy is available in Appendix IV.

Table IV-15: Search strategy.

Variable	Search terms
Training load	AB OR SU (“training load” OR “training impulse” OR TRIMP OR “external load” OR “internal load” OR duration OR exposure OR RPE OR “rating of perceived exertion” OR summated-heart-rate-zone OR SHRZ OR PlayerLoad OR BodyLoad OR “global positioning system” OR GPS OR accelerometer)
Neuromuscular fatigue	AB OR SU (“neuromuscular fatigue” OR “neuromuscular function” OR “neuromuscular performance” OR “neuromuscular power” OR fatigue OR fatiguing OR fatigability)
Well-being	AB OR SU (wellbeing OR well-being OR “well being” OR wellness OR health OR psychological OR “mental state*” OR “state of mind” OR affect OR affective OR affects OR mood* OR emotion* OR anxiety OR confidence OR self-esteem OR self-efficacy OR motivation OR depression OR stress OR tension OR feeling* OR “physical state” OR “physical functioning” OR “perceived recovery” OR “perceived strength” OR soreness OR “quality of life” OR readiness OR vitality OR vigor OR vigour OR sleepiness OR “sleep quality” OR fatigue OR tiredness OR alertness OR distress OR “social function” OR appetite OR overtrain* OR overreach*)
Volleyball	AB OR SU (volleyballer* OR “volleyball player*” OR “volleyball athlete*”)
Final search	training load OR neuromuscular fatigue OR well-being AND volleyball

AB = abstract; SU = subject; * = truncation; “ ” = phrase search.

Selection and Data Collection Process

All retrieved papers were exported to CADIMA software, a tool designed to increase the efficiency of the evidence synthesis process and facilitate reporting of all activities to maximize methodological rigor [23]. Duplicates were automatically removed. Titles and abstracts of potentially relevant papers were screened by two reviewers (A.R. and J.R.P.). Disagreements between authors were solved through discussion and, when necessary, the remaining authors (P.C., M.J.C-S. and J.V-S.) were involved. Full-text copies were acquired for all papers that met title and abstract screening criteria. Full-text screening was performed by two reviewers (A.R. and J.R.P.). Again, any discrepancies were discussed until the authors reached an agreement and consulted the four other authors when required. In the process of article selection, inter-rater reliability was quantitatively assessed using the Cohen kappa coefficient. For the initial title and abstract screening, the kappa coefficient was 0.810. Similarly, for the full-text review phase, the kappa coefficient was 0.979.

Data Extraction

Data were extracted from each article by the lead author (A.R.). Data not provided or presented non-numerically were identified as “not reported”. The following data, when possible, were extracted from each article: (1) participants’ characteristics (sample size, sex and age); (2) participants’ level (young, collegiate or professional); (3) monitoring period (i.e., seasonal phase(s) and duration); (4) training load measures (e.g., RPE, heart rate, time motion analysis); (5) neuromuscular fatigue tests (e.g., heart rate, biochemical markers); (6) well-being assessment methods (e.g., scale, questionnaire).

Risk of Bias Assessment

Methodological quality was assessed using a modified version of the Downs and Black [24] checklist for assessing the methodological quality of randomized and nonrandomized healthcare interventions. This checklist has been validated for use with observational study designs [24] and has been previously used to assess methodological quality in systematic reviews assessing cross-sectional and longitudinal studies [25,26]. The number of items from the original checklist can be tailored to the scope and needs of the systematic review, with 10–15 items used in previous systematic reviews [25,26]. For this review, 11 items in the checklist were deemed relevant (Table S3). Each item is scored as “1” (yes) or “0” (no/unable to determine), and the scores for each of the 11 items are summed to provide the total quality score. The quality of each included article was rated against the checklist independently by two authors (A.R. and J.R.P.). Any disparity in the outcome of the quality appraisal was discussed, and a third author (J.V-S.) was consulted if a decision could not be reached. In the assessment of methodological quality and risk of bias, inter-rater reliability was quantitatively evaluated using the Cohen kappa coefficient. The kappa value obtained was 0.903.

Data Synthesis

Results were not pooled as the studies were heterogeneous in their methods, data, and context. Instead, we presented a narrative synthesis of the findings from included studies. We identified three categories of monitoring interventions through the process of reviewing the included studies. The definitions of these interventions are provided in Appendix IV. Summary tables were provided as means and standard deviations were reported for age of participants, body mass, and body height. The period of each study (i.e., pre-season, competitive period, or both) and the duration of the study, in weeks, were also reported.

4.4.4. Results

Study Selection

The electronic search yielded 2535 articles (PsycINFO = 121, PubMed = 411, SPORTDiscus = 661, Scopus = 731, Web of Science = 611). A total of 868 duplicate records were removed, and a further 1570 irrelevant articles were excluded based on title and abstract; 97 fulltext articles were screened and 66 were removed, leaving 31 articles for inclusion in the review. Reasons for exclusion were: study designs did not meet the inclusion criteria (n = 33), no volleyball players in the sample (n = 20), failure to perform any monitoring strategy (n = 7), and duplicate dataset (n = 6). The full results of the search are presented in Figure IV-7.

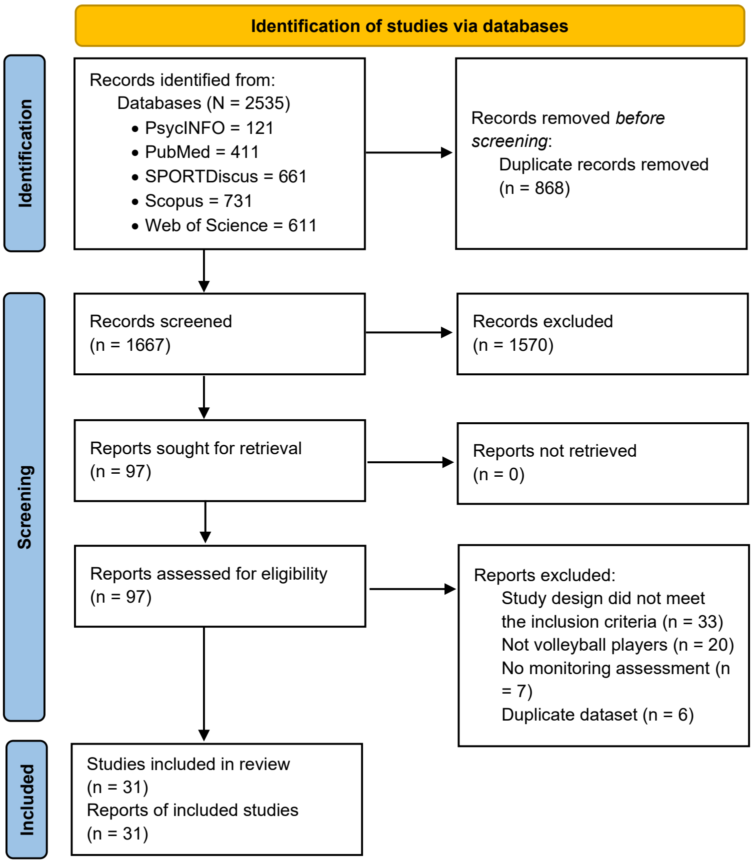

Figure IV-7: PRISMA flow diagram.

Risk of Bias in Studies

The ratings from the quality appraisal for each article are presented in Appendix IV. Methodological quality scores ranged from 7 to 9 out of 11. The predominant concerns identified in the evaluation of these studies centre around issues of external validity, particularly the representativeness of the study participants. This limitation significantly hampers the generalizability of the findings. The studies fall short in ensuring that the subjects included are reflective of the broader population from which they are drawn, raising questions about the applicability of their conclusions beyond the specific sample studied. In line with previous literature using the Downs and Black checklist [25,26], no articles were excluded based on methodological quality.

Study Characteristics

Study characteristics for all 31 included studies are presented [16-18,27-54] (Table IV-6). From these 31 articles, 22 included professional athletes [16-18,28,30-32,34-36,38-

43,46,48,50-53], seven were collegiate-level volleyball athletes [27,29,33,37,44,45,47], and two included young athletes [49,54]. Nine articles used female volleyball players [27-29,32,33,37,44,45,47], while the remaining 22 were male volleyball athletes [16-18,30,31,34-36,38-43,46,48-54].

Table IV-16: Characteristics of the included studies.

Author, year	N	Level	M/F	Age (years)	Duration
Rebelo et al, 2023 [18]	15	Professional	M	28.51 ± 5.39	5 weeks
Herring and Fukuda, 2022 [27]	9 (5 across both seasons)	Collegiate	F	NR	2 seasons
Berriel et al, 2022 [30]	16	Professional	M	23.60 ± 4.93	Pre-season
Rabbani et al, 2021 [28]	13	Professional	F	25.8 ± 3.0	4 training camps (≈1 month)
Haraldsdottir et al, 2021 [29]	17	Collegiate	F	19.6 ± 1	1 season
Andrade et al, 2021 [31]	15	Professional	M	24 ± 4	1 season
Timoteo et al, 2021 [17]	14	Professional	M	26.7 ± 5.5	1 season
Ungureanu et al, 2021 [32]	12	Professional	F	22 ± 4	1 season
Kupperman et al, 2021 [33]	11	Collegiate	F	19.36 ± 1.27	1 season
Berriel et al, 2020 [34]	13	Professional	M	23.80 ± 5.40	Pre-season
Horta et al, 2020 [35]	9	Professional	M	26.4 ± 4.0	1 season
García-de-Alcaraz et al, 2020 [36]	11	Professional	M	28.0 ± 6.12	1 season
Roy et al, 2020 [37]	15	Collegiate	F	NR	1/2 season
Clemente et al, 2020 [38]	13	Professional	M	31.0 ± 5.0	1 season
Lima et al, 2020 [39]	8	Professional	M	23.0 ± 5.22	15 weeks
Duarte et al, 2019 [40]	14	Professional	M	24.0 ± 3.59	1 season
Clemente et al, 2019 [41]	13	Professional	M	31.0 ± 5.0	1 season
Horta et al, 2019 [42]	12	Professional	M	26.9 ± 4.6	Pre-season
Silva et al, 2019 [43]	8	Professional	M	23.0 ± 0.2	1 season
Roy et al, 2019 [44]	15	Collegiate	F	NR	1/2 season

Hyatt and Kavazis, 2019 [45]	8	Collegiate	F	NR	1 season
Skazalski et al, 2018 [46]	14	Professional	M	NR	1 season
Castello et al, 2018 [47]	10	Collegiate	F	19.80 ± 1.23	8 weeks
Mendes et al, 2018 [48]	13	Professional	M	31 ± 5.0	1 season
Tavares et al, 2018 [49]	13	Young	M	18 ± 1	1 week
Debien et al, 2018 [50]	15	Professional	M	24.0 ± 3.6	1 season
Brandão et al, 2018 [51]	14	Professional	M	26.7 ± 5.5	1 season
Nogueira et al, 2017 [52]	12	Professional	M	23.50 ± 3.39	1 season
Horta et al, 2017 [53]	15	Professional	M	G1: 25.9 ± 3.8 G2: 23.1 ± 3.1	10 weeks (without matches)
Timoteo et al, 2017 [16]	12	Professional	M	26.7 ± 5.5	1 week (5 matches)
de Freitas et al, 2015 [54]	7	Young	M	15.8 ± 0.5	Pre-season

F = female; M = male; NR = not reported; G1 = group 1; G2 = group 2.

Quantifying Training Stress in Volleyball Athletes

Quantifying training stress can be done in different ways. The most common one can be achieved by multiplying the training session intensity by the training session duration. Training load can be either internal or external [55]. Internal training load refers to the physiological stress that a training session induces in the athlete [55]. Measures such as heart rate (HR) and rating of perceived exertion (RPE) are the most common methods to monitor internal load [2]. On other hand, external training load is defined as the physical work prescribed in the training plan [55]. The most common method of monitoring external load is with time-motion analysis devices, such as GPS, accelerometers, or inertial motion units (IMUs) [2].

The effects of different training loads measurements have been investigated in volleyball with durations ranging from one week [16,49] to two seasons [27] (Table IV-17). Moreover, the effects of single training load measurement (i.e., internal, or external) [16,17,27,28,30-32,35-38,40-42,44,46-51,53,54] or a combination of both training load measurements [18,33,39,43] have been investigated. The session rating of perceived exertion (sRPE) (77%) [16-18,28,30-33,35,37-44,47-51,53,54] and the IMUs (16%) [18,27,39,43,46] are the most commonly used training load measurement strategies in volleyball. Other training load measures investigated in the volleyball literature include HR [32], accelerometers [33], and video-cameras [36].

Table IV-17: Training stress monitoring strategies and protocols in the volleyball literature.

Author, year	Training stress measurements	Methodology	Results
Rebelo et al, 2023 [18]	Internal load - sRPE External load - IMU (jump metrics)	Jumping metrics and sRPE of each training session	wITL (range): 1229.00 ± 247.74 to 2188.13 ± 693.36 wETL (range): 11,144.92 ± 3648.12 kJ to 18,328.99 ± 8358.20 kJ
Herring and Fukuda, 2022 [27]	External load - IMU (jump metrics)	53 matches across 2 seasons.	MB - HT: 47.4 ± 5.4; OJC: 89.2 ± 30.7; OJR = 0.95 ± 0.21 OH - HT: 51.9 ± 2.2; OJC: 72.8 ± 22.8; OJR = 0.77 ± 0.13 RSH - HT: 45.4 ± 11.4; OJC: 50.3 ± 22.1; OJR = 0.57 ± 0.19
Berriel et al, 2022 [30]	Internal load - sRPE	sRPE of each training session	wITL (range): 1388 ± 111 to 3852 ± 149
Rabbani et al, 2021 [28]	Internal load - sRPE	sRPE of each training session	sRPE (range): 1052 ± 163 to 1105 ± 121
Andrade et al, 2021 [31]	Internal load - sRPE	sRPE of each training session	PS - TWTL: 3,512.84 ± 876.48 CPI - TWTL: 2,843.93 ± 1,026.14 CPII - TWTL: 2,696.40 ± 933.51
Timoteo et al, 2021 [17]	Internal load - sRPE	sRPE of each training session	PS - TWTL: 3,492.75 ± 2,320.68 CP - TWTL: 3,207.02 ± 2,423.04
Ungureanu et al, 2021 [32]	Internal load - sRPE, HR	HR and sRPE of each training session	MB - sRPE: 534; EHR: 207 OH - sRPE: 402; EHR: 172 RSH - sRPE: 463; EHR: 206 L - sRPE: 313; EHR: 180 SE - sRPE: 351; EHR: 233
Kupperman et al, 2021 [33]	Internal load - sRPE External load - accelerometer (jump metrics, COD, accelerations)	sRPE and accelerometer in each training session and game	Training sessions: OJC: 90.9 ± 51.2; COD: 247.5 ± 121.7; ACC: 93.6 ± 46.9; DEC: 94.8 ± 52.9 Games: OJC: 81.1 ± 49.8; COD: 229.4 ± 124.8; ACC: 85.2 ± 47.2; DEC: 66.0 ± 39.7
Horta et al, 2020 [35]	Internal load - sRPE	sRPE of each training session	PS - TWTL: 3,228.44 ± 521.96 CPI - TWTL: 3,369.44 ± 605.33 CPII - TWTL: 2,973.22 ± 727.23
García-de-Alcaraz et al, 2020 [36]	External load - camera (jump count)	each training session	MB - OJC: 41,432 OH - OJC: 40,694 RSH - OJC: 22,997 SE - OJC: 13,226
Roy et al, 2020 [37]	Internal load - sRPE	sRPE of each training session and game	sRPE: 566 ± 260

Clemente et al, 2020 [38]	Internal load - sRPE	sRPE of each training session and game	CPI - ACWR: 1.10 ± 0.13; M: 4.28 ± 1.23 CPII - ACWR: 1.66 ± 0.15; M: 3.39 ± 0.69
Lima et al, 2020 [39]	Internal load - sRPE External load - IMU (jump metrics)	Jumping metrics and sRPE of each training session	sRPE and OJC was higher in MD-2 and MD-3 than in MD-1.
Duarte et al, 2019 [40]	Internal load - sRPE	sRPE of each training session and game	CPI - TWTL: 4,546.0 ± 620.9 CPII - TWTL: 4,006.6 ± 687.6
Clemente et al, 2019 [41]	Internal load - sRPE	sRPE of each training session and game	CPI > TWTL > CPII
Horta et al, 2019 [42]	Internal load - sRPE	sRPE of each training session	The TWTL increased progressively from Week 2 to Week 6
Silva et al, 2019 [43]	Internal load - sRPE External load - IMU (jump metrics)	Jumping metrics and sRPE of each training session	sRPE: MD-1: 462.04 ± 330.05; MD-2: 586.68 ± 365.66; MD-3: 477.44 ± 267.34; MD-4: 466.68 ± 295.71; MD-5: 430.21 ± 215.77 OJC: MD-1: 106.40 ± 42.77; MD-2: 143.10 ± 60.11; MD-3: 120.31 ± 46.58; MD-4: 118.87 ± 68.61; MD-5: 106.56 ± 35.65
Roy et al, 2019 [44]	Internal load - sRPE	sRPE of each training session	sRPE: 566 ± 260
Skazalski et al, 2018 [46]	External load - IMU (jump metrics)	Jumping metrics each training session and game	MB - OJC: 92 OH - OJC: 62 RSH - OJC: 75 SE - OJC: 121
Castello et al, 2018 [47]	Internal load - sRPE	sRPE of each training session	wITL: 2484.32
Mendes et al, 2018 [48]	Internal load - sRPE	sRPE of each training session	Preparatory weeks: training load had an undulating distribution during the week; regular and congested weeks: training load was higher at the beginning of the week
Tavares et al, 2018 [49]	Internal load - sRPE	sRPE of each training session	sRPE had an undulating distribution during the week
Debien et al, 2018 [50]	Internal load - sRPE	sRPE of each training session and game	PS - TWTL: 3,748 ± 472 CPI - TWTL: 2,858 ± 472 CPII - TWTL: 3,728 ± 650
Brandão et al, 2018 [51]	Internal load - sRPE	sRPE of each training session	Preparatory weeks: training load had an undulating distribution during the week; regular and congested weeks: training load was higher at the beginning of the week
Horta et al, 2017 [53]	Internal load - sRPE	sRPE of each training session	First team players > TWTL > reserve players
Timoteo et al, 2017 [16]	Internal load - sRPE	sRPE of each training session and game	sRPE: Day 2 > Day 1 > Day 6 > Day 3 > Day 5 > Day 4
de Freitas et al, 2015 [54]	Internal load - sRPE	sRPE of each training session	Week 1 - TWTL: 1,922 ± 654 Week 2 - TWTL: 1,530 ± 691 Week 3 - TWTL: 1,874 ± 528 Week 4 - TWTL: 1,568 ± 312

COD = change of direction; CP = competitive period; CPI = competitive period I; CPII = competitive period II; EHR = Edwards Heart Rate; HT = mean jump height from all jumps (cm); IMU = inertial motion unit; L = libero; M = monotony; MB = middle blocker; OH = outside hitter; OJC = overall jump count; OJR = overall jump rate (jumps/min); PS = pre-season; RSH = right-side hitter; SE = setter; TWTL = total weekly training load (arbitrary units); sRPE = session rating of perceived exertion; wITL = weekly internal training load (arbitrary units).

Quantifying Fitness and Fatigue in Volleyball Athletes

The reduction in maximal voluntary contractile force is designated by neuromuscular fatigue and tests to detect this type of fatigue are broadly used in sport [2]. Low-frequency fatigue (i.e., resulted from high-force, high-intensity, or repeated stretch-shortening cycles muscle actions) is frequently a topic of interest while monitoring athletes [56]. Consequently, many research studies have established the reliability and validity of vertical jumps as an indicator of neuromuscular fatigue in athletes [57]. One of the most valid measures of fatigue is the ratio of flight time to contraction time (FT:CT), which can be explained by the fact that time-related variables are more sensitive to fatigue [58]. Nevertheless, other measures such as jump height, peak and mean power, and peak force are also popular among coaches [59].

In addition to being used to monitor training stress, submaximal exercise protocols and physiological markers such as HR can be used as objective markers of fatigue. Heart rate variability (HRV) is widely used, in particular the natural logarithm of the square root of the mean sum of squared differences between adjacent normal RR intervals (Ln rMSSD) [60]. Another monitoring tool that can be used is the recovery period after a training session, indicated with the heart rate recovery (HRR) [61]. Finally, examining hormonal and biochemical markers can provide a good indicator of athletes' adaptation process [62].

Only five studies included fitness and fatigue measurements as tools to monitor volleyball athletes [18,28,34,42,49]. (Table IV-18). The countermovement jump (CMJ) is the most used fatigue measurement strategy in volleyball [18,28,42,49]. Other fitness and fatigue monitoring tools are hormonal and biochemical markers [34,42] and HR variables [28].

Table IV-18: Fitness and fatigue monitoring strategies and protocols in the volleyball literature.

Author, year	Fitness and fatigue measurements	Design	Results
Rebelo et al, 2023 [18]	Fatigue - CMJ	3 maximal attempts of the CMJ on Matchday -1	CMJ (range): 44.46 ± 6.09 to 47.24 ± 7.21

Rabbani et al, 2021 [28]	Fatigue - CMJ, HR	3 maximal attempts of the CMJ and a submaximal running test at the beginning of the first training session for each camp; Ln rMSSD after waking up (supine and seated)	CMJ (range): 32.1 ± 3.5 to 35.1 ± 4.1 HRex (range): 148.0 ± 8.6 to 156.8 ± 7.6 HRR (range): 37.9 ± 9.8 to 41.7 ± 15.3
Berriel et al, 2020 [34]	Biochemical markers - CK	6 times in different weeks of the 16 studied	CK increased after the first weeks of training and remained stable until the beginning of the pre-competitive period, at which time they dropped significantly
Horta et al, 2019 [42]	Fatigue - CMJ Biochemical markers - CK, T, Cr	CMJ and blood samples 4 times each 14 days	CMJ: M1: 46.92 ± 5.75; M2: 45.55 ± 6.16; M3: 46.91 ± 5.95; M4: 46.94 ± 5.92 T: M1: 511 ± 100; M2: 559 ± 122; M3: 487 ± 117; M4: 549 ± 61 Cr: M1: 17.3 ± 7.1; M2: 15.5 ± 6.1; M3: 14.2 ± 3.6; M4: 13.8 ± 3.8
Tavares et al, 2018 [49]	Fatigue - CMJ	Days 1, 2, 4 and 5	CMJ height decreased during the week

CK = creatine kinase; CMJ = countermovement jump (cm); Cr = cortisol (ng.dL-1); HRR = heart rate recovery (b/min); HRex = submaximal exercise heart rate (b/min); Ln rMSSD = natural logarithm of the square root of the mean sum of squared differences between adjacent normal RR intervals; M1 = moment one; M2 = moment two; M3 = moment three; M4 = moment four; T = testosterone (ng.dL-1).

Quantifying Well-Being in Volleyball Athletes

Questionnaires can be useful to monitor athletes' levels of stress [1] and identify those at greater risk of becoming injured [63]. Research has shown that athletes often have a mood disturbance while developing symptoms of overreaching and overtraining [2]. Therefore, assessing athlete's mood state and level of tension through tools such as the Profile of Mood States (POMS) and the Brunel Mood Scale (BRUMS) can be useful [64]. Wellness inventories, like the Hooper index [65], are also common if the goal is to gather as much information as possible about different metrics, such as fatigue, stress, sleep, or recovery.

The current literature search returned 22 studies that applied some form of well-being questionnaire [16-18,28,29,31-35,38,40-42,44,45,48-52,54] (Table IV-19). The Hooper index

[16,28,32,38,41,44,48], the Total Quality Recovery (TQR) scale [16,17,31,35,40,50,51], and general wellness questionnaires [18,29,33,40,49,51,52] are the most commonly used well-being measurement strategies in volleyball. Other well-being measuring tools investigated in the volleyball literature include the Recovery Stress Questionnaire for Athletes (RESTQ-Sport) [34,42,54] and the POMS [35].

Table IV-19: Well-being monitoring strategies and protocols in the volleyball literature.

Author, year	Well-being measurements	Results
Rebelo et al, 2023 [18]	Well-being - Questionnaire	No differences observed in most wellness items measured during the 5 weeks
Rabbani et al, 2021 [28]	Well-being - Hooper's index	2.19 ± 0.35 to 2.24 ± 0.30
Haraldsdottir et al, 2021 [29]	Well-being - Questionnaire	7.9 ± 1.2
Andrade et al, 2021 [31]	Recovery - TQR Scale	PS - TQR: 14.27 ± 1.50 CPI - TQR: 15.26 ± 1.43 CPII - TQR: 15.06 ± 1.47
Timoteo et al, 2021 [17]	Recovery - TQR Scale	No injured players - 16.67 ± 6.09 Injured players (overuse) - 15.26 ± 2.66 Injured players (trauma) - 14.63 ± 2.20
Ungureanu et al, 2021 [32]	Well-being - Hooper's index	MB - 15.9 OH - 13.8 RSH - 15.3 L - 15.6 SE - 15.0
Kupperman et al, 2021 [33]	Well-being - Questionnaire	F: 2.1 ± 0.9 M: 1.7 ± 0.9 S: 2.1 ± 1.1 SO: 1.9 ± 0.9
Berriel et al, 2020 [34]	Well-being - RESTQ-Sport	M1: 169.01 ± 94.42; M2: 673.92 ± 461.45; M3: 520.77 ± 348.87; M4: 631.76 ± 579.30; M5: 270.78 ± 245.37; M6: 330.23 ± 206.98
Horta et al, 2020 [35]	Well-being - POMS Recovery - TQR Scale	PS - V: 20.62 ± 3.96; F: 11.82 ± 2.76; TQR: 14.95 ± 0.79 CPI - V: 18.31 ± 4.62; F: 12.89 ± 2.73; TQR: 15.33 ± 0.94 CPII - V: 18.76 ± 3.74; F: 8.65 ± 2.65; TQR: 15.74 ± 1.01
Clemente et al, 2020 [38]	Well-being - Hooper's index	CPI - Weekly index: 61.82 ± 11.57 CPII - Weekly index: 54.46 ± 16.68
Duarte et al, 2019 [40]	Well-being - Questionnaire Recovery - TQR Scale	CPI - TQR: 16.7 ± 1.1 CPII - TQR: 15.9 ± 1.1
Clemente et al, 2019 [41]	Well-being - Hooper's index	CPI > index > CPII
Horta et al, 2019 [42]	Well-being - RESTQ-Sport	The General Well-being value was lower at Weeks 2 and 6 than at baseline. The Injury at Week 4 was larger than that at baseline.

Roy et al, 2019 [44]	Well-being - Hooper's index	10.3 ± 3.5
Hyatt and Kavazis, 2019 [45]	Stress scale	Perceived stress peaked during the mid-season
Mendes et al, 2018 [48]	Well-being - Hooper's index	Regular weeks: best index score MD; congested weeks: index disrupted several days of the week
Tavares et al, 2018 [49]	Well-being - Questionnaire Muscle soreness - Questionnaire	Decrease in wellness scores and increase in fatigue and soreness during the week
Debien et al, 2018 [50]	Recovery - TQR Scale	PS - TQR: 15.63 ± 0.80 CPI - TQR: 15.02 ± 1.03 CPII - TQR: 14.75 ± 0.79
Brandão et al, 2018 [51]	Well-being - Questionnaire Recovery - TQR Scale	Regular weeks - TQR: 15.61 ± 0.33 Congested weeks - TQR: 15.58 ± 0.57
Nogueira et al, 2017 [52]	Well-being - Questionnaire	Decrease in wellness scores and increase in fatigue and soreness during the week
Timoteo et al, 2017 [16]	Well-being - Hooper's index Recovery - TQR Scale	Hooper: Day 1 > Day 2 > Day 5 > Day 3 > Day 6 > Day 4 TQR: Day 1 > Day 2 > Day 6 > Day 5 > Day 4 > Day 3
de Freitas et al, 2015 [54]	Well-being - RESTQ-Sport	Higher fatigue and injury scores during the pre-season period

All data are in arbitrary units. CPI = competitive period I; CPII = competitive period II; F = fatigue; M = mood; PS = pre-season; RESTQ-Sport = Recovery Stress Questionnaire for Athletes; S = stress; SD = sleep duration; SO = soreness; SQ = sleep quality; TQR = total quality recovery scale; V = vigor.

4.4.5. Discussion

Literature that has evaluated the effect of all monitoring strategies (i.e., training stress, fitness and fatigue, and well-being) during volleyball training and/or competition is limited. Besides, there is a small number of studies describing the external training load when compared with the internal training load. Furthermore, not only fitness and fatigue monitoring studies are limited, but also have questionable methodologies within volleyball athletes. A sample monitoring system for volleyball is suggested in Figure IV-8.

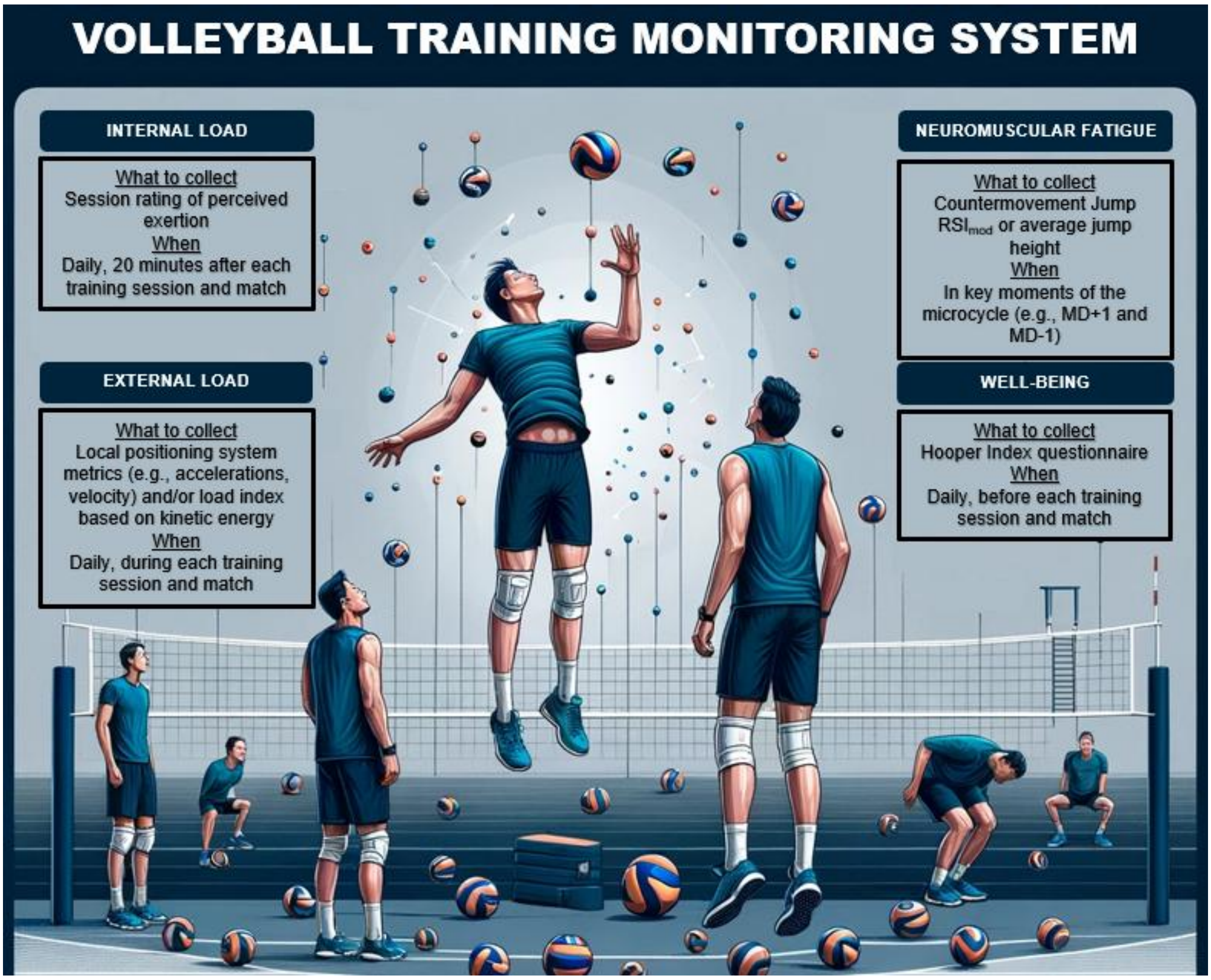

Figure IV-8: General recommendations for assessing the training load, neuromuscular fatigue, and well-being of volleyball players.

Training Stress in Volleyball

Seven studies analysed the internal load of volleyball players during the pre-season with the sRPE [17,30,31,41,42,50,54]. During the first weeks of pre-season the internal load of the players is defined by a progressive increase characterized by a decrease in performance [30,31,42]. This can also be seen with external training load measures, as jump load is higher during the first phase of pre-season [36]. To better prepare athletes for the start of the competition phase, this periodization approach is common in team-sports during the pre-season [54,66]. Coaches are advised to introduce the load progressively and, in the middle of the pre-season period, decrease the training loads to allow recovery and better balance the fitness-fatigue relationship [67]. In fact, elevated injury rates have been observed during this period in other sports [68]. This is in line with what is reported in volleyball's literature, as weekly workloads, acute-chronic workload ratio (ACWR), and incidence of injury values are higher during the pre-season period [17,50]. Coaches and practitioners should evaluate athletes' fitness in the beginning of the pre-season period and assess what were the workloads that players were familiarized during the off-season so that weekly internal training load peaks do not occur.

Sixteen studies analysed the internal training load of volleyball athletes during the competitive period with the sRPE method [17,18,31-33,35,37-41,43,44,48,50,51]. It can be observed that volleyball periodization is characterized by a wave distribution of the training load during this period [31,35,37,40,48,50]. This is distinctive of sports in which the pre-season period is short compared to the competitive period with the objective to adapt the stress applied during training sessions [11]. Due to various travels made and games played against teams of different levels the number of training sessions reduce during the competitive period [66]. Therefore, this wave distribution of the training load can avoid a possible decrement in performance. This can be done by increasing training loads in weeks in which the team has a low possibility of winning or losing the game [11,66]. In a more in-depth analysis, results of the literature indicate that during the first phase of the competitive period, volleyball athletes experience higher internal loads compared to the second phase of the same period [31,35,38,40,41]. The first phase of the competitive period of volleyball professional season is characterized by a focus on the development of fitness components while the second phase comprises the most specific training sessions (technical and tactical skills) [11]. Thus, this can explain these differences in internal load levels observed during the competitive period. Moreover, while looking into a single week, it can be observed that higher sRPE values are recorded during the middle of the week and lower values at the end of the week [39,43,48]. This is a common strategy to optimize the adaptation process in team sports by augmenting athletes' recovery status by reducing training loads [11].

There are significant differences in competition and in training jump count, jump height and jump load between positions in female [27] and male volleyball athletes [33,36,46]. Outside hitters had the highest jump height followed by middle blockers and right-side hitters [27]. Female [27] and male [36,46] volleyball middle blockers showed a higher jump count and jump rate compared to outside hitters and right-side hitters. This is in line with another study with female volleyball athletes that reported that middle blockers experienced both a higher HR-method internal training load and sRPE than the rest of the players [32]. Middle blockers are often required to be involved in every defensive blocking aspect of the game [69], hence their higher values of both external and internal training load. Nevertheless, HR measures of internal training load should be interpreted with caution. While the HR represents a valid means through which to measure exercise intensity in endurance sports, these methods are questionable in team sports, such as volleyball, which are characterized by short but maximal anaerobic efforts [70]. In fact, the results of one study stated no association between well-being and HR-based internal training load [32]. Thus, given the limitations inherent in using the HR for monitoring the intensity of volleyball training sessions, coaches are advised to not use HR-based methods to quantify training stress in this sport.

Fitness and Fatigue in Volleyball

One study demonstrated that submaximal exercise heart rate (HRex) values decreased over a period of 4 weeks [28]. Reductions in HRex are generally associated with improved aerobic fitness, while elevations in HRex are related to acute fatigue or loss of fitness [71]. One study also showed positive associations between seated Ln rMSSD and training load (i.e., sRPE) in female volleyball athletes [28]. These results must be interpreted carefully as these positive associations can vary depending on how loads are being tolerated by athletes. If training loads increase in response to increments in fitness and performance, then seated Ln rMSSD will reduce [72]. On other hand, if converse cardiac-autonomic responses are stimulated through mechanisms of fatigue resulted from high training loads, then seated Ln rMSSD will increase [73]. These inconsistencies in associations between Ln rMSSD and training load show the importance of monitor various markers of fatigue, fitness, load, and well-being. Previous research showed that HRV values return to baseline 24 hours after an intense exercise bout in the supine position [74]. Therefore, it can be hypothesized that high training loads induces greater fluctuations in the seated Ln rMSSD compared to supine Ln rMSSD. Thus, coaches and practitioners should have this into consideration when monitoring fatigue of volleyball athletes through HRV.

In response to a high-load exercise, various enzymes and blood markers, such as creatine kinase (CK), increase [63]. This type of exercises induces muscle damage and since CK is released from muscle cells to blood, practitioners have been using CK levels to assess the degree of muscle damage [75]. According to the search conducted, volleyball athletes experience an increase of CK levels during the first weeks of pre-season and a decrease in the final weeks [34,42]. This is in line with what was already mentioned in this manuscript about the levels of sRPE during the pre-season period. It is expected to observe higher increment in

CK levels in individuals with lower physical fitness [75], particularly during initial training periods (i.e., pre-season) characterized as an initial training time followed by a period with no structured training. This also indicates that CK levels increase in response to high training loads, which is in line with what was previously reported [75]. However, CK has a large variability [76] and personnel involved in the collection of this marker must understand the importance of establishing baseline values from many samples over several days. Testosterone and cortisol are other two markers that are associated with cellular catabolism, anabolism, and overreaching [62]. Literature shows that during volleyball pre-season, both testosterone and cortisol levels do not change [42]. This is probably an indicator that volleyball pre-season is not enough to induce disturbances in the balance of the immune system.

Results from a study conducted during the pre-season showed that the CMJ height did not change during a 6-week period, assessed four times during this time-window [42]. Another study revealed that, across a single training week, the CMJ jump height decreased [49]. Both studies' methodologies indicated that the best of all jumps was retained for analysis. However, when the comparison between highest and average results is possible, the averaged jump results is more sensitive than the highest jump in detecting fatigue or supercompensation effects [77]. Therefore, these results should be interpreted with caution and volleyball coaches should have into consideration that averaged CMJ performance without arm swing should be used to track neuromuscular status.

Well-Being in Volleyball

One study reported well-being measures, such as mood, soreness, and sleep duration, as independent predictors of injury in female volleyball athletes [29]. This is aligned with other non-volleyball studies [78]. According to the literature, athletes do not get the sleep duration that is recommended [79] which is a minimum of 7 hours to minimize injury risk [80]. Therefore, volleyball staff should seek to include these subjective markers into their daily training monitoring routines to identify athletes with higher injury risk.

Volleyball athletes' recovery state is lower in the final stage of the pre-season, compared to other points of the competitive period [31]. In the last phase of the pre-season, coaches are advised to employ a taper strategy to avoid the undesirable outcomes of fatigue already mentioned in the beginning of the present manuscript, like nonfunctional overreaching [8]. In fact, the results of a study with professional male volleyball players showed that the odds of injury were inversely proportional to the values of TQR scale (i.e., the less recovered the player, the greater the odds of sustaining an injury) [17]. Likewise, athletes' readiness to start the competitive period is important since the perception of stress increase whereas their perception of recovery decrease during a volleyball pre-season [31,34,54]. The results from other studies suggested that the RESTQ-Sport [42] and the Hooper index [16,44] are sensitive to an increase in the training load in volleyball athletes, showing promising results as tools to indicate early symptoms of overtraining. Consequently, balancing pre-season training stress and recovery is essential so athletes' adaptation process is optimized for match-days.

During periods of congested travels and games, volleyball athletes reported poorer well-being responses in questionnaires [16,33,35,40,48,51,52]. Time lost to travel, and the ensuing disruption of routines and training schedules may inhibit the use of recovery and medical interventions. Since travels can decrease the well-being and increase athletes' risk for illness, coaches and staff should implement some strategies, such as: provide adequate recovery time after travels; avoid flying on the same day as match-day; and encourage athletes to drink water during travels [81]. By tracking well-being values coaches can make informed decisions about the demands that incur from both in and out of sport activities.

During the last stage of the competitive period, higher levels of stress can be observed in professional volleyball athletes [38,41]. Anxiety of a pre-match situation seems to impact the perception of stress levels by professional athletes [82]. This stage is characterized by the decisive matches of the season. On other hand, stress levels in collegiate volleyball athletes may not be as heavily influenced by athletic events during the season and may be more a consequence of the temporal relation to the academic school year [45]. Therefore, challenges that occur in social and academic settings are the offset to higher stress levels in collegiate athletes.

Limitations, Strengths, and Recommendations for Future Research

Many conclusions can be drawn from the available literature on the monitorization strategies in the volleyball context. Studies addressing the responses of the three types of monitorization strategies in volleyball are limited [18,28,42,49]. Of these four studies, none was conducted during a full season. Thus, future research should examine fitness and fatigue outcomes, internal and external training load data, and well-being questionnaires responses during a longer period (i.e., at least one full season) to better understand the relationship of different monitoring strategies in volleyball athletes. Besides, only five studies analysed fitness and fatigue in this athletic population [18,28,34,42,49]. Moreover, none of these studies was performed during a full season and future research should point in that direction. More specifically, fatigue in female volleyball athletes can be even more expanded by analysing the menstrual tracking and biochemical markers to develop a further understanding of how Ln rMSSD responses influence training adaptations.

Although the jump analysis is accepted as a reflection of external load, displacements and changes of direction also seem to affect this dimension (especially for the libero position). Therefore, those movements should be considered in future research as only one study analysed these metrics in a sample of collegiate female volleyball athletes [33]. Furthermore, the simple jump count method is not ideal to measure external load. Six studies expressed external load by analysing the jump height of each athlete [18,27,33,39,43,46]. Still, two volleyball players with different body mass that achieve the same jumping height will not experience the same load. Due to gravity, linear velocity at landing increases with higher jumping height values, which subsequently increases kinetic energy (i.e., energy related to the body mass) levels at landing [83]. So, coaches should consider the vertical displacement of each jump as well as the mass of the athlete to have a better external load metric that is more reflective of what the volleyball athlete is experiencing [83]. Future research should explore the prospective relationship between external load calculated with the parameters mentioned before, the incidence of injury and the landing mechanics of volleyball players. This would potentially inform training and match-play guidelines by designing thresholds for injury prevention purposes.

One notable limitation in the current volleyball literature, and a promising direction for future research, is the exploration of GPS and Local Positioning Systems (LPS) for monitoring external load. While extensively used in outdoor sports, the application of GPS in volleyball, particularly indoor, is less common [84]. However, advancements in LPS technology now allow for its potential application in indoor environments, such as volleyball courts [85]. The adoption of these systems could provide detailed insights into player movements, intensity, and workload, which are crucial for training optimization, performance enhancement, and injury prevention [5,85]. This area remains under-researched in volleyball, highlighting a significant gap and an opportunity for future studies. It is recommended that subsequent research investigates the utility and implementation of these technologies in volleyball, offering a comprehensive perspective on managing external load in athletes. Such exploration could substantially contribute to the evolving landscape of volleyball training and competition analysis.

The average CMJ height is more sensitive than highest CMJ height in monitoring the effects of fatigue [77]. However, three of the four studies that used this test to monitor neuromuscular fatigue opted to use the best of all attempts [28,42,49]. So, average CMJ height should be used in future volleyball studies to track neuromuscular status. Additionally, peak power, mean power, peak velocity, peak force, mean impulse, and calculated power would seem merit worthy in quantifying supercompensation effects [77] and no study evaluated the impact of these variables within volleyball athletes. Nevertheless, the more useful indicators of readiness and neuromuscular fatigue within the plethora of variables that the CMJ give are the FT:CT and reactive strength index modified (RSImod) [86]. The RSImod is obtained by dividing the jump height to the contraction time and, similarly to FT:CT, the emphases of these two variables are jump process and force production [87]. Because time and contraction-specific measures better reflect the strategy employed by the neuromuscular system, compared with jumping height, contraction time is more sensitive to detect adaptations resulted from fatigue [88]. Since the ability of vertical jump height to reflect fatigue in athletes show inconsistencies in the literature [89,90], future studies in volleyball should consider the use of RSImod and FT:CT to monitor neuromuscular fatigue.

While the CMJ test is prevalently used in the current literature, exploring alternative assessments could provide a more comprehensive understanding of neuromuscular responses in volleyball athletes. Tests like the Drop Jump, which involves a short-duration stretch-shortening cycle, can offer insights into reactive strength and plyometric capabilities under fatigued conditions [87]. Additionally, isometric tests, such as isometric mid-thigh pulls or isometric calf raises, could be utilized to assess force in specific joint positions [91]. These alternative tests could reveal different dimensions of fatigue that may not be fully captured by the CMJ alone. Incorporating a variety of neuromuscular assessments can help in developing a more nuanced understanding of fatigue patterns in volleyball players, which in turn could inform more effective training and recovery protocols. Therefore, it is recommended that future research in volleyball expand the repertoire of fatigue assessment tools to include dynamic, plyometric, and isometric evaluations, providing a broader spectrum of data to optimize athlete performance.

Finally, to mitigate divergency in fatigue, relative velocity loss thresholds have recently been implemented during the strength training prescription [92]. Thus, velocity based training (VBT) can be a great alternative to the most used percentage-based methods since the latter do not have into consideration training-related fatigue [93]. Therefore, strength and conditioning coaches should consider monitoring velocity attained at the start of a training session to help objectively monitor changes in athlete fitness and fatigue. This is a topic that needs more understanding and future research should seek to answer if VBT is a reliable and valid tool to monitor neuromuscular fatigue in volleyball athletes.

Due to the heterogeneity of the measures used, it was not possible to conduct a meta-analysis. Plus, RPE and well-being data can be collected without following specific procedures and across a range of methods (e.g., different RPE scales and/or different operational questions). Therefore, practitioners working in professional volleyball can use this information in various ways with different assessment standards between them and this systematic review did not have that into consideration. Nevertheless, since there is a growing interest in topics related to athletes' monitoring this study can aid volleyball coaches to select which training load measures, fatigue and well-being assessments can be used with their athletes.

4.4.6. Conclusions

Within the context of team sport athletes, such as volleyball, coaches should use a mixed-methods approach when monitoring these athletes. No single measure can determine how a player is fully coping with the demands of training and matches. Therefore, practitioners not only need a range of methods, but also ensure athletes are familiarized with them to better improve their buy-in and the quality of the data analysis. According to this review, internal training load should be collected daily after training sessions and matches with the sRPE method. External training load should also be measured daily according to the method proposed by Charlton et al. [83] based on jump height, jump count, and kinetic energy. If force platforms are available, neuromuscular fatigue can be assessed weekly using the FT:CT ratio of a CMJ or, in cases where force platforms are not available, the average jump height can also be used. Finally, the Hooper Index has been shown to be a measure of overall wellness, fatigue, stress, muscle soreness, mood, and sleep quality in volleyball when used daily.

4.4.7. References

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4.5. Study V – Training Load, Neuromuscular Fatigue, and Well-Being of Elite Male Volleyball Athletes During an In-Season Mesocycle

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4.5.1. Abstract

Purpose: Most high-intensity bouts of exercise in volleyball consist in jumping activities, which are responsible for inducing muscle damage, high levels of fatigue, and muscle soreness. Therefore, the aim of the current study was to quantify and analyse the training loads, neuromuscular fatigue, and perceptual well-being of a 5-week in-season mesocycle carried out by a professional male volleyball team. Methods: Fifteen volleyball players (age: 28.51 ± 5.39 years; height: 193.19 ± 9.87 cm; body mass: 88.46 ± 13.18 kg) participated in this study. Internal training load (ITL), assessed through the rating of perceived exertion, external training load (ETL), using an inertial motion unit, countermovement jump (CMJ) height and peak power, and wellness questionnaire responses were obtained from all athletes. Results: Results indicated a progressively decrease of the ITL during the week and by the undulatory pattern of the ETL during the microcycles. Moreover, training monotony increased across the microcycles and was negatively associated with CMJ peak power ($r = -0.681$, $p < 0.05$). Finally, sleep quality ($\rho = -0.747$, $p < 0.01$) and fatigue ($\rho = -0.789$, $p < 0.01$) were negatively associated with weekly ETL. Conclusions: This study indicated that sleep quality and fatigue were negatively associated with weekly ETL (wETL). Therefore, decreases in wETL might be needed to improve sleep quality and decrease fatigue in professional volleyball players. Plus, higher values of training monotony were associated with lower values of CMJ peak power. Consequently, avoiding training monotony might be important to improve jumping performance in professional volleyball athletes.

Key Words: jump performance; monitoring; periodization; recovery; rating of perceived exertion; team sports.

4.5.2. Introduction

Volleyball is a sport characterized by short high-intensity efforts interspersed between low-intensity periods and recovery time [1]. At elite level, volleyball players can train twice a day for multiple consecutive days [2]. Most high-intensity bouts of exercise consist in jumping activities, such as spike jumps, jousts, or block jumps [1,3]. Jumps are characterized by a pre-activation (stretch) of the extensors' muscles, followed by a shortening phase of these same extensors' muscles which represents the stretch-shortening cycle (SSC) [4]. Previous findings showed a reduced EMG activation during the eccentric phase of SSC exercises [5]. In fact, eccentric muscle actions are responsible for inducing more muscle damage when compared with concentric muscle contractions [6]. Thus, high levels of fatigue, muscle soreness, and muscle damage are expected after a volleyball microcyle. Previous research showed that high levels of fatigue and muscle soreness are associated with higher injury rates in volleyball [7].

Therefore, one of the major reasons high performance sports invests so much time in athlete monitoring strategies is to reduce the time lost to injury [8] and illness [9]. Changes in cumulative training loads are related to the risk of injury [10], whereas during heavy periods of training, athletes are at increased risk of developing illnesses [11]. Within the volleyball literature, one training microcyle have shown decreases in the neuromuscular performance and an increase in muscle soreness in professional male players [2]. Furthermore, rises in weekly training loads were followed by increases in fatigue in professional male volleyball athletes [12].

One of the ways to assess fatigue is by monitoring the athletes' load. Training load can be sub-divided into two different categories – internal and external [13]. Internal training load (ITL) refers to the physiological stress that a training session induces in the athlete.[14] Measures such as heart rate (HR) and rating of perceived exertion (RPE) are the most common methods of monitoring internal load [13]. On the other hand, external training load (ETL) is defined as the physical work prescribed in the training plan [14]. The most common method of monitoring external load is with time-motion analysis devices, such as GPS, accelerometers, or inertial motion units (IMUs) [13]. Questionnaires can be useful for monitoring athletes' levels of stress[15] and identifying those at greater risk of becoming injured [16]. Research in volleyball reported well-being measures, such as mood, soreness, and sleep duration, as independent predictors of injury [7]. Therefore, assessing athlete's mood state and level of tension through tools such as the Profile of Mood States (POMS) and the Brunel Mood Scale

(BRUMS) can be useful [17]. Wellness inventories, like the Hooper index [18], are also common if the goal is to gather as much information as possible about different metrics, such as fatigue, stress, sleep, or recovery.

Besides ITL, ETL, and wellness questionnaires, low-frequency fatigue (i.e., resulted from high-force, high-intensity, or repeated stretch-shortening cycles muscle actions) is frequently a topic of interest while monitoring athletes [19]. Consequently, many research studies have established the reliability and validity of vertical jumps as an indicator of neuromuscular fatigue in athletes [20], including in professional volleyball [21]. Measures such as jump height, peak and mean power, and peak force are popular among coaches as they are valid methods to assess neuromuscular fatigue [22].

Therefore, the aim of the current study was to quantify and analyse the training loads, neuromuscular fatigue, and perceptual well-being of a 5-week in-season mesocycle carried out by a professional male volleyball team. Furthermore, the present study also aimed to compare the responses of different perceptual well-being measures to neuromuscular fatigue and to training load to see if there were associations between the variables. The mesocycle corresponded to the first weeks of the national championship.

4.5.3. Methods

Subjects

The experimental protocol fitted the recommendations from the Declaration of Helsinki produced by the World Medical Association for research with humans [23]. In addition, all procedures adhered to established ethical standards for sports medicine [24]. Data were obtained from 15 professional male volleyball players (age: 28.51 ± 5.39 years; height: 193.19 ± 9.87 cm; body mass: 88.46 ± 13.18 kg). All participants were players from the first Portuguese Volleyball Division – Liga UNA Seguros. Inclusion criteria were regular participation in most of the training sessions (80% of weekly training sessions) or the completion of at least half the duration of a match.

Procedures

To study the training load, neuromuscular fatigue and perceptual well-being during volleyball, a non-interventional study was designed (i.e., no intervention during training) and data was collected over a 5-week period of competition phase (5 microcycles) where 5 matches occurred each weekend during the 2021–2022 annual season. Only data from volleyball training sessions and matches were considered. Total minutes of training sessions included warm-up, main phase, and slow down phase. Gym sessions were not considered for analysis.

Training data were analysed in relation to the number of days away from the competitive one-match week (i.e., match day minus). In a week with only one match, the team typically trained six or five days a week (match day (MD) minus (-); MD-6; MD-5; MD-4; MD-3; MD-2; MD-1), plus one day after the match (MD+1). This approach was used before within team-sports context [25].

All analysis were based on the different periodization cycles described in the literature defined as microcycles and mesocycles [26]. Mesocycles usually last for two to six weeks. Each mesocycle is then broken down into individual microcycles where their most common duration is one week [26]. In the present study, there were a total of five microcycles with a duration of one week each. All five microcycles corresponded to the same mesocycle.

Quantification of Training Load

Internal training load data were collected 15–20 min following each training session and match. Players were asked to provide an RPE score using a 0-10 scale (a 0 was allocated every time there was a rest day on MD+1) and answered the question "How hard was your workout?" [27]. Players were prompted for their RPE individually using a designed application (XPS Network, Sideline Sports, Iceland) on each athlete smartphone. The players selected their RPE by touching the respective score on their smartphones, which was then automatically saved under the player's profile. This method helped minimise factors that may influence a player's RPE score, such as peer pressure and replicating other player's ratings [28,29]. Each individual RPE value was multiplied by the session duration to generate a session-RPE (s-RPE) value [28,29]. The total weekly ITL (wITL), consisted in the sum of the ITLs of all training sessions during that week. Monotony (calculated as daily load divided by the daily load standard deviation) and strain (calculated as the product of monotony and load) were also obtained.

External training load data were collected with a commercially available IMU (Vert, Mayfonk Athletic, Fort Lauderdale, FL, USA) which has been found to have excellent inter-device reliability [30], validity [31], and precision [32] in volleyball. The IMU was inserted into an elastic waistband as recommended by the manufacturer. Each device was connected to a tablet via Bluetooth. All jumps were individually assigned, time-stamped, and recorded for jump height. External training load was calculated as the product of the jump count and the average kinetic energy, as measured in kilojoules (kJ) [32]. The total weekly ETL (wETL), consisted in the sum of the ETLs of all training sessions during that week.

Quantification of Neuromuscular Fatigue

Neuromuscular fatigue was assessed though the CMJ test, once a week, before MD-1 training session in a randomized order. All athletes were well familiarized with the testing procedures. All subjects were instructed to perform maximal effort jumps with hands remaining on hips throughout the movement to limit the influence of the upper body on jump performance [33]. The CMJ was performed on a contact platform (Chronojump Boscosystem, Barcelona, Spain) and each athlete had 3 trials, with 90 seconds rest between them. The mean values of jump height and peak power calculated with the Sayers et al. equation [34] of the 3 attempts were used for analysis, as averaged jump results are more sensitive in detecting fatigue and supercompensation effects [35].

Quantification of Perceptual Well-Being

A wellness questionnaire adapted from McLean et al. [36] was used to monitor fatigue, recovery, stress, muscle soreness, and sleep perception (Appendix V). In each morning, approximately 30 min after waking up, athletes had to answer a questionnaire with 6 different items, in which answers were rated from -3 to 3 from the same smartphone application used to answer the RPE (XPS Network, Sideline Sports, Iceland).

Statistical Analysis

All analyses were performed using Statistical Package for Social Science (V. 27.0, SPSS Inc., Chicago, IL, USA) and statistical significance was set at an alpha level of 0.05. Descriptive data are presented as means and standard deviations (SD). Descriptive statistics were used to describe and characterize the sample and the Shapiro-Wilk and the Levene tests were used to assess the assumption of normality and homoscedasticity, respectively. A repeated-measures analysis of variance with a post hoc Bonferroni adjustment was used once variables obtained normal distribution (Shapiro-Wilk > 0.05), to compare the 5 microcycles and to compare days away from the competitive match fixture. The effect size (ES) was calculated to determine the magnitude of the effects by standardizing the coefficients according to the appropriate between-subjects standard deviation. The magnitude of the effects was assessed using the following criteria: <0.2 = trivial, 0.2 to 0.6 = small, 0.6 to 1.2 = moderate, 1.2 to 2.0 = large, and >2.0 = very large [37]. The associations between two continuous variables were tested with the Pearson product-moment correlation, whereas the associations between two ordinal variables or one ordinal and one continuous variable were tested with the Spearman correlation.

4.5.4. Results

Microcycle Analysis

For internal training load, the s-RPE was higher in microcycle 5 than in microcycles 1 and 4, with moderate ES observed in both comparisons (Table IV-20). In microcycle 1 the wITL was significantly lower ($p < 0.05$) than the values observed in microcycles 2, 3, and 5, with large ES identified. Moderate ES were also observed for wITL between microcycle 4 and microcycles 2 and 5. In microcycle 3 the wITL was significantly higher ($p < 0.05$) than in microcycle 4 with large ES. Strain and monotony values increased during the first four microcycles with large to very large ES noted from microcycle 4 to microcycles 1, 2, and 3. An undulatory pattern of the wETL can be observed as this metric increased during the first three microcycles, decreased in microcycle 4, and increased once again in microcycle 5. Microcycle 3 had the greatest wETL with statistically significant differences observed compared with microcycles 1 and 4. Regarding the wellness questionnaire, the stress item reported small and moderate effect sizes observed between microcycle 2 and microcycles 3 and 4, respectively (Table IV-21).

Table IV-20: Training load during the five microcycles for squad average.*

Microcycle	Training sessions	Session training duration (min)	Internal training load				External training load
			sRPE (AU)	wITL (AU)	Strain (AU)	Monotony (AU)	wETL (kJ)
1	3	80.00 ± 14.14	4.00 ± 0.68	1229.00 ± 247.74[†, ‡, #, a, c, h]	524.05 ± 118.26[†, §, a, c, f, g]	2.13 ± 0.62[§, b, e]	12195.14 ± 3810.77[‡, #, b, g]
2	6	77.50 ± 13.46	4.22 ± 1.19	1939.00 ± 815.31[d]	807.63 ± 212.57[§, e]	2.46 ± 0.67[§, e]	12779.81 ± 6655.26[#, b, g]
3	6	87.50 ± 10.31	4.05 ± 0.74[g]	2188.13 ± 693.36[§, e]	855.11 ± 249.43[e]	2.59 ± 0.73[§, e]	18328.99 ± 8358.20[§, d]
4	3	80.00 ± 7.07	3.94 ± 0.57[g]	1347.19 ± 185.92[#, h]	1894.08 ± 892.58[g]	5.61 ± 2.51[h]	11144.92 ± 3648.12[h]
5	4	90.00 ± 10.61	4.65 ± 1.21	2017.50 ± 646.24	993.42 ± 665.26	2.69 ± 1.34	16903.30 ± 5633.89

*AU = arbitrary units; sRPE = session rating of perceived exertion; wITL = weekly internal training load; wETL = weekly external training load.

† Signals represent significant differences from microcycle 2 ($p < 0.05$).
‡ Signals represent significant differences from microcycle 3 ($p < 0.05$).
§ Signals represent significant differences from microcycle 4 ($p < 0.05$).
# Signals represent significant differences from microcycle 5 ($p < 0.05$).
a Signals represent large effect sizes from microcycle 2 (1.2 ≤ d > 2.0)
b Signals represent moderate effect sizes from microcycle 3 (0.6 ≤ d ≥ 1.2)
c Signals represent large effect sizes from microcycle 3 (1.2 ≤ d ≥ 2.0)
d Signals represent moderate effect sizes from microcycle 4 (0.6 ≤ d > 1.2)
e Signals represent large effect sizes from microcycle 4 (1.2 ≤ d ≥ 2.0)
f Signals represent very large effect sizes from microcycle 4 (d > 2.0)
g Signals represent moderate effect sizes from microcycle 5 (0.6 ≤ d ≥ 1.2)
h Signals represent large effect sizes from microcycle 5 (1.2 ≤ d ≥ 2.0)

Table IV-21: Neuromuscular fatigue and well-being during the five microcycles for squad average.*

Microcycle	Training sessions	CMJ		Wellness questionnaire					
		Jump height (cm)	Peak power (w)	Fatigue	Sleep quality	Sleep time	Soreness	Mood	Stress
1	3	46.75 ± 6.29	4777.16 ± 621.61	0.84 ± 0.67	1.54 ± 0.65	1.89 ± 0.51	0.57 ± 0.84	1.46 ± 0.69	1.56 ± 0.73
2	6	46.62 ± 5.42	4676.03 ± 718.06	0.95 ± 0.79	1.55 ± 0.57	1.94 ± 0.44	0.60 ± 1.34	1.50 ± 0.60	1.55 ± 0.66[a]
3	6	47.24 ± 7.21	4770.33 ± 646.47	1.06 ± 0.83	1.78 ± 0.64	1.84 ± 0.50	0.74 ± 1.11	1.68 ± 0.74	1.89 ± 0.51
4	3	44.46 ± 6.09	4626.18 ± 647.55	1.04 ± 1.04	1.77 ± 0.76	2.01 ± 0.60	0.83 ± 1.38	1.60 ± 0.75	1.94 ± 0.67
5	4	44.97 ± 7.06	4652.16 ± 637.80	0.94 ± 0.89	1.58 ± 0.47	1.69 ± 1.06	0.66 ± 1.08	1.37 ± 0.93	1.48 ± 1.11

*CMJ = countermovement jump.
a Signals represent moderate effect sizes from microcycle 4 ($0.6 \leq d \geq 1.2$)

There were associations between wETL and s-RPE in microcycle 2 ($\rho = 0.628$, $p < 0.05$), and between wETL and CMJ peak power in microcycles 2 ($r = 0.697$, $p < 0.05$), 3 ($r = 0.591$, $p < 0.05$), and 5 ($r = 0.663$, $p < 0.01$) (Appendix V). Associations were found between wETL and sleep quality in microcycles 1 ($\rho = -0.747$, $p < 0.01$) and 2 ($\rho = -0.703$, $p < 0.05$) (Figure IV-9) and between wETL and fatigue in microcycles 2 ($\rho = -0.789$, $p < 0.01$) and 5 ($\rho = -0.612$, $p < 0.05$) (Figure IV-10). Muscle soreness was associated with strain ($\rho = -0.695$, $p < 0.01$) and monotony ($\rho = -0.575$, $p < 0.05$) in microcycle 4. Associations were also found between strain and mood ($\rho = -0.534$, $p < 0.05$), and monotony and CMJ peak power ($r = -0.681$, $p < 0.05$) in microcycles 4 and 2, respectively.

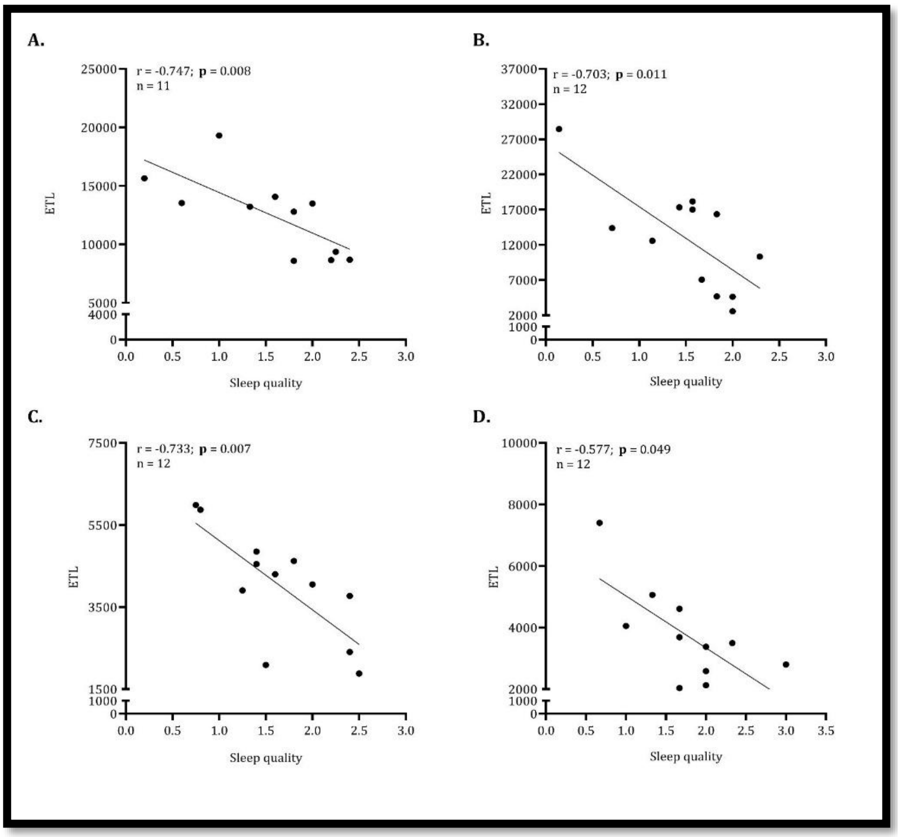

Figure IV-9: Scatterplots with regression lines and correlation coefficients between external training load and sleep quality in (A) microcycle 1, (B) microcycle 2, (C) MD-3, and (D) MD-4. CI, confidence interval; MD-, matchday minus; ETL, external training load. Liberos were excluded from the analysis as they do not perform a significant number of jumps.

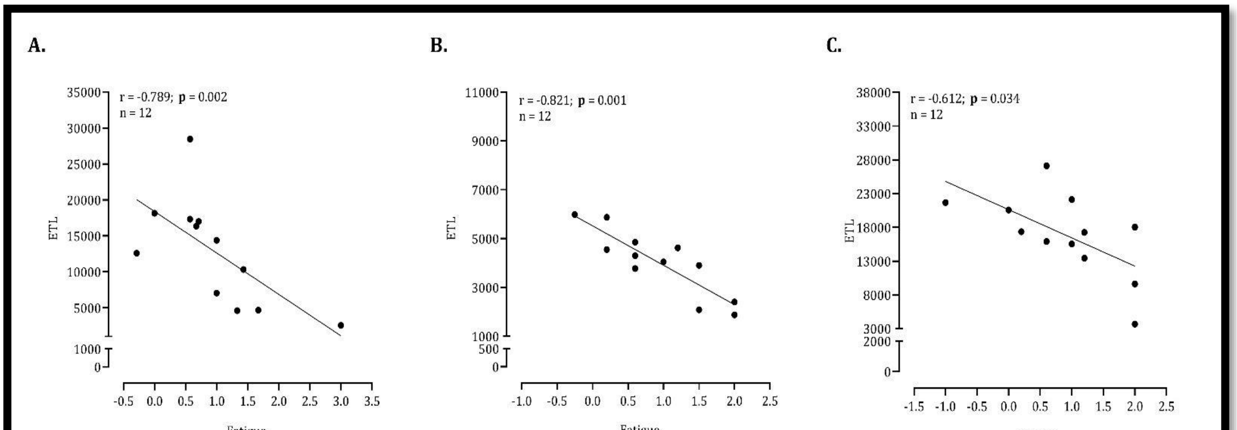

Figure IV-10: Scatterplots with regression lines and correlation coefficients between external training load and fatigue in (A) microcycle 2, (B) MD-3, and (C) MD-5. CI, confidence interval; MD-, matchday minus; ETL, external training load. Liberos were excluded from the analysis as they do not perform a significant number of jumps.

Training Sessions Analysis

The s-RPE gradually decreased over the training sessions during the week (Table IV-22). Statistically significant differences were observed between MD-5 and MD-3, MD-2, and MD-1 ($p < 0.05$), with moderate to large ES. In fact, MD-1 registered the lowest s-RPE value and had statistically significant differences compared to MD-5, MD-4, and MD-3 ($p < 0.05$), with large ES. Following the same tendency of s-RPE, MD-1 registered the lowest ITL value of the week with statistically significant differences compared to MD-6, MD-5, MD-4, MD-3, MD-2, and MD ($p < 0.05$), with moderate to very large ES. The ETL registered the greatest value on MD-5 which had statistically significant differences to MD-6, MD-1, and MD ($p < 0.05$) with large ES. Of the training sessions, both MD-6 and MD-1 registered the lowest ETL values. The ETL value on MD-1 was statistically significantly lower than those observed on MD-5 and MD-2 ($p < 0.05$) with large ES. On MD+1 the fatigue item of the wellness questionnaire showed that athletes were more fatigued compared with MD-6, MD-5, MD-3, MD-2, MD-1, and MD with small ES (Table IV-23). The sleep quality item had worse answers on MD-1 and MD+1, compared with MD-6, MD-5, MD-3, and MD-2 with small ES. Athletes had less muscle soreness on MD than on MD+1 ($p < 0.05$) with small ES. Mood and stress responses were better on MD-6 than on MD-3, MD-2, and MD+1 with small ES.

Associations were found between ETL and sleep quality on MD-4 ($\rho = -0.577$, $p < 0.01$) and MD-3 ($\rho = -0.733$, $p < 0.05$) (Appendix V).

Table IV-22: Training load data during the MD minus for squad average.*

	n	Duration (min)	sRPE (AU)	ITL (AU)	ETL (kJ)
MD-6	2	67.50 ± 7.50	4.33 ± 0.94[a, d, h, k]	303.75 ± 56.17[†, ‡, #, c, e, g, l]	2885.12 ± 913.98[†, §, b, d, f, i]
MD-5	2	97.50 ± 7.50	5.30 ± 1.35[‡, §, #, f, i, l, n]	522.50 ± 131.09[‡, §, #, g, j, m, n]	4613.27 ± 1246.83[#, ¶, d, l, o]
MD-4	3	90.00 ± 12.25	5.18 ± 1.60[#, h, i, l, n]	468.59 ± 155.54[#, f, l, m]	3748.89 ± 1386.72[¶, k, n]
MD-3	5	87.00 ± 6.00	4.47 ± 0.78[§, #, i, k, n]	389.86 ± 69.69[§, #, i, m]	3943.38 ± 1253.30[k, o]
MD-2	5	84.00 ± 12.00	3.51 ± 0.53	302.63 ± 45.15[#, l]	4358.98 ± 1253.31[#, ¶, l, o]
MD-1	5	75.00 ± 9.49	3.65 ± 0.70	231.05 ± 46.78[n]	3044.49 ± 955.01[n]
MD	5	90.00 ± 28.46	3.74 ± 1.35	374.22 ± 171.21	2438.62 ± 1005.53

*AU = arbitrary units; sRPE = session rating of perceived exertion; ITL = internal training load; ETL = external training load.
† Signals represent significant differences from MD-5 ($p < 0.05$).
‡ Signals represent significant differences from MD-3 ($p < 0.05$).
§ Signals represent significant differences from MD-2 ($p < 0.05$).
# Signals represent significant differences from MD-1 ($p < 0.05$).
¶ Signals represent significant differences from MD ($p < 0.05$).
a Signals represent moderate effect sizes from MD-5 ($0.6 \leq d > 1.2$)
b Signals represent large effect sizes from MD-5 ($1.2 \leq d \geq 2.0$)
c Signals represent very large effect sizes from MD-5 ($d > 2.0$)
d Signals represent moderate effect sizes from MD-4 ($0.6 \leq d > 1.2$)
e Signals represent large effect sizes from MD-4 ($1.2 \leq d \geq 2.0$)
f Signals represent moderate effect sizes from MD-3 ($0.6 \leq d > 1.2$)
g Signals represent large effect sizes from MD-3 ($1.2 \leq d \geq 2.0$)
h Signals represent moderate effect sizes from MD-2 ($0.6 \leq d > 1.2$)
i Signals represent large effect sizes from MD-2 ($1.2 \leq d \geq 2.0$)
j Signals represent very large effect sizes from MD-2 ($d > 2.0$)
k Signals represent moderate effect sizes from MD-1 ($0.6 \leq d > 1.2$)
l Signals represent large effect sizes from MD-1 ($1.2 \leq d \geq 2.0$)
m Signals represent very large effect sizes from MD-1 ($d > 2.0$)
n Signals represent moderate effect sizes from MD ($0.6 \leq d > 1.2$)
o Signals represent large effect sizes from MD ($1.2 \leq d \geq 2.0$)

Table IV-23: Well-being data during the MD minus for squad average.*

	n	Fatigue (AU)	Sleep Quality (AU)	Sleep Time (AU)	Soreness (AU)	Mood (AU)	Stress (AU)
MD-6	2	1.12 ± 0.77[a]	1.62 ± 0.51	2.19 ± 0.60[b, d, e]	0.65 ± 1.20	1.69 ± 0.75	1.85 ± 0.59[a]
MD-5	2	0.85 ± 0.83	1.69 ± 0.90	1.96 ± 0.59	0.46 ± 1.11	1.58 ± 0.67	1.69 ± 0.69
MD-4	3	0.62 ± 0.84[e]	1.89 ± 0.63[d]	1.89 ± 0.52	0.36 ± 1.38	1.26 ± 1.06	1.32 ± 0.89
MD-3	5	1.01 ± 0.71	1.70 ± 0.58	1.76 ± 0.61	0.61 ± 0.84	1.53 ± 0.66	1.70 ± 0.54
MD-2	5	0.83 ± 0.58	1.66 ± 0.45	1.91 ± 0.53	0.64 ± 0.97	1.47 ± 0.60	1.70 ± 0.57
MD-1	5	0.90 ± 0.72	1.45 ± 0.76	1.80 ± 0.52	0.68 ± 1.09	1.60 ± 0.64	1.72 ± 0.73
MD	5	1.10 ± 0.74	1.56 ± 0.57	1.68 ± 0.61	0.94 ± 1.17[†]	1.59 ± 0.60	1.71 ± 0.69
MD+1	4	0.61 ± 1.26	1.46 ± 0.85	1.93 ± 0.74	0.46 ± 1.37	1.34 ± 1.34	1.66 ± 0.77

*AU = arbitrary units.
† Signals represent significant differences from MD+1 ($p < 0.05$).
a Signals represent moderate effect sizes from MD-4 ($0.6 \leq d > 1.2$)
b Signals represent moderate effect sizes from MD-3 ($0.6 \leq d > 1.2$)
c Signals represent moderate effect sizes from MD-1 ($0.6 \leq d > 1.2$)
d Signals represent moderate effect sizes from MD-1 ($0.6 \leq d > 1.2$)
e Signals represent moderate effect sizes from MD ($0.6 \leq d > 1.2$)

4.5.5. Discussion

The purpose of the present study was to quantify and analyze the ITL, ETL, neuromuscular fatigue, and perceptual well-being of a professional volleyball team in a 5-week in-season mesocycle. Plus, the associations between the different variables were also assessed. The main findings of the study are related to a progressively decrease of the ITL during the week (i.e., from MD-5 to MD-1), whereas ETL have an undulatory pattern, increasing from MD-6 to MD-5, decreasing from MD-5 to MD-4, increasing again from MD-4 to MD-2, and decreasing one last time from MD-2 to MD-1. Plus, this study showed promising novel results and indicated that sleep quality and fatigue were negatively associated with wETL.

This study analyzed the first weeks of a competitive period of a professional male volleyball team. This specific mesocycle was characterized by microcycles with relatively high values of wITL and wETL. This is common in professional volleyball [38,39] since the first phase of the competitive period is described by a focus on the development of fitness components while the second phase comprises the most specific training sessions (technical and tactical skills) [40]. The wITL and wETL differences observed between microcycles are due to various travels made and games played against teams of different levels which will influence the number of training sessions during the competitive period [41]. Since the main goal of coaches and practitioners is to have the athletes ready for MD, this wave distribution of wITL and wETL between microcycles can be applied. For example, this can be done by increasing training loads in microcycles in which the team has a low possibility of losing the game.

Both training strain and monotony also increased during the microcycles. Monotony is a measure of day-to-day training variability that has been found to be related to the onset of overtraining when monotonous training is combined with high training loads [42]. Research shown that a decrease in monotony is associated with improvements in physical fitness [43]. The results of the present study somehow confirm this tendency, as increases in training monotony were associated with decreases in CMJ peak power, especially in microcycle 2 ($p < 0.05$). Nevertheless, more research is needed in this topic, particularly with studies with a longer time frame. When combined with high training loads, training strain can indicate a high risk of overtraining, illness, or injury [42]. However, when coupled with low training loads, high values of strain might indicate that the training program is lacking the necessary stimulus to drive positive adaptations. In fact, one strategy that has been recommended to reduce training strain is alternating high and low training loads [42], and the results of this study show an undulatory pattern of the ETL within the training sessions of the week.

Albeit small changes were observed in CMJ height between microcycles, this was not reflected in statistically significantly differences. This is in line with another study with elite male volleyball athletes, where the authors reported no differences in the CMJ height across a 6-week period [21]. Research with a longer time-frame is needed to understand what differences (if any) can be observed across a complete competitive period of professional volleyball athletes.

There were no differences observed in most wellness items measured. This was expected since only during periods of congested travels and games [44], or in the last stage of the competitive period [38] volleyball athletes report poorer well-being responses in questionnaires. The present study analysed the responses in the first weeks of an in-season of professional volleyball team which was characterized by one game per week. Besides, the opposition was not that challenging as the s-RPE results of the MD show. It should be interesting to see what fluctuations occur in perceptual fatigue, mood, stress, and sleep quality during a complete in-season macrocycle. Still, this study showed promising results and indicated that sleep quality and fatigue were negatively associated with wETL. Coaches should have that into consideration, especially in the most important mesocycles where every recovery detail (such as sleep quality and fatigue) matter. Therefore, decreases in wETL might be needed to improve sleep quality and decrease fatigue in professional volleyball players. To the best of the authors knowledge, this is a novel finding as research in professional volleyball has only shown associations between ITL and perceptual well-being [21,45]. To continue this trending, and since IMU technology shows promising results to monitor jumping metrics, such as jump height and jump count, future studies should explore the long-term associations between ETL data and perceptual fatigue and sleep quality. Regarding the training sessions analysis, athletes reported worse responses on the fatigue item on MD+1. This was expected as this day occurred after a competitive match (i.e., MD). Muscle soreness was also lower on MD, which indicated that athletes were ready for the game that would occur later that day. Finally, volleyball athletes reported worse answers regarding the sleep quality item on MD-1 and MD+1. This could mean different things. First, anxiety of a pre-match situation seems to impact the well-being perception levels by professional athletes which, in the end, will negatively affect their sleep quality [46]. Secondly, the results on post-competition (i.e., MD+1) sleep are an object of controversy. Previous studies, for instance, reported that sport competition did not cause substantial disruption to sleep behaviour in elite footballers [47], whereas in a study with professional volleyball athletes sleep was significantly disrupted after a match [48]. Late match start time might be the key factor that could significantly and negatively impact sleep variables for team sport players. Nevertheless, the negative impact that a competitive match might have in sleep quality was faded in the day after MD+1 (i.e., MD-6, or MD-4, or MD-3, depending on the week).

Albeit the novel findings, the present study is not without limitations. Firstly, we investigated only one volleyball team and, therefore, the results may differ with other teams. Secondly, in volleyball, where the technical movements are frequently repeated, collecting muscle soreness data from different muscle sites might provide important information and a single question about this variable might mask soreness in some areas. Future studies should analyse the impact of a questionnaire that monitor different muscle sites soreness. Lastly, another limitation was the fact that the different game positions were not considered. However, this study presents some strengths, such as the integrative approach applied, which analysed the physiological, psychological, and performance parameters in the same athletes and team. Thus, our study brings some novelties and interesting results like the support to the relationship between perceptual well-being markers (i.e., sleep quality and fatigue) and training load parameters (i.e., ETL).

From a practical standpoint, most of the monitoring should occur as part of the normal training and competition process. When a mixed-methods approach (i.e., internal and external measures of training load, fatigue, and well-being) is taken in conjunction with appropriate statistical analyses, coaches can make informed decisions regarding the training process. Approaches such as the use of a traffic light system (i.e., green for good, yellow for caution, and red for danger) to denote an athlete's status can be useful. Volleyball coaches should be aware that variations in ETL can influence well-being parameters such as fatigue and sleep quality. Therefore, in microcycles where all details matter (e.g., playoffs or cup matches), a decrease in ETL might be needed to make sure professional volleyball athletes are well recovered for the competition.

4.5.7. Conclusions

Volleyball training in professional athletes elicit meaningful changes in physiological and perceptual measures of well-being. These changes were evident by progressively decrease of the ITL during the week (i.e., from MD-5 to MD-1) and by the undulatory pattern of the ETL during the week. Moreover, training monotony increased during the microcycles and was associated with decreases in CMJ peak power. The wITL and wETL differences observed between microcycles are due to various travels made and games played against teams of different levels which will influence the number of training sessions during the competitive period. Finally, the results of the present study indicated that sleep quality and fatigue were negatively associated with wETL. Research with a longer timeframe is needed to understand what differences can be observed across a complete competitive period of professional volleyball athletes.

These results reinforce the need to monitor training load, neuromuscular fatigue, and perceptual well-being in professional volleyball teams during the in-season period. The authors recommend that training loads increase progressively, avoiding negative performance effects such as nonfunctional overreaching at the beginning of the season. When looking into a microcycle, training load needs to be lower at the end of the week, maintaining training intensity and with reduced volume.

4.5.8. References

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4.6. Study VI – Impact of Congested Match Schedules on Countermovement Jump Metrics in Elite Volleyball Players

Rebelo, A., Loturco, I., Pereira, J. R., Martinho, D. V., Valente-Dos-Santos, J., & Vande Broek, G. (2024). Impact of Congested Match Schedules on Countermovement Jump Metrics in Elite

Volleyball Players. *Journal of Strength and Conditioning Research*. Published ahead of print. https://doi.org/10.1519/JSC.0000000000005031.

4.6.1. Abstract

This study aimed to assess the impact of a congested match schedule on various countermovement jump (CMJ) metrics recorded across the braking, transfer, propulsive, and flight phases of the CMJ. Fourteen male elite volleyball players were monitored across seven microcycles, with CMJ assessments conducted at fourteen time points using portable force plates. Repeated measures ANOVA with Bonferroni post-hoc tests and coefficient of variation (CV) analysis were used to analyze the data. The CVs for all metrics indicated a moderate variability between microcycles and low variability between the beginning and end of the weeks. Significant variability was observed in key performance metrics, including peak propulsive power ($p < 0.001$, $\eta p^2 = 0.336$), peak propulsive velocity ($p = 0.005$, $\eta p^2 = 0.207$), propulsive phase duration ($p = 0.008$, $\eta p^2 = 0.197$), and jump momentum ($p = 0.019$, $\eta p^2 = 0.225$), across microcycles. These findings indicate that these CMJ metrics may be used as sensitive indicators of fatigue and performance changes during intense training and competitive periods. The Total Score of Athleticism, calculated by averaging a set of standardized scores from multiple tests or repeated measures of the same test, for the propulsive and flight phases, proved to be particularly useful in providing a comprehensive view of the neuromuscular status. This emphasizes the importance of recording and analyzing a range of CMJ metrics to optimize training and recovery strategies in elite volleyball players.

Key Words: fatigue, recovery, performance, team sports, jumping ability.

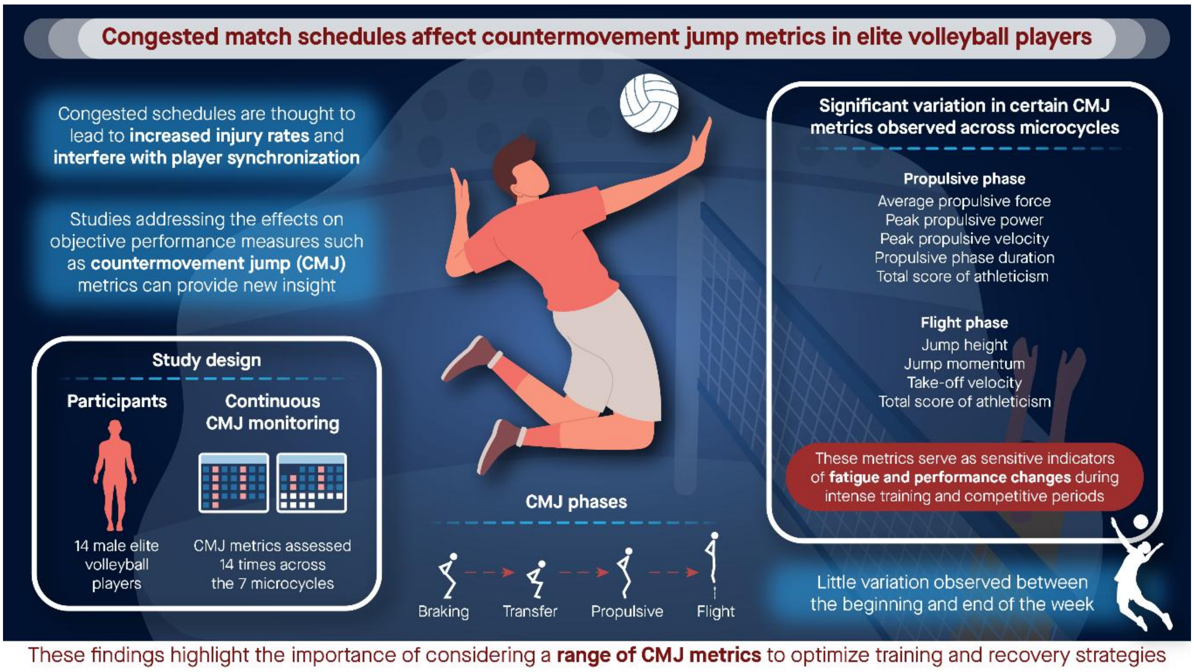


Figure IV-11: Graphical abstract of Study VI.

4.6.2. Introduction

Jump tests are widely utilized in sports performance evaluations due to their simplicity, efficiency, and biomechanical relevance for many sport-specific movements [1,2]. The triple flexion and extension actions involved in these tests closely mimic those performed in various sports, making them particularly useful for assessing athletic performance [3]. Among the various jump tests available, the selection of a specific test should be aligned with the specific requirements and characteristics of the athlete or sport in question [2]. In this regard, the countermovement jump (CMJ) is one of the most frequently employed jump tests in both practical and academic fields [4]. This popularity is likely due to the CMJ's ability to provide and reproduce a natural and familiar movement pattern for athletes from numerous sports. Therefore, it has become a standard tool for practitioners and researchers seeking applied and efficient methods to monitor and assess the physical performance of their athletes.

Volleyball, with its high demands on power and jumping qualities, may particularly benefit from jump-related assessments [5]. Developing a training strategy that focuses on key jump performance indicators aligns well with the principle of dynamic correspondence in sport science [6]. This approach ensures that the physical training is directly relevant to the development and specialization of the sport-specific tasks and demands of the sport in question (i.e., volleyball). Under this rationale, the CMJ has been extensively used in volleyball to explore novel and more efficient methods to improve the physical and technical performance of volleyball players (e.g., [7,8]).

The impact of match and training exposure on team sports has been thoroughly studied, revealing that congested schedules can lead to increased injury rates [9] and interfere with the proper synchronization of technical and tactical strategies [10]. In volleyball, research conducted during these critical periods of the season has primarily focused on variations in training loads and subjective markers of stress and fatigue [11-13]. However, these studies often overlook the analysis of objective performance measures (e.g., different jump metrics) and fatigue monitoring indicators in team-sport athletes, such as the force-time curve of the CMJ [14].

Previous studies have indicated that practitioners should consider linking various metrics when interpreting data from jump tests, as this approach allows for a more comprehensive analysis of the available information [2]. For instance, it has been demonstrated that CMJ height might be less responsive to changes following intense exercise compared to other metrics like time to peak power and time to take-off [15]. This discrepancy can create a challenge when trying to assess whether overall jump performance has improved, declined, or remained unchanged, especially when evaluating multiple jump metrics simultaneously. To address these challenges, recent literature has emphasized the significance of the "Total Score of Athleticism" (TSA) method [16]. The TSA is calculated by averaging a set of standardized scores (e.g., z-scores) from various tests, or from repeated measures of the same test, performed by a given athlete [16]. This method provides a holistic and more analytical view of a range of athletic capabilities by integrating multiple performance indicators into a single comprehensive score.

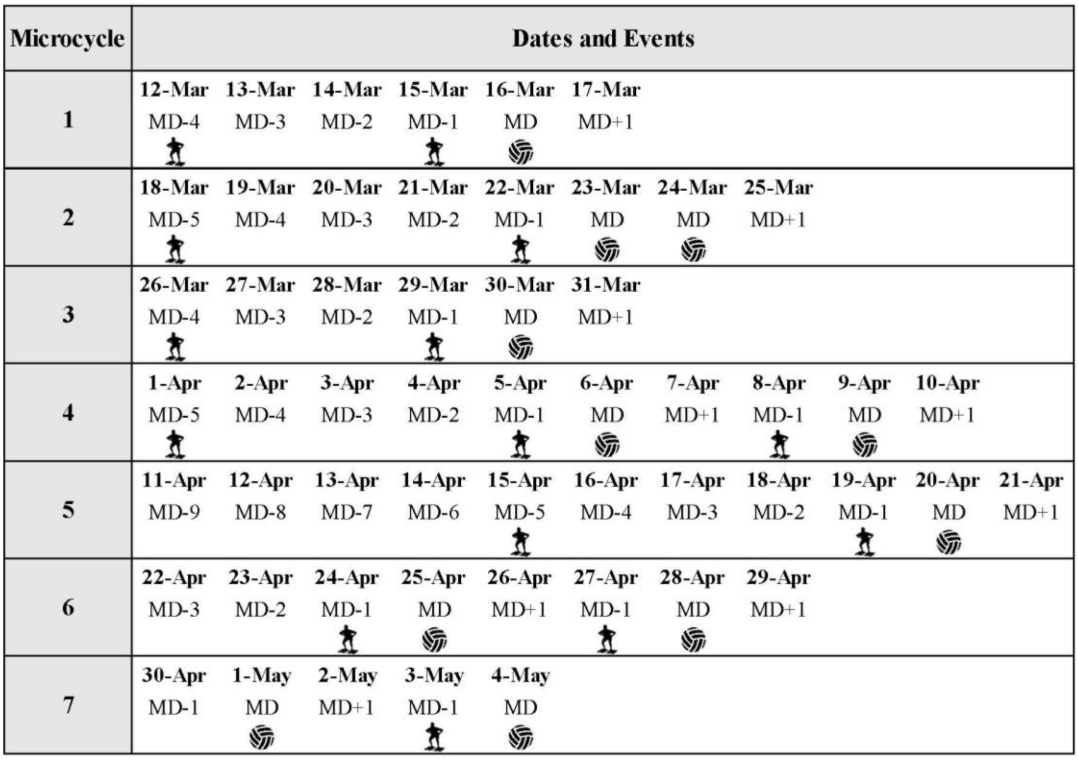
The primary objective of this study was to evaluate the impact of a congested match schedule on CMJ performance and its respective metrics in elite volleyball players. Specifically, the study aimed to investigate how different CMJ metrics varied across successive microcycles and between the beginning and end of the competitive week. The analysis encompassed various metrics recorded across different phases of the CMJ to determine if any specific phase was more affected by the congested training and match schedule. We hypothesized that metrics involving temporal components would exhibit greater variability since athletes potentially have to adjust their jump strategy to maintain force production throughout the entire range of motion [15].

4.6.3. Methods

Experimental Approach to the Problem

The study was conducted with a male volleyball team competing in the Portuguese Championship, Liga UNA Seguros (i.e., men's senior first division of the Portuguese Volleyball Federation). Data collection took place during the final mesocycle of the competitive season, spanning from March 12 to May 4, 2024. This period included the last game of the second phase of the Championship, the two matches of the final four of the Portuguese Cup, and the eight matches of the final four of the Championship (three matches of the semi-final and five matches of the final), totaling 11 matches. In addition, 34 training sessions were conducted during this period, with one training session on each non-match day, except for MD+1 (i.e., the day following a match, where MD stands for match day), where no training sessions took place. Microcycle lengths were determined based on the match schedule, with each microcycle ending on MD+1. For microcycles with multiple matches (such as Microcycles 4, 6, and 7), the microcycle continued until MD+1 of the final match. In the case of Microcycle 2, which had back-to-back matches on consecutive days, the microcycle shifted after the first (and only) MD+1 to account for the unique scheduling.

Recruitment occurred at the start of the mesocycle, and players were continuously monitored throughout the period of the study. The CMJ assessments were conducted fourteen times across this period. These dates, along with the match schedule, are detailed in Figure IV-12. This timeline includes periods of recruitment, exposure, follow-up, and data collection, providing a comprehensive view of the study's temporal structure.



Microcycle	Dates and Events										
1	12-Mar	13-Mar	14-Mar	15-Mar	16-Mar	17-Mar					
	MD-4	MD-3	MD-2	MD-1	MD	MD+1					
2	18-Mar	19-Mar	20-Mar	21-Mar	22-Mar	23-Mar	24-Mar	25-Mar			
	MD-5	MD-4	MD-3	MD-2	MD-1	MD	MD	MD+1			
3	26-Mar	27-Mar	28-Mar	29-Mar	30-Mar	31-Mar					
	MD-4	MD-3	MD-2	MD-1	MD	MD+1					
4	1-Apr	2-Apr	3-Apr	4-Apr	5-Apr	6-Apr	7-Apr	8-Apr	9-Apr	10-Apr	
	MD-5	MD-4	MD-3	MD-2	MD-1	MD	MD+1	MD-1	MD	MD+1	
5	11-Apr	12-Apr	13-Apr	14-Apr	15-Apr	16-Apr	17-Apr	18-Apr	19-Apr	20-Apr	21-Apr
	MD-9	MD-8	MD-7	MD-6	MD-5	MD-4	MD-3	MD-2	MD-1	MD	MD+1
6	22-Apr	23-Apr	24-Apr	25-Apr	26-Apr	27-Apr	28-Apr	29-Apr			
	MD-3	MD-2	MD-1	MD	MD+1	MD-1	MD	MD+1			
7	30-Apr	1-May	2-May	3-May	4-May						
	MD-1	MD	MD+1	MD-1	MD						

Figure IV-12: Timeline of countermovement jump assessments and match schedule across microcycles.

The study adhered to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement guidelines [17]. The study methods were reviewed and approved by the institutional review board at the first author's affiliated university (IRB approval number: M1623). The experimental protocol conformed to the recommendations of the Declaration of Helsinki by the World Medical Association for research involving human subjects [18]. Additionally, all procedures adhered to established ethical standards for sports medicine [19].

Subjects

The participants in this study needed to be classified as elite level players, according to a previously published classification framework based on their participation in national and international competitions and professional status within the sport [20]. Eligible participants were required to be aged 18 years or older and competing during a congested match period. Players needed to regularly participate in team training sessions and matches and be free from any injury or condition that could affect their ability to perform jump tests across the study. Exclusion criteria included any injuries or conditions that impaired the players' ability to perform the required physical assessments, or an inability to consistently participate in training and matches. During the experimental period, participants were closely monitored to ensure consistent data collection and adherence to the study protocol.

A total of 14 elite male volleyball players (age: 28.94 ± 4.99 years; body-mass: 90.84 ± 10.57 kg; height: 1.94 ± 0.09 m) were included in the study. There were no exclusions during the study period, and all players completed the follow-up. Throughout the study, there were no missing data for any of the primary variables of interest, ensuring a complete dataset for analysis. The participants comprised 2 liberos, 4 middle blockers, 4 outside hitters, 2 setters, and 2 opposite hitters.

Variables and Data Collection

The primary outcomes of this study were the CMJ metrics, categorized into distinct phases: braking, transfer, propulsive, and flight phases. Each phase encompasses specific metrics that were carefully defined and are detailed in Table IV-24.

All CMJ trials were conducted using two portable adjacent force plates (Hawkin Dynamics, Westbrook, Maine, USA), with data collected at a frequency of 1000 Hz. Participants performed three maximal effort trials following a standardized instruction, which required them to jump "as fast and high as possible" with their hands on their hips. The average of all trials was used for analysis.

Table IV-24: Selected countermovement jump phases and metrics with definitions.

Phase	Metric	Definition
Braking	Braking impulse	Vertical impulse applied to the system COM during the braking phase
	Average braking force	Average vertical GRF applied to the system COM during the braking phase
	Peak braking force	Peak instantaneous vertical GRF applied to the system COM during the braking phase
	Peak braking power	Peak negative instantaneous mechanical power applied to the system COM during the braking phase
	Average braking velocity	Average vertical velocity of the system COM during the braking phase
	Peak braking velocity	Peak negative instantaneous vertical velocity of the system COM during the braking phase
	Braking phase duration	Time taken to complete the braking phase

Transfer	Countermovement depth	Peak negative vertical displacement of the system COM
	Relative force at minimum displacement	Vertical GRF applied to the system COM at the point of the peak negative vertical displacement of the system COM as a percentage of system weight
	Force at minimum displacement	Vertical GRF applied to the system COM at the point of the peak negative vertical displacement of the system COM
	Impulse ratio	Ratio between the net vertical impulse applied to the system COM during the braking phase and the net vertical impulse applied to the system COM during the propulsion phase
	Stiffness	Vertical GRF applied to the system COM at the instant of peak negative vertical displacement of the system COM divided by the peak negative vertical displacement of the system COM
Propulsive	Propulsive impulse	Vertical impulse applied to the system COM during the propulsive phase
	Average propulsive force	Average vertical GRF applied to the system COM during the propulsive phase
	Peak propulsive force	Peak instantaneous vertical GRF applied to the system COM during the propulsive phase
	Peak propulsive power	Peak instantaneous mechanical power applied to the system COM during the propulsive phase
	Average propulsive velocity	Average vertical velocity of the system COM during the propulsive phase
	Peak propulsive velocity	Peak instantaneous vertical velocity of the system COM during the propulsive phase
	Propulsive phase duration	Time taken to complete the propulsive phase
Flight	Jump height	Change in system COM position between the instant of take-off and peak positive vertical displacement of the system COM
	Jump momentum	Vertical momentum of the system COM at the instant of take-off
	Take-off velocity	Vertical velocity of the system COM at the instant of take-off
	Flight time	Time taken to complete the flight phase
General	$mRSI_{JH}$	Jump height divided by the time to take-off
	$mRSI_{FT}$	Flight time divided by the time to take-off
	Time to take-off	Total time taken from the initiation of movement to the instant of take-off

$mRSI_{JH}$ = reactive strength index modified with jump height as numerator, $mRSI_{FT}$ = reactive strength index modified with flight time as numerator, COM = center of mass, GRF = ground reaction force.

Body weight was calculated by averaging the vertical force trace over the first second of data collection, during which the athlete was required to stand as still as possible for at least one second to accurately determine their body weight [21]. Movement onset was defined as the 30 milliseconds before the vertical ground reaction force exceeded the mean plus or minus five times the standard deviation during the weighing phase [22]. The braking phase was identified as the period from the instant of peak negative center of mass (COM) velocity until the COM velocity increased to zero, corresponding with the bottom portion of the countermovement [21]. The transfer phase was defined as the point between the braking and propulsive phases when velocity is zero. The propulsive phase was defined as the period during which the athlete forcefully extended their hips, knees, and ankles to propel their COM vertically. This phase occurs between the point where the velocity exceeds 0.01 meters per second and the instant of take-off [21].

Statistical Analyses

The sample size necessary for this study was determined using G*Power (v. 3.1.9.7; Heinrich Heine University Dusseldorf, Dusseldorf, Germany). Based on the highest effect size observed in the preliminary data ($\eta p^2 = 0.225$, which corresponds to Cohen's $f = 0.54$), an a priori power analysis for repeated measures ANOVA within factors was conducted. The analysis was set with an alpha level of 0.05 and a desired power of 0.95. Other parameters included a correlation among repeated measures set at 0.5 and a nonsphericity correction ε set at 1. The output parameters indicated a noncentrality parameter of 28.5768, a critical F value of 2.3638, with 6 degrees of freedom for the numerator and 36 degrees of freedom for the denominator. The analysis revealed that a total sample size of 7 participants would be sufficient to achieve an actual power of 0.975.

All CMJ metrics were transformed into scaled z-scores ranging from 0 to 100. This transformation standardizes the data and allows for meaningful comparisons across different metrics and phases [23]. A z-score of 50 represents the mean value, a z-score of 0 represents the absolute worst performance observed; and a z-score of 100 represents the absolute best performance observed. The scaled z-scores were calculated using the following formula:

$$Scaled\ z - score\ = \frac{raw\ score\ -\ mean}{standard\ deviation} \times\ 12.5\ +\ 50.$$

The TSA for each phase was computed as the average of all scaled z-scores within that phase [16]. This approach allowed the compilation of multiple performance inputs into a single output, providing a clear and concise measure of athletic performance.

The statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS, version 27, IBM Corp., Armonk, NY, USA). A simple univariate repeated measures analysis of variance (ANOVA) with Mauchly's test of sphericity was employed to assess the impact of congested match schedules on CMJ metrics. The repeated measures ANOVA was performed separately for comparisons between microcycles and between the beginning (i.e., MD-5 or MD-4) and end of the week (i.e., MD-1). When the p-value of the Mauchly's Test was less than 0.05, indicating a violation of the sphericity assumption, the

Greenhouse-Geisser correction was applied to adjust the degrees of freedom. The reported variables include the F-value, the p-value, and partial eta squared (ηp^2) as the measure of effect size. Effect sizes were interpreted using the following thresholds: small ($\eta p^2 = 0.01$), medium ($\eta p^2 = 0.06$), and large ($\eta p^2 = 0.14$) [24]. Post-hoc analyses were conducted using the Bonferroni correction to identify specific pairwise differences between the successive microcycles and between the beginning and end of the week. This method adjusts for multiple comparisons to control for Type I errors, providing more reliable identification of significant differences [25].

Additionally, the coefficient of variation (CV) for each CMJ metric was calculated to assess the relative variability across microcycles and matchdays. The CV was computed using the following formula [26]:

$$CV\ (\%) = \frac{standard\ deviation}{mean} \times 100$$

Thresholds for CV interpretation were defined as follows (13): low variability (< 10%), moderate variability (10% - 20%), and high variability (> 20%).

4.6.4. Results

The repeated measures ANOVA revealed significant differences in several CMJ metrics across the microcycles. Table IV-25 summarizes the descriptive statistics, Mauchly's test of sphericity, and the repeated measures ANOVA results for CMJ metrics across the seven microcycles.

Table IV-25: Descriptive statistics, Mauchly's test of sphericity, and repeated measures ANOVA results for countermovement jump metrics across microcycles.

Phase	Metric (scaled z-score)	Descriptive statistics (mean ± SD)							Mauchly's test of sphericity			RMANOVA		
		Microcycle 1	Microcycle 2	Microcycle 3	Microcycle 4	Microcycle 5	Microcycle 6	Microcycle 7	W	χ2	*p*	F	*p*	η_p^2
Braking	Braking impulse	50.64 ± 11.60	52.93 ± 10.23	47.57 ± 10.79	49.83 ± 12.68	52.50 ± 13.04	54.39 ± 7.22	51.71 ± 7.80	0.053	31.611	0.056	2.409	0.035*	0.156
	Average braking force	55.46 ± 4.17	50.39 ± 8.89	54.21 ± 5.42	54.36 ± 4.41	54.39 ± 4.28	52.29 ± 7.87	53.57 ± 10.72	0.024	40.301	0.006	0.923	0.437	0.066
	Peak braking force	55.07 ± 6.23	50.07 ± 7.23	54.25 ± 5.07	54.36 ± 4.60	53.43 ± 5.31	50.46 ± 8.07	51.93 ± 13.32	0.021	41.504	0.004	1.124	0.348	0.080
	Peak braking power	55.32 ± 4.25	51.07 ± 10.89	52.82 ± 6.50	54.40 ± 5.60	55.18 ± 6.90	54.54 ± 8.76	53.21 ± 9.42	0.077	27.643	0.132	0.716	0.638	0.052
	Average braking velocity	53.29 ± 7.40	51.43 ± 10.95	51.46 ± 9.10	53.12 ± 8.21	55.11 ± 7.92	55.39 ± 8.89	51.64 ± 8.49	0.031	37.385	0.013	1.060	0.375	0.075
	Peak braking velocity	54.18 ± 7.09	51.71 ± 11.93	51.64 ± 8.00	53.07 ± 7.95	55.36 ± 8.75	55.89 ± 9.22	52.93 ± 8.63	0.028	38.527	0.010	0.959	0.416	0.069
	Braking phase duration	53.50 ± 6.85	48.96 ± 9.37	54.43 ± 7.37	52.81 ± 8.66	51.50 ± 8.23	49.11 ± 5.79	51.50 ± 10.04	0.024	40.015	0.006	1.557	0.222	0.107
	Braking phase TSA	53.92 ± 3.62	50.94 ± 7.80	52.34 ± 4.82	53.14 ± 3.38	53.92 ± 4.17	53.15 ± 6.31	52.36 ± 7.59	0.026	39.195	0.008	0.656	0.570	0.048
Transfer	Countermovement depth	48.86 ± 10.55	46.64 ± 12.10	48.50 ± 8.99	48.05 ± 10.67	50.50 ± 12.13	53.04 ± 8.24	50.57 ± 10.29	0.013	46.649	0.001	1.962	0.131	0.131
	Relative force at min displacement	54.93 ± 7.52	49.86 ± 8.96	54.21 ± 5.30	54.17 ± 4.98	52.96 ± 6.61	50.82 ± 7.27	51.29 ± 12.79	0.011	48.848	<0.001	1.052	0.371	0.075
	Force at min displacement	55.46 ± 6.50	50.36 ± 7.44	54.11 ± 5.04	54.05 ± 3.87	53.39 ± 5.26	50.64 ± 7.61	51.86 ± 13.01	0.013	46.864	0.001	1.079	0.364	0.077
	Impulse ratio	48.50 ± 6.01	48.50 ± 10.64	51.32 ± 8.44	49.81 ± 7.59	47.75 ± 8.73	45.75 ± 7.06	48.21 ± 8.02	0.027	39.032	0.008	1.210	0.319	0.085
	Stiffness	52.71 ± 8.68	52.50 ± 10.13	52.68 ± 7.23	53.40 ± 9.52	51.21 ± 10.98	47.29 ± 7.14	50.64 ± 10.13	0.064	29.628	0.087	1.970	0.080	0.132
	Transfer phase TSA	52.09 ± 3.37	49.57 ± 3.06	52.16 ± 2.80	51.89 ± 2.74	51.16 ± 3.31	49.51 ± 3.44	50.51 ± 5.69	0.044	33.577	0.035	1.946	0.143	0.130
Propulsive	Propulsive impulse	50.75 ± 11.62	47.89 ± 11.45	49.29 ± 9.31	49.64 ± 10.92	52.68 ± 11.95	53.07 ± 8.57	54.43 ± 11.18	0.036	35.867	0.020	2.446	0.076	0.158
	Average propulsive force	56.89 ± 7.73	53.96 ± 7.87	56.71 ± 8.31	55.57 ± 9.71	54.86 ± 10.35	49.32 ± 8.38	50.29 ± 12.65	0.096	25.282	0.209	3.769	0.002*	0.225
	Peak propulsive force	55.54 ± 6.82	52.25 ± 8.09	53.82 ± 5.96	54.26 ± 6.71	52.86 ± 8.61	50.89 ± 8.49	52.93 ± 12.57	0.018	43.215	0.003	0.837	0.487	0.060
	Peak propulsive power	59.29 ± 5.72	53.82 ± 6.92	60.42 ± 8.10	59.69 ± 7.25	59.89 ± 9.93	51.68 ± 7.91	51.93 ± 11.93	0.087	26.320	0.172	6.568	<0.001*	0.336
	Average propulsive velocity	57.82 ± 6.01	50.18 ± 8.55	55.79 ± 4.50	55.98 ± 3.25	55.68 ± 5.99	54.00 ± 6.56	54.29 ± 11.51	0.025	39.594	0.007	1.886	0.159	0.127
	Peak propulsive velocity	58.89 ± 7.06	49.86 ± 9.02	58.18 ± 6.39	58.48 ± 5.33	59.18 ± 8.08	55.57 ± 8.75	54.79 ± 12.45	0.066	29.281	0.094	3.399	0.005*	0.207

	Propulsive phase duration	53.93 ± 8.85	53.46 ± 9.87	54.39 ± 7.95	53.41 ± 10.54	51.46 ± 11.34	48.54 ± 8.08	48.36 ± 12.54	0.056	31.095	0.063	3.181	0.008*	0.197
	Propulsive phase TSA	56.16 ± 3.67	51.63 ± 3.74	55.52 ± 4.09	55.29 ± 3.88	55.23 ± 5.43	51.87 ± 5.14	52.43 ± 8.08	0.087	26.370	0.170	3.420	0.005*	0.208
Flight	Jump height	58.79 ± 7.11	49.43 ± 8.82	58.25 ± 7.13	58.17 ± 6.14	58.96 ± 8.18	55.00 ± 9.19	53.50 ± 12.88	0.058	30.699	0.068	3.768	0.002*	0.225
	Jump momentum	60.25 ± 8.49	51.21 ± 6.59	58.36 ± 7.09	58.22 ± 6.13	60.46 ± 7.60	54.50 ± 11.35	55.71 ± 12.04	0.018	43.202	0.003	3.783	0.019*	0.225
	Take-off velocity	58.71 ± 6.89	49.46 ± 8.83	57.86 ± 7.28	58.14 ± 6.08	58.82 ± 8.01	54.89 ± 8.91	53.43 ± 12.70	0.065	29.451	0.090	3.698	0.003*	0.221
	Flight time	57.39 ± 8.09	52.36 ± 6.39	57.11 ± 9.86	56.26 ± 7.13	57.00 ± 8.22	56.39 ± 7.68	55.07 ± 9.78	0.075	27.922	0.125	0.933	0.476	0.067
	Flight phase TSA	59.15 ± 6.91	50.62 ± 6.80	57.90 ± 7.15	57.70 ± 5.52	58.82 ± 7.26	55.20 ± 8.62	54.43 ± 10.98	0.044	33.656	0.034	3.410	0.022*	0.208
General	$mRSI_{JH}$	55.89 ± 7.30	52.21 ± 9.19	54.68 ± 5.82	55.26 ± 9.46	56.43 ± 10.28	51.39 ± 7.58	53.29 ± 11.36	0.152	20.273	0.462	1.250	0.290	0.088
	$mRSI_{FT}$	54.39 ± 7.56	53.46 ± 9.15	53.21 ± 5.81	53.91 ± 9.80	54.79 ± 9.89	51.25 ± 7.55	53.64 ± 10.00	0.230	15.861	0.740	0.548	0.770	0.040
	Time to take-off	52.54 ± 7.97	52.57 ± 9.05	51.36 ± 6.44	52.52 ± 9.63	53.07 ± 9.64	49.68 ± 7.10	52.43 ± 9.76	0.207	16.971	0.672	0.633	0.704	0.046
	General metrics TSA	54.27 ± 7.41	52.75 ± 8.97	53.08 ± 5.64	53.88 ± 9.55	54.76 ± 9.82	50.77 ± 7.20	53.12 ± 9.99	0.188	18.004	0.606	0.735	0.623	0.054

RMANOVA = repeated measures analysis of variance, $mRSI_{JH}$ = reactive strength index modified with jump height as numerator, $mRSI_{FT}$ = reactive strength index modified with flight time as numerator, TSA = total score of athleticism. * Significant p-values ($p < 0.05$) from the RMANOVA.

Significant main effects ($p < 0.05$) were found in the ANOVA for multiple metrics, including braking impulse ($F(6, 78) = 2.409$, $p = 0.035$, $\eta p^2 = 0.156$), average propulsive force ($F(6, 78) = 3.769$, $p = 0.002$, $\eta p^2 = 0.225$), peak propulsive power ($F(6, 78) = 6.568$, $p < 0.001$, $\eta p^2 = 0.336$), peak propulsive velocity ($F(6, 78) = 3.399$, $p = 0.005$, $\eta p^2 = 0.207$), propulsive phase duration ($F(6, 78) = 3.181$, $p = 0.008$, $\eta p^2 = 0.197$), propulsive phase TSA ($F(6, 78) = 3.420$, $p = 0.005$, $\eta p^2 = 0.208$), jump height ($F(6, 78) = 3.768$, $p = 0.002$, $\eta p^2 = 0.225$), jump momentum ($F(6, 78) = 3.783$, $p = 0.019$, $\eta p^2 = 0.225$), take-off velocity ($F(6, 78) = 3.698$, $p = 0.003$, $\eta p^2 = 0.221$), and flight phase TSA ($F(6, 78) = 3.410$, $p = 0.022$, $\eta p^2 = 0.208$). However, for some metrics, despite the significant results, the post-hoc analyses did not show statistically significant mean differences between specific microcycles. These metrics included braking impulse, average propulsive force, propulsive phase duration, and propulsive phase TSA. Despite this, the effect size for these metrics were large ($\eta p^2 \geq 0.14$), indicating substantial variability and potentially meaningful differences that were not detected in the pairwise comparisons.

The repeated measures ANOVA comparing CMJ metrics between the beginning and end of the week revealed that the majority of CMJ metrics did not show significant differences (Table IV-26). However, jump momentum, demonstrated a significant difference ($F(1, 13) = 7.568$, $p = 0.017$, $\eta p^2 = 0.368$). Other metrics, such as propulsive impulse ($\eta p^2 = 0.258$) and propulsive phase TSA ($\eta p^2 = 0.169$), showed large effect sizes despite not reaching statistical significance, indicating substantial variability that may still be of practical importance.

Table IV-26: Descriptive statistics and repeated measures ANOVA results for countermovement jump metrics between matchdays (beginning vs. end of week).

Phase	Metric (scaled z-score)	Descriptive statistics (mean ± SD)		RMANOVA		
		Beginning of week	End of week	F	*p*	η_p^2
Braking	Braking impulse	51.60 ± 11.01	51.03 ± 9.45	0.341	0.569	0.026
	Average braking force	54.13 ± 3.89	53.28 ± 4.37	0.318	0.582	0.024
	Peak braking force	54.06 ± 3.90	52.37 ± 5.09	1.043	0.326	0.074
	Peak braking power	54.27 ± 5.69	53.66 ± 5.29	0.155	0.700	0.012
	Average braking velocity	53.70 ± 7.53	52.87 ± 7.33	0.316	0.584	0.024
	Peak braking velocity	53.90 ± 7.73	53.36 ± 7.29	0.114	0.741	0.009
	Braking phase duration	52.13 ± 6.61	51.59 ± 6.25	0.191	0.670	0.014

	Braking phase TSA	53.40 ± 3.86	52.59 ± 4.05	0.456	0.511	0.034
Transfer	Countermovement depth	49.69 ± 10.50	49.04 ± 8.86	0.291	0.599	0.022
	Relative force at min displacement	53.40 ± 5.25	52.48 ± 5.35	0.297	0.595	0.022
	Force at min displacement	54.07 ± 4.18	52.40 ± 4.88	0.953	0.347	0.068
	Impulse ratio	48.80 ± 7.03	48.59 ± 6.60	0.023	0.882	0.002
	Stiffness	52.06 ± 9.41	51.48 ± 7.20	0.196	0.666	0.015
	Transfer phase TSA	51.60 ± 2.28	50.80 ± 2.60	1.276	0.279	0.089
Propulsive	Propulsive impulse	51.93 ± 10.55	50.12 ± 9.05	4.522	0.053	0.258
	Average propulsive force	55.40 ± 9.14	53.72 ± 7.12	1.782	0.205	0.121
	Peak propulsive force	53.77 ± 6.03	53.06 ± 6.64	0.261	0.618	0.020
	Peak propulsive power	58.34 ± 7.23	56.61 ± 6.17	1.989	0.182	0.133
	Average propulsive velocity	55.80 ± 4.46	54.46 ± 4.29	0.784	0.392	0.057
	Peak propulsive velocity	57.51 ± 6.03	56.22 ± 5.63	0.960	0.345	0.069
	Propulsive phase duration	52.23 ± 9.87	52.33 ± 8.12	0.012	0.913	0.001
	Propulsive phase TSA	55.00 ± 3.22	53.79 ± 3.66	2.645	0.128	0.169
Flight	Jump height	57.14 ± 6.23	55.90 ± 6.07	0.957	0.346	0.069
	Jump momentum	59.11 ± 5.14	56.04 ± 6.85	7.568	0.017*	0.368
	Take-off velocity	57.10 ± 6.16	55.76 ± 5.98	1.090	0.316	0.077
	Flight time	56.01 ± 6.02	56.03 ± 5.54	<0.001	0.987	<0.001
	Flight phase TSA	57.49 ± 5.29	55.94 ± 5.44	1.920	0.189	0.129
General	$mRSI_{JH}$	54.41 ± 7.29	54.23 ± 6.85	0.030	0.866	0.002
	$mRSI_{FT}$	53.16 ± 7.25	53.76 ± 7.09	0.529	0.480	0.039
	Time to take-off	51.49 ± 7.53	52.33 ± 7.12	1.051	0.324	0.075
	General metrics TSA	53.02 ± 7.23	53.44 ± 6.88	0.238	0.634	0.018

RMANOVA = repeated measures analysis of variance, $mRSI_{JH}$ = reactive strength index modified with jump height as numerator, $mRSI_{FT}$ = reactive strength index modified with flight time as numerator, TSA = total score of athleticism. * Significant p-values ($p < 0.05$) from the RMANOVA.

The post-hoc analyses using the Bonferroni correction identified specific pairwise differences for various metrics, as presented in Table IV-27. Notable significant comparisons include:

• Peak propulsive power: Significant differences were observed between Microcycle 3 and Microcycle 6 (mean difference = 8.750, p = 0.027) and between Microcycle 4 and Microcycle 6 (mean difference = 8.012, p = 0.044).

• Peak propulsive velocity: A significant difference was observed between Microcycle 1 and Microcycle 2 (mean difference = 9.036, p = 0.012).

• Jump height: Significant differences were found between Microcycle 1 and Microcycle 2 (mean difference = 9.357, p = 0.008), between Microcycle 2 and Microcycle 4 (mean difference = -8.738, p = 0.038), and between Microcycle 2 and Microcycle 5 (mean difference = -9.536, p = 0.033).

• Jump momentum: Significant differences were noted between Microcycle 1 and Microcycle 2 (mean difference = 9.036, p = 0.006) and between Microcycle 2 and Microcycle 5 (mean difference = -9.250, p = 0.023).

• Take-off velocity: Significant differences were identified between Microcycle 1 and Microcycle 2 (mean difference = 9.250, p = 0.009), between Microcycle 2 and Microcycle 4 (mean difference = -8.679, p = 0.041), and between Microcycle 2 and Microcycle 5 (mean difference = -9.357, p = 0.033).

• Flight phase TSA: Significant differences were seen between Microcycle 1 and Microcycle 2 (mean difference = 8.526, p = 0.009) and between Microcycle 2 and Microcycle 5 (mean difference = -8.196, p = 0.041).

• Jump momentum decreased significantly from the beginning of the week to the end of the week (mean difference = 3.076, p = 0.017).

Table IV-27: Post-hoc comparisons for countermovement jump metrics between microcycles and between beginning and end of the week matchdays.

Phase	Metric (scaled z-score)	Comparison	Mean difference	Std. error	*p* (adjusted)	95% Confidence interval	
						Lower	Upper
Propulsive	Peak propulsive power	Microcycle 3 vs Microcycle 6	8.750	2.138	0.027	0.711	16.789
		Microcycle 4 vs Microcycle 6	8.012	2.096	0.044	0.130	15.895
	Peak propulsive velocity	Microcycle 1 vs Microcycle 2	9.036	1.987	0.012	1.563	16.508
Flight	Jump height	Microcycle 1 vs Microcycle 2	9.357	1.964	0.008	1.974	16.740
		Microcycle 2 vs Microcycle 4	-8.738	2.241	0.038	-17.166	-0.310
		Microcycle 2 vs Microcycle 5	-9.536	2.393	0.033	-18.534	-0.538
	Jump momentum	Microcycle 1 vs Microcycle 2	9.036	1.826	0.006	2.170	15.901
		Microcycle 2 vs Microcycle 5	-9.250	2.215	0.023	-17.579	-0.921
		Beginning of week vs End of week	3.076	1.118	0.017	0.660	5.491
	Take-off velocity	Microcycle 1 vs Microcycle 2	9.250	1.967	0.009	1.853	16.647
		Microcycle 2 vs Microcycle 4	-8.679	2.243	0.041	-17.114	-0.244
		Microcycle 2 vs Microcycle 5	-9.357	2.348	0.033	-18.187	-0.527
	Flight phase TSA	Microcycle 1 vs Microcycle 2	8.526	1.812	0.009	1.714	15.337
		Microcycle 2 vs Microcycle 5	-8.196	2.123	0.041	-16.181	-0.212

TSA = total score of athleticism.

The CVs for all metrics were consistently higher across microcycles, ranging from 7.01% to 12.05%, indicating moderate variability (Table IV-28). In contrast, the CVs for all metrics across matchdays were significantly lower, ranging from 1.79% to 4.14%, indicating low variability.

Table IV-28: Coefficient of variation for countermovement jump metrics across microcycles and matchdays.

Phase	Metric (scaled z-score)	Coefficient of variation (%)	
		Across microcycles	Across matchdays
Braking	Braking impulse	10.50	2.80
	Average braking force	10.63	3.99
	Peak braking force	11.40	3.71
	Peak braking power	10.94	4.13
	Average braking velocity	9.78	3.25
	Peak braking velocity	10.32	3.74
	Braking phase duration	10.53	3.41
	Braking phase TSA	7.82	2.93
Transfer	Countermovement depth	10.33	3.49
	Relative force at min displacement	11.48	4.14
	Force at min displacement	11.16	4.00
	Impulse ratio	10.69	3.85
	Stiffness	10.00	3.02
	Transfer phase TSA	5.37	1.79
Propulsive	Propulsive impulse	10.41	3.06
	Average propulsive force	10.65	3.09
	Peak propulsive force	10.21	3.25
	Peak propulsive power	10.55	3.42
	Average propulsive velocity	10.67	3.99
	Peak propulsive velocity	11.67	3.83
	Propulsive phase duration	10.34	2.19
	Propulsive phase TSA	7.01	2.13
Flight	Jump height	12.05	3.58
	Jump momentum	11.31	3.85
	Take-off velocity	11.95	3.59
	Flight time	10.61	2.83
	Flight phase TSA	10.65	3.06
General	$mRSI_{JH}$	10.11	2.85
	$mRSI_{FT}$	9.13	2.22

Time to take-off	9.29	2.28
General metrics TSA	9.18	2.38

$mRSI_{JH}$ = reactive strength index modified with jump height as numerator, $mRSI_{FT}$ = reactive strength index modified with flight time as numerator, TSA = total score of athleticism.

4.6.5. Discussion

The primary objective of this study was to assess the impact of a congested match schedule on various CMJ metrics in elite volleyball players. Our main findings indicated significant variability in several CMJ metrics across microcycles, with the propulsive phase (average propulsive force, peak propulsive power, peak propulsive velocity, propulsive phase duration, propulsive phase TSA) and the flight phase (jump height, jump momentum, take-off velocity, flight phase TSA) showing the most differences. Additionally, while most metrics did not show significant changes between the beginning and end of the week, jump momentum exhibited a significant decrease. Previous research has already indicated that variables used to monitor neuromuscular fatigue should exhibit a small to moderate CV and a moderate to large effect size [4]. The significant metrics identified in this study align with these findings.

The braking impulse is directly influenced by the strategy employed by the athlete. If an athlete aims to minimize the time spent in the braking phase (i.e., braking phase duration), they must produce a larger force over a shorter period to match the unweighting phase net impulse and reduce momentum to zero [21]. The significant variability in braking impulse across microcycles ($p = 0.035$, $\eta p^2 = 0.156$) suggests that athletes may alter their braking strategies in response to the high physical and physiological demands they face during a congested match schedule. In the same vein, the significant variability in average propulsive force observed across microcycles may indicate that athletes adjust their propulsive strategies due to accumulated fatigue. Indeed, the lowest values were observed in the last microcycles, which might be expected due to fatigue. Previous research has primarily focused on peak force rather than on average force during any phase [15,27]. However, a previous study following a 19-week fatigue protocol demonstrated that athletes applied less force and took longer to reach peak force [27]. These reductions in CMJ performance clearly reflect the athletes' response to fatigue. While the present study did not show any significant differences in peak braking force, it suggested that average propulsive force might be worth monitoring over time.

In recent years, there has been an increasing interest in time-related data, with metrics such as jumping phase duration becoming more prominent in various studies [4,28,29]. In this study, the z-scores for propulsive phase duration across the microcycles decreased ($p = 0.008$, $\eta p^2 = 0.197$), indicating that the propulsive phase was taking longer as the season progressed. This trend aligns with previous research on the acute effects of training, which has shown that fatigued athletes tend to spend more time in the propulsive phase [27]. For practical purposes, this means that as athletes become more fatigued, they require longer periods of time to produce the necessary force for propulsion. Despite the significant results for these three respective metrics (i.e., braking impulse, average propulsive force, and propulsive phase duration), the post-hoc analysis did not reveal statistically significant pairwise differences between certain specific microcycles. This suggests that while overall trends in the variability of these metrics were detected, specific comparisons between microcycles did not reach the threshold for significance. This could be due to the relatively small sample size or the inherent variability in individual responses to both training and match loads. Therefore, these findings should be interpreted with caution.

The last two microcycles exhibited the lowest peak propulsive power values, especially when comparing microcycle 6 with microcycles 3 ($p = 0.027$) and 4 ($p = 0.044$). Peak power, along with jump height, is commonly reported in studies using the CMJ [4]. It has been extensively studied due to its associations with various strength measures. Specifically, peak power has been linked to maximal force production capability during the isometric mid-thigh pull ($r = 0.43–0.75$) and dynamic squatting ($r = 0.66–0.84$) [30,31]. The results from the present study suggest that peak propulsive power might be a valuable metric to monitor weekly during CMJ tests, especially in mesocycles with a congested match schedule. The observed decreases in peak propulsive power in the final microcycles align with the expectation that accumulated fatigue would negatively impact power production.

It is important to connect this discussion with the discussion on peak propulsive velocity, as peak propulsive power is the product of peak propulsive force and peak propulsive velocity. Although peak propulsive force did not show any significant changes, peak propulsive velocity decreased significantly ($p = 0.005$, $\eta p^2 = 0.207$). This decrease in peak propulsive velocity was directly influenced by the prolonged propulsive phase duration, as discussed earlier. These results indicate that the decline in peak propulsive power was primarily due to reductions in peak propulsive velocity rather than peak propulsive force. These findings highlight the importance of linking CMJ metrics during ongoing monitoring [2]. For instance, peak propulsive velocity and peak propulsive force represent the two component parts of peak propulsive power and should be interpreted in conjunction with it. Practitioners can better understand changes in peak propulsive power by considering both components. Changes in peak propulsive power can arise from alterations in peak propulsive force, alterations in peak propulsive velocity, or a combination of both. Therefore, adopting a comprehensive approach that includes monitoring all these metrics can provide a clearer understanding of an athlete's neuromuscular status and assist in tailoring training and recovery strategies more effectively.

Other metrics that exhibited significant differences between microcycles were jump height ($p = 0.002$, $\eta p^2 = 0.225$) and take-off velocity ($p = 0.003$, $\eta p^2 = 0.221$). Jump height was calculated using the equation ½ * (take-off velocity² / 9.81); hence, it is logical that both metrics showed similar trends. In this study, we averaged the results of all three CMJ trials instead of selecting the best trial, providing a more comprehensive assessment of performance across multiple attempts. This approach is consistent with previous studies that have highlighted the sensitivity of average CMJ height in monitoring the neuromuscular status [4].

Jump momentum showed significant differences across microcycles ($p = 0.019$, $\eta p^2 = 0.225$) and between the beginning and end of the week ($p = 0.017$). These differences highlight the sensitivity of this jump metric in controlling and monitoring the demands of a congested match schedule. In practical terms, jump momentum reflects the force and duration with which an athlete propels their body mass upwards before take-off during a vertical jump trial. Jump momentum is equivalent to net propulsive impulse (despite differences in units of measurement) and can be divided by body mass to determine take-off velocity, which, as discussed earlier, directly influences jump height. To illustrate this situation, consider an athlete weighing 80 kg (typical for a libero) and another weighing 100 kg (typical for a middle blocker) [32]. If both athletes generate the same jump momentum, the lighter athlete (libero) will achieve a higher take-off velocity and consequently a greater jump height. This distinction is particularly valuable when comparing athletes of varying body masses within a team, as is common in volleyball. Unlike jump height and take-off velocity, jump momentum inherently accounts for body mass, making it a more precise metric for evaluating jump performance across athletes with different physical traits. The results of this study suggest that jump momentum may be a crucial metric for monitoring athletes during periods of congested fixtures and throughout the week.

There are several limitations to this study that should be acknowledged. One limitation of this study is the decision to use z-scores rather than raw data. While this approach allowed us to standardize performance metrics across athletes, making it easier to identify relative changes, it may make comparisons with other studies that use raw data more challenging. Nevertheless, the use of z-scores was essential for our study's objective, as it minimized the influence of individual variations in baseline performance and allowed us to focus on the sensitivity of key metrics to changes in neuromuscular status during congested match periods. This approach provided valuable insights for practitioners aiming to monitor performance and recovery trends across the team. Another limitation is the exclusion of the unweighting and landing phases of the CMJ from the analysis. These phases could provide additional insights into the neuromuscular status and fatigue levels of the athletes. Finally, the study did not account for potential confounding factors such as training and match load, which could also influence CMJ ability. Future research should consider including these phases and factors to offer a more complete evaluation of jumping performance.

4.6.6. Conclusions

This study provides valuable insights into the phases and metrics of the CMJ that coaches and sport scientists may use to assess and manage athletic performance during congested match schedules. The TSA values for the propulsive and flight phases demonstrated significant variability across microcycles, indicating their sensitivity in evaluating the physical demands and fatigue experienced by athletes throughout the season.

Key metrics that should be recorded and controlled include peak propulsive power and peak propulsive velocity for the propulsive phase, as well as jump height, jump momentum, and take-off velocity for the flight phase. These metrics showed significant differences between successive microcycles and should be regularly assessed to monitor physical performance and fatigue levels during the competitive season.

Other metrics may potentially be used for training monitoring, even though they did not consistently show significant differences in post-hoc analyses. These metrics include braking impulse, average propulsive force, and propulsive phase duration, which showed significant ANOVA differences with large effect sizes, indicating substantial variability and suggesting a certain sensitivity to detecting performance changes. Practitioners should consider monitoring these metrics as part of a more comprehensive and effective interpretation of CMJ measurements, as they could provide additional insights for making informed decisions during intense training and competitive periods.

4.6.7. References

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4.7. Study VII – Optimizing Recovery: The Impact of Training Load in Elite Volleyball Players

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4.7.1. Abstract

This study aimed to analyse the relations between training load metrics and various dimensions of recovery over the course of 105 days during the competitive season. The study included 14 elite male volleyball players who participated in 95 training sessions and 18 matches. Session rating of perceived exertion and inertial measurement units were utilized to measure internal (ITL) and external training loads (ETL), respectively. Biological recovery was assessed using the countermovement jump test, while social and psychological recoveries were measured through the RESTQ-Sport. Relationships were examined using linear mixed-effects models to account for repeated measures across players and time points. The results revealed that chronic ETL negatively influenced biological recovery, with increases in chronic ETL associated with longer time to take-off ($\beta = -0.008$, $p = 0.03$) and reduced RSI modified ($\beta = -0.008$, $p = 0.047$). Social recovery was influenced by ITL metrics, with acute ITL increasing social stress ($\beta = -3.512$, $p = 0.034$). For psychological recovery, chronic ITL and the acute:chronic ITL ratio were linked to higher emotional exhaustion ($\beta = -0.013$, $p = 0.029$; $\beta = 0.021$, $p < 0.001$, respectively). These findings highlight the critical role of external load management in biological recovery and the relevance of subjective internal load measures in monitoring social and psychological recovery dimensions. Coaches are encouraged to integrate time-based neuromuscular metrics and perceptual load assessments into their recovery monitoring protocols to optimize athlete well-being and performance.

Key Words: Neuromuscular fatigue; Athlete well-being; Performance metrics; Health; Sports science.

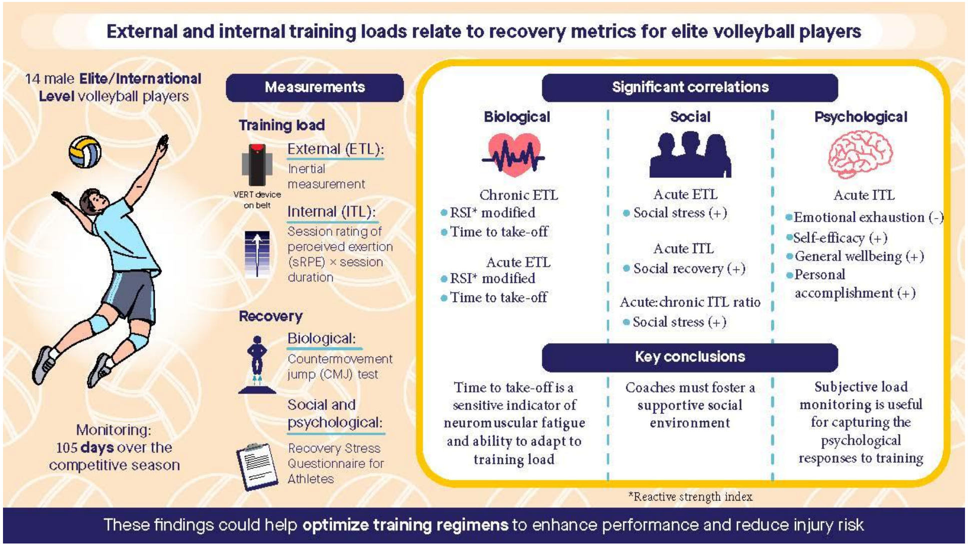

Figure IV-13: Graphical abstract of Study VII

4.7.2. Introduction

The concept of training load is central to athletic training and performance optimization, and is essential in elite team sports [1]. Training load can be broadly categorized into external and internal load, each representing different facets of the training process [2]. External training load (ETL) refers to the quantifiable aspects of physical work prescribed in a training plan, such as the number of jumps, accelerations, or kinetic energy expended during volleyball practice [3]. These metrics provide a tangible measure of the training volume and intensity an athlete is subjected to during training sessions. Internal training load (ITL), on the other hand, captures the athlete's psychophysiological response to the ETL [2]. In volleyball, this includes heart rate and perceived exertion as the most common measures, reflecting how the athlete's body responds to the physical demands placed upon it [4]. The interplay between external and internal loads is crucial, as it helps coaches and sports scientists to tailor training programs that maximize performance [1]. Furthermore, it is essential to consider that training load not only affects recovery but may also be influenced by the athlete's recovery state prior to training. Recent research in volleyball has highlighted that presession well-being can influence perceived training load, and conversely, training load can affect well-being perception in subsequent sessions, suggesting a bidirectional relationship between these variables [5,6].

Monitoring athletes is aimed at enhancing performance and plays a crucial role in assessing training load and subsequent fatigue to quantify recovery status. By evaluating whether an athlete is highly or poorly recovered, coaches and sports scientists can implement recovery-related processes such as sleep optimization, nutritional strategies, and light exercise activities during both training and competition periods [7]. Recovery is a complex, time-dependent process that encompasses both physiological and psychological dimensions, aiming to restore a balanced psychophysiological state [8]. Given that recovery needs vary both between individuals and within the same individual over time, and are influenced by a range of internal and external factors, a structured and comprehensive framework for monitoring recovery is essential.

Previous research highlights the importance of considering three distinct facets of monitoring—biological, social, and psychological [9]. Each facet provides unique insights into an athlete's recovery status, offering information that cannot be fully captured by any single approach alone. In detail, biological parameters are recognized as objective indicators of fatigue and recovery needs in elite team sports contexts. In volleyball, performance-based tests like the countermovement jump (CMJ) are commonly used to assess these parameters, providing clear evidence of an athlete's physiological status following intense training sessions [10-12]. Psychological monitoring tools, often self-report measures, gauge an athlete's perceived recovery status. These instruments assess changes in psychological states such as mood and stress, focusing on how athletes feel in response to acute or chronic training loads [10,13]. Although social monitoring may seem less prominent in athletic contexts, it plays a significant role in an athlete's recovery process [14]. Social factors such as support from coaches, family, and teammates can influence an athlete's compliance with recovery protocols, their susceptibility to stress, and their overall ability to manage recovery effectively [15].

Overuse injuries are particularly prevalent in sports that involve repetitive movement patterns, such as the frequent jumping in volleyball. According to the theoretical framework of Kenttä and Hassmén, maintaining a balance between training loads and recovery is crucial not only for performance enhancement but also for minimizing the risk of overuse injuries [16]. Despite the theoretical understanding, empirical studies exploring the relationship between training loads and recovery are limited and often rely on yearly [17] or monthly assessments [18]. By monitoring changes in training loads and recovery more frequently, specifically on a weekly basis throughout a competitive season, this study aims to provide deeper insights into how these variables interact. Such frequent monitoring can help to identify relations and patterns that are not evident in less frequent assessments.

Therefore, the primary objective of this study is to analyse the correlations between training load and various dimensions of recovery (i.e., biological, social, and psychological) of elite volleyball players. Our hypotheses are that higher acute training loads are associated with reduced biological, social, and psychological recovery metrics, and that higher chronic training loads are similarly associated with diminished recovery metrics across these dimensions. By testing these hypotheses, the aim of this study is to provide insights that can inform better management of training loads to ensure optimal recovery and performance among elite volleyball players.

4.7.3. Methods

Design

This study is a prospective cohort study conducted over 105 days, encompassing four mesocycles during the second phase of the National Championship season. The primary aim was to analyse the correlations between training load and various dimensions of recovery (biological, social, and psychological) in elite volleyball players. The study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement guidelines to ensure the accuracy and transparency of the research process [19]. The study methods were reviewed and approved by the institutional review board at the first author's affiliate university. The experimental protocol conformed to the recommendations of the Declaration of Helsinki produced by the World Medical Association for research involving human subjects [20]. Additionally, all procedures adhered to established ethical standards for sports medicine [21].

Setting

The study was conducted with one volleyball team competing in the highest Portuguese division, Liga UNA Seguros. Data collection took place over a period of 105 days, from December 2023 to March 2024, during the second phase of the national championship. This phase involved the top 8 teams in the country competing against each other twice (home and away) to qualify for the championship's playoffs (i.e., the top 4 teams). This accounts for 14 matches. Additionally, the team played two domestic cup matches and the final two matches of the first phase of the championship in December, where the league had 14 teams playing against each other once, adding up to a total of 18 matches during the study period. Recruitment and exposure periods coincided with the competitive season, ensuring that the training and recovery data reflected real-world conditions.

Participants

A total of 14 volleyball players, classified as elite players according to a previously published participant classification framework [22] were included in this study. The participants had a mean height of 193.93 cm (SD: 9.38), a mean chronological age of 28.59 years (SD: 4.99), and a mean body mass of 90.88 kg (SD: 10.56). Among the 14 players, four were outside hitters, two were setters, two were opposite hitters, four were middle blockers, and two were liberos. These players participated in 95 training sessions (averaging 90 minutes each), with 25 days involving both morning and afternoon sessions, 17 days off, and 18 competitive matches

Throughout the 105-day study period, all participants completed the follow-up and were included in the final analysis. Two players were injured and did not participate in two days of measurements each, and another two players were injured and did not participate in one day of measurements each, resulting in a total of 246 measures per variable instead of the expected 252 (14 players × 18 matches). Given that 18 variables were measured, this equated to a total of 4,428 data points across the study. A detailed flow diagram of participant involvement and data collection at each measurement stage is presented in Figure IV-14.

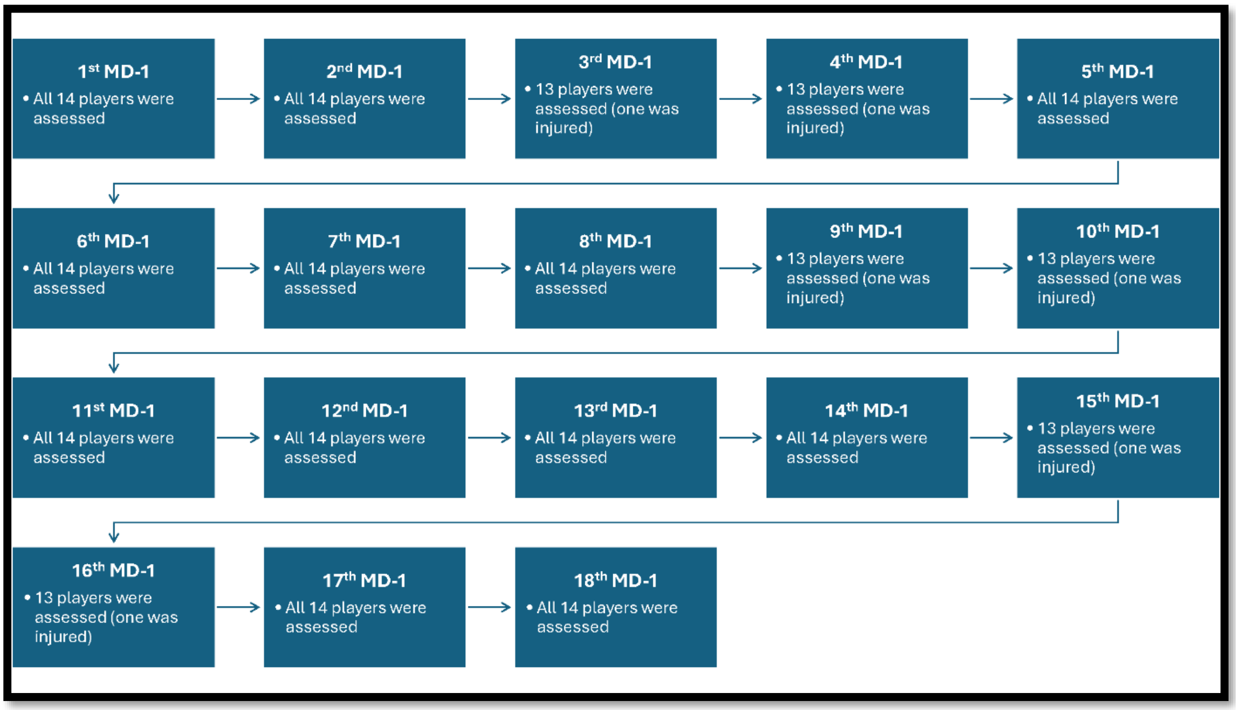

Figure IV-14: Flow diagram of participant involvement and data collection at each measurement stage (MD-1).

Eligibility criteria for participation were: being a member of the team's roster during the second phase of the National Championship and having no current injuries at the start of the study period. Players were excluded if they were recovering from a major injury. The sources and methods of selection involved direct recruitment from the team's roster. Player participation was tracked to ensure compliance and to record any deviations due to injuries or other factors.

Variables and data sources/measurement

All measurements were taken on MD-1 (the day before each match) before the first training session of the day. This ensured consistent data collection across the entire competitive phase, accounting for both the championship and domestic cup matches.

Training Load

The ITL was measured using the session rating of perceived exertion (sRPE) method, which was selected based on previous research in volleyball [23]. Approximately 15 minutes after each training session, players responded to the question "How hard was your session?"

using the BORG-CR10 scale [23]. The ITL was calculated by multiplying the sRPE value by the duration of the session in minutes. The ETL was measured using an inertial measurement unit (IMU) with 3-axis gyroscopes, 3-axis magnetometers, and 3-axis accelerometers (Vert® Classic, MyVert, Florida, FL, USA). This IMU has been validated for use with volleyball players [24]. The IMU was placed on a belt secured to the athletes' hips, and data were transmitted via Bluetooth to an iPad. The metric "Energy" was selected as the primary ETL metric because it captures all movements across all axes. Previous research suggests that volleyball players should be monitored across all axes and not only for the sagittal plane (e.g., jumps) [3].

For both ITL and ETL, the following calculations were made: acute training load, chronic training load, and the acute:chronic workload ratio (ACWR). Acute and chronic training loads were calculated using the following formula [25]:

$$Training\ load = \left(daily\ training\ load \times \frac{2}{N+1}\right) + \left(1 - \frac{2}{N+1}\right) \times previous\ day's\ training\ load$$

Where N = 7 for acute training load and N = 28 for chronic training load. The ACWR was derived by dividing the acute training load by the chronic training load.

Biological Recovery

Biological recovery was assessed using the CMJ test. All CMJ trials were conducted on two portable adjacent force plates (Hawkin Dynamics, Westbrook, Maine, USA), with data collected at 1000 Hz. Participants performed three maximal effort trials following a standardized protocol, jumping "as fast and high as possible" with arms akimbo to ensure they performed with the intent of reaching maximum height while also emphasizing velocity throughout the different phases of the jump (unweighting, braking, and propulsive). This approach was used to prevent athletes from focusing exclusively on either height or speed, thereby standardizing performance across trials [26]. Body weight was calculated by averaging the vertical force trace over the first second of data collection, during which the athlete was required to stand as still as possible in what is known as the quiet phase [27]. Movement onset was defined as the 30 ms before the vertical ground reaction force exceeded the mean plus or minus five times the standard deviation during the quiet phase [28]. The braking phase was defined as the period from the instant of peak negative centre of mass (COM) velocity until the COM velocity increased to zero, corresponding with the bottom portion of the countermovement [27]. The propulsive phase was defined as the period where the athlete forcefully extends their hips, knees, and ankles to propel their COM vertically, occurring between the velocity exceeding 0.01 m/s and the instant of take-off [27].

According to previous research, both neuromuscular fatigue and performance metrics were included to provide a comprehensive assessment of recovery [29]. Time-based metrics sensitive to detecting true changes after intense exercise, such as reactive strength index (RSI) modified, time to take-off, and propulsive phase duration, were selected as indicators of neuromuscular fatigue [29]. Performance metrics, strongly associated with independent measures of strength, linear speed, and change of direction ability, included propulsive impulse, mean propulsive force, and jump height [29]. Detailed descriptions of the selected force-time variables of the CMJ and their calculations are provided in Table IV-29.

To evaluate the correlations between training load metrics and biological recovery, individual scaled z-scores of the CMJ variables were used. This scaling converts the raw scores into a standardized scale ranging from 0 to 100, with 50 representing the individual mean of the athlete based on all measurements taken during the entire 105-day study period [30]. The scaled z-score reflects how many standard deviations away from the individual mean the athlete's metric is on a given day. Using z-scores allows for a more accurate comparison between different athletes and over different time periods, accounting for individual variability [30, 31]. This standardization is particularly useful in longitudinal studies, as it normalizes the data across different contexts and conditions, making it easier to detect meaningful changes and correlations. Additionally, z-scores mitigate the impact of outliers and reduce the influence of individual differences in absolute performance levels [30, 31], thus providing a clearer picture of relative changes in performance and recovery.

Table IV-29: Descriptions and calculations of selected force-time variables from the countermovement jump test.

Variable	Description
Reactive strength index modified	The jump height calculated using the vertical velocity of the system centre of mass at the instant of take-off divided by the total time taken from the initiation of movement to the instant of take-off (i.e., time to take-off).
Time to take-off (s)	The total time taken from the initiation of movement to the instant of take-off.
Propulsive phase duration (s)	The time taken to complete the propulsion phase.
Propulsive impulse (N.s)	The vertical impulse applied to the system centre of mass during the propulsion phase.

Mean propulsive force (N)	The average vertical ground reaction force applied to the system centre of mass during the propulsion phase.
Jump height (m)	The change in centre of mass position between the instant of take-off and peak positive vertical displacement of the centre of mass during the flight phase, calculated as take-off velocity squared divided by 19.62.

Social and Psychological Recovery

Social and psychological recovery metrics were assessed using the 36-item version of the Recovery Stress Questionnaire for Athletes (RESTQ-Sport-36) [32]. This questionnaire includes 12 factors, each with 3 items, measured on a 7-point Likert scale, with a minimum score of 1 and a maximum score of 7. The study focused on two factors for social recovery (social stress and social recovery) and four factors for psychological recovery (general well-being, emotional exhaustion, self-efficacy, and personal accomplishment), as recommended by previous research [9]. The RESTQ-Sport has demonstrated good reliability and validity, with homogeneity reflected in Cronbach's alpha ratings above $\alpha = 0.70$ [33]. Unlike the biological recovery metrics, which were scaled using z-scores, the actual questionnaire responses were used to evaluate the correlations between training load metrics and social and psychological recovery.

Statistical methods

The sample size required for this study was determined using G*Power (v. 3.1.9.7; Heinrich Heine University Dusseldorf, Dusseldorf, Germany). The calculation was based on the following parameters: a two-tailed test, an expected medium effect size (Correlation ρ H1 = 0.30), an alpha level (err prob) of 0.05, a desired power (1-β err prob) of 0.85, and a null hypothesis correlation (Correlation ρ H0) of 0. The results indicated that a total sample size of 96 observations (i.e., individual data points from all participants across multiple measurement days) would be required to achieve an actual power of 0.851.

Data were analysed using IBM® SPSS® Statistics 27 software (IBM Co., USA). The relationships between training load metrics and various dimensions of recovery were analysed using a General Linear Model (GLM) to account for repeated measures across 18 time points for 14 elite volleyball players. The dependent variables included six biological recovery metrics derived from CMJ measurements and six psychological and social recovery metrics derived from the RESTQ-36 questionnaire. The independent variables consisted of ITL and ETL measures. The GLM was chosen due to its capacity to simultaneously evaluate the effects of multiple predictors (training load metrics) on multiple outcomes (biological, psychological, and social recovery metrics) while accommodating repeated measures and controlling for individual variability among players. This approach is well-suited for handling both continuous and categorical predictors, ensuring robust and comprehensive analysis of the combined and independent effects of training load metrics on recovery dimensions [34]. The level of significance was set at $p \leq 0.05$.

4.7.4. Results

Descriptive statistics for all variables, calculated from measurements taken on MD-1, are presented in Table IV-30.

The outcomes of the linear mixed-effects models examining the relationships between training load metrics and CMJ performance indicators are presented Table IV-31. Significant relationships were observed for acute ETL and chronic ETL with specific CMJ metrics. Acute ETL showed significant positive associations with both RSI modified ($\beta = 0.007$, $p = 0.046$) and time to take-off ($\beta = 0.007$, $p = 0.033$). Similarly, Chronic ETL was negatively associated with RSI modified ($\beta = -0.008$, $p = 0.047$) and time to take-off ($\beta = -0.008$, $p = 0.03$).

Table IV-30: Descriptive statistics (mean ± standard deviation) of training load and recovery metrics on MD-1.

Metric		Mean ± SD
Training load	Acute ITL (AU)	292.82 ± 101.53
	Chronic ITL (AU)	274.67 ± 77.47
	Acute:chronic ITL ratio	1.05 ± 0.24
	Acute ETL (J)	2514.34 ± 1169.36
	Chronic ETL (J)	2335.28 ± 945.80
	Acute:chronic ETL ratio	1.06 ± 0.24
Biological recovery	RSI modified	54.78 ± 9.04
	Time to take-off	53.30 ± 8.61
	Propulsive phase duration	53.04 ± 9.68

	Propulsive impulse	48.96 ± 10.40
	Mean propulsive force	54.07 ± 10.18
	Jump height	54.68 ± 9.53
Social recovery	Social stress	1.96 ± 1.17
	Social recovery	4.84 ± 1.32
Psychological recovery	General well-being	5.23 ± 1.09
	Emotional exhaustion	1.67 ± 1.09
	Self-efficacy	4.56 ± 1.31
	Personal accomplishment	3.98 ± 1.46

Biological recovery metrics are presented as scaled z-scores.
Social recovery and psychological recovery metrics are presented as a Likert-type scale with values ranging from 1 to 7 (e.g., a social stress of 1 means a low value of stress, while a social stress of 7 means a high value of stress).
AU = arbitrary units, ETL = external training load, ITL = internal training load, MD-1 = day before match, RSI = reactive strength index.

The results of the generalized linear mixed-effects models assessing the relationships between training load metrics and psychological and social recovery metrics are presented in Table IV-32. Significant associations were observed for acute ITL across multiple recovery dimensions. Acute ITL was negatively associated with social stress ($\beta = -3.512$, $p = 0.034$) and emotional exhaustion ($\beta = -3.401$, $p = 0.039$), while showing positive relationships with social recovery ($\beta = 4.798$, $p = 0.015$), general well-being ($\beta = 7.815$, $p < 0.001$), self-efficacy ($\beta = 7.705$, $p < 0.001$), and personal accomplishment ($\beta = 4.083$, $p = 0.039$). Chronic ITL displayed a significant negative association with social stress ($\beta = -0.015$, $p = 0.015$) and emotional exhaustion ($\beta = -0.013$, $p = 0.029$), but no significant relationships were observed with the other recovery metrics. The acute:chronic ITL ratio was positively associated with social stress ($\beta = 0.021$, $p < 0.001$) and emotional exhaustion ($\beta = 0.019$, $p = 0.004$), but no significant relationships were found with other dimensions. Acute ETL showed a positive association with social stress ($\beta = 3.694$, $p = 0.035$), but it did not significantly correlate with any other recovery metric.

Table IV-31: Outcomes of linear mixed-effects models (β) applied for training load parameters in relation to the individual z-scores of countermovement jump metrics for assessing biological recovery.

Parameter	RSI modified			Time to take-off			Propulsive phase duration			Propulsive impulse			Mean propulsive force			Jump height		
	β	**SE**	***p***	***β***	**SE**	***p***	***β***	**SE**	***p***	***β***	**SE**	***p***	***β***	**SE**	***p***	***β***	**SE**	***p***
Acute ITL	-0.06	0.06	0.322	-0.068	0.057	0.238	-0.074	0.065	0.253	0.039	0.07	0.577	-0.112	0.067	0.098	0.041	0.064	0.524
Chronic ITL	0.074	0.067	0.269	0.071	0.063	0.262	0.068	0.072	0.343	-0.014	0.078	0.862	0.123	0.075	0.1	-0.021	0.071	0.769
Acute:chronic ITL ratio	14.342	17.861	0.423	17.345	16.9	0.306	24.527	19.131	0.201	-13.745	20.803	0.509	35.128	19.915	0.079	-12.687	18.84	0.501
Acute ETL	0.007	0.004	0.046*	0.007	0.003	0.033*	0.003	0.004	0.514	-0.003	0.004	0.55	0.003	0.004	0.452	0.003	0.004	0.455
Chronic ETL	-0.008	0.004	0.047*	-0.008	0.004	0.03*	-0.003	0.004	0.547	0.003	0.005	0.564	-0.003	0.005	0.46	-0.003	0.004	0.481
Acute:chronic ETL ratio	-5.989	9.989	0.549	-6.461	9.452	0.495	3.194	10.7	0.766	0.076	11.635	0.995	4.198	11.139	0.707	-4.031	10.537	0.702

ETL = external training load, ITL = internal training load, RSI = reactive strength index.

* Correlation is significant at the 0.05 level.

** Correlation is significant at the 0.01 level.

Table IV-32: Outcomes of generalized linear-effects models (β) applied for training load parameters in relation to the RESTQ-Sport scales representing social and psychological recovery.

Parameter	Social stress			Social recovery			General well-being			Emotional exhaustion			Self-efficacy			Personal accomplishment		
	β	**SE**	***p***	***β***	**SE**	***p***	***β***	**SE**	***p***	***β***	**SE**	***p***	***β***	**SE**	***p***	***β***	**SE**	***p***
Acute ITL	-3.512	1.645	0.034*	4.798	1.949	0.015*	7.815	1.574	0.000**	-3.401	1.640	0.039*	7.705	1.944	0.000**	4.083	1.968	0.039*
Chronic ITL	-0.015	0.006	0.015*	-0.003	0.007	0.687	0.003	0.006	0.577	-0.013	0.006	0.029*	0.007	0.007	0.345	-0.007	0.007	0.310
Acute:chronic ITL ratio	0.021	0.006	0.001**	0.002	0.008	0.788	-0.009	0.006	0.154	0.019	0.006	0.004**	-0.014	0.008	0.077	0.003	0.008	0.674
Acute ETL	3.694	1.738	0.035*	1.236	2.059	0.549	-0.392	1.663	0.814	3.333	1.732	0.056	-2.796	2.054	0.175	1.957	2.079	0.348
Chronic ETL	2.511E-05	0.000	0.953	0.000	0.001	0.839	0.000	0.000	0.639	0.000	0.000	0.338	7.151E-05	0.000	0.886	0.000	0.001	0.762
Acute:chronic ETL ratio	0.000	0.000	0.488	0.000	0.001	0.382	0.000	0.000	0.276	0.000	0.000	0.445	0.000	0.001	0.679	0.000	0.001	0.379

ETL = external training load, ITL = internal training load.

* Correlation is significant at the 0.05 level.

** Correlation is significant at the 0.01 level.

4.7.5. Discussion

The primary objective of this study was to analyse the correlations between training load metrics and various dimensions of recovery - biological, social, and psychological - in elite volleyball players. The results of this study provide deeper insights into how different aspects of training load impact the multifaceted recovery processes in athletes. Given the high demands placed on elite volleyball players and the repetitive nature of their sport, understanding these relationships is crucial for optimizing training regimens, enhancing performance, and reducing injury risks. One of the strengths of this study is that it followed elite athletes across 105 days during the competitive period, providing a broad view of how training loads interact with recovery over an extended timeframe.

Training Load and Biological Recovery

The findings of this study highlight the significant impact of ETL on CMJ performance metrics, emphasizing the importance of managing jump volume and intensity in volleyball players. For the metric time to take-off, which was standardized as a z-score, the interpretation of increases or decreases is reversed relative to the raw values. Specifically, an increase in the z-score corresponds to a decrease in the raw value, and vice versa. This unique relationship must be considered when interpreting the findings of this study. As chronic ETL increased, the z-score for time to take-off decreased, indicating an increase in the raw value of time to take-off. This prolongation of the movement phase aligns with a decrease in RSI modified, which is calculated by dividing jump height by time to take-off. These results suggest that higher chronic ETL impairs the efficiency of jump execution, reflecting neuromuscular fatigue.

Previous research has demonstrated that cumulative training loads can induce neuromuscular fatigue [35], which manifests as longer time to take-off durations in CMJ performance. This finding is consistent with the idea that athletes under chronic external load demands adjust their jump strategies, taking more time during the countermovement phase to generate sufficient force. Although these adaptations may allow athletes to maintain overall jump height, they lead to reductions in RSI modified, making time-sensitive metrics such as time to take-off valuable indicators of cumulative fatigue. Metrics incorporating time elements are particularly effective for detecting neuromuscular fatigue over extended periods, as they are more responsive to fatigue-related changes compared to outcome-based metrics like jump height or mean propulsive force, which athletes can maintain through compensatory strategies [36].

The observed increase in raw time to take-off under chronic ETL emphasizes the importance of monitoring cumulative ETLs in sports like volleyball, where repeated jumping is a fundamental performance requirement. Chronic ETL, driven by the frequency and intensity of jumps, directly influences neuromuscular fatigue and biological recovery. By routinely assessing time-based CMJ metrics, practitioners can detect early signs of cumulative fatigue, even when outcome-based metrics appear unaffected [37, 38]. This aligns with findings by Setuain et al. [39], who observed no significant changes in outcome-based bilateral CMJ metrics, such as jump height and power, following a controlled volleyball training session. Similarly, in the present study, metrics such as jump height and propulsive impulse showed no significant relationships with training load. These shared findings underscore the limited sensitivity of outcome-based metrics for detecting neuromuscular fatigue and highlight the added value of time-based metrics for monitoring the impact of training load. In practice, tracking time-sensitive metrics such as time to take-off and RSI modified provides coaches with actionable insights to refine training regimens and maintain athlete readiness throughout competitive periods. Integrating these metrics into routine monitoring protocols enhances the ability to detect and address neuromuscular fatigue, ensuring sustained performance and reduced injury risk over the course of a demanding season.

Moreover, the findings of this study revealed no significant relationships between ITL and any of the CMJ metrics assessed. This lack of correlation contrasts with the notable associations observed for ETL, particularly with time-sensitive CMJ metrics. A potential explanation for this disparity lies in the methodology used to calculate ITL and the nature of the CMJ test itself. ITL, derived using the sRPE method, reflects an athlete's subjective perception of training intensity combined with the session duration [23]. While this metric provides valuable insight into the psychophysiological strain experienced during training, it does not directly quantify the mechanical load imposed on the neuromuscular system. In volleyball, where external loads are heavily influenced by jump frequency and intensity [3], it is possible that ITL captures a broader spectrum of stressors, including psychological and cardiovascular demands, which may not directly translate to immediate neuromuscular fatigue or recovery as assessed by CMJ performance. Furthermore, the CMJ is primarily a test of neuromuscular function, focusing on parameters such as jump height, propulsive force, and time-based metrics [29]. These outcomes are closely tied to the mechanical demands placed on the musculature and tendons, which are more directly represented by ETL metrics. ITL, on the other hand, is an aggregate measure that may dilute the specific contribution of mechanical load, particularly in a sport like volleyball, where the perceptual response to training might be influenced by non-mechanical factors such as tactical complexity, mental fatigue, or external stressors.

Training Load and Social Recovery

The results highlighted distinct relationships between training load metrics and the social dimensions of recovery, particularly social recovery and social stress, which represent opposing aspects of social well-being. Social recovery reflects positive social experiences, such as enjoying time with friends or laughing, indicating moments of rejuvenation and emotional connection [32]. In contrast, social stress captures negative interactions or tensions, such as being annoyed or frustrated by others, reflecting the strain that social environments can impose on athletes [32].

Acute ITL demonstrated contrasting effects on these dimensions, enhancing social recovery while simultaneously increasing social stress. This dual influence may stem from the heightened interpersonal dynamics inherent in intense training environments. On one hand, such environments can foster camaraderie and shared positive experiences, leading to improved social recovery. On the other hand, they may also heighten social tensions and pressures, particularly as athletes contend with collective fatigue or competition-related stressors, thereby increasing social stress. Chronic ITL further amplified social stress, suggesting that sustained high ITLs may exacerbate interpersonal friction or perceived pressures over time.

Additionally, acute ETL showed a significant positive association with social stress, indicating that short-term increases in external load may also contribute to negative social interactions. This finding suggests that the physical demands of external load may indirectly influence perceptions of social strain, perhaps due to increased fatigue or irritability associated with higher physical effort.

These findings underscore the significant role that social recovery plays in the overall well-being and performance of elite athletes. While social monitoring may traditionally play a subordinate role in athletic contexts, this study highlights its critical importance. Social factors, such as interactions with coaches, family, and teammates, significantly influence performance by impacting compliance, stress susceptibility, and recovery management [14]. This is the first study conducted in elite volleyball that evaluated social recovery over an extended competitive period, providing novel insights into how social dimensions interact with training loads. Previous research has indicated that a supportive social environment can serve as a buffer against the stresses of intense athletic training and competition [40]. Positive social interactions and a supportive climate can mitigate stress and promote recovery, thereby enhancing performance. The significant correlations found in this study between high ACWRs and increased social stress emphasize the need for coaches and support staff to consider social factors when designing training and recovery programs.

In practical terms, coaches should foster a positive and appreciative communication environment, allowing athletes regular opportunities to interact with family and friends. This social support can help mitigate the negative effects of high training loads on social recovery [41]. Strategies such as team-building activities, open communication channels, and involving family in the support network can enhance the athletes' social recovery, leading to better overall performance and well-being.

Training Load and Psychological Recovery

The correlations between training load metrics and psychological recovery metrics are equally significant. Acute ITL showed significant negative correlations with emotional exhaustion and positive correlations with general well-being, self-efficacy, and personal accomplishment. Chronic ITL was significantly negatively correlated with emotional exhaustion. Similarly, as the acute:chronic ITL ratio increases, the emotional exhaustion also increases. In contrast, no measure of ETL was significantly correlated with any of the psychological recovery variables, suggesting that ITL, as measured by sRPE, is more reflective of psychological responses to training stress than ETL metrics.

These findings are consistent with previous research indicating that high training loads can negatively impact an athlete’s psychological state. Following intensive training periods, adaptive outcomes can include short-term fatigue and depressed immune cell function [42]. Non-functional overreaching and overtraining syndrome are accompanied by negative psychological symptoms such as mood disturbances, reduced well-being, poor sleep quality, irritability, or boredom [43, 44]. Moreover, research has found psychological reactions to changes in ITL to be more sensitive than biological markers [45], a finding supported by this study. The stronger associations between ITL and psychological variables compared to ETL highlight the importance of subjective measures like sRPE in capturing the broader training stress experienced by athletes. Unlike ETL, which primarily quantifies mechanical load, ITL reflects the athlete's perception of effort, encompassing both physiological and psychological stressors [2]. This multidimensional perspective makes ITL particularly useful for identifying early signs of psychological strain, which may precede observable decrements in performance or neuromuscular fatigue.

In practice, the findings suggest that psychological support is crucial alongside physical training and recovery programs. Coaches and sports scientists should integrate regular psychological assessments to monitor athletes' well-being and overall mental health. However, it might not be the role of athletic or strength and conditioning coaches alone to provide this support. Many athletic trainers feel their roles go beyond the care and prevention of athletic injuries, yet they do not necessarily feel qualified to counsel athletes or comfortable doing so, often due to a lack of formal training in psychological intervention [46]. To address this gap, it is essential to involve sports psychologists or mental health professionals to help maintain athletes' psychological well-being, particularly during periods of high training intensity.

Limitations and Future Directions

Despite the valuable insights gained from this study, several limitations must be acknowledged. Firstly, future research should explore whether alternative methods of assessing ITL, particularly objective measures such as heart rate-based monitoring, would yield similar results in relation to biological recovery metrics assessed through the CMJ. Heart rate-based methods provide a more direct measure of the cardiovascular and physiological strain experienced during training and may offer a different perspective on the relationship between ITL and neuromuscular function. Comparing these methods to subjective approaches like the sRPE could help clarify whether the lack of correlation observed in this study is specific to the chosen ITL method or reflects a broader disconnect between ITL and CMJ performance metrics. Secondly, the study's observational design means that causality cannot be inferred from the correlations observed. While significant relationships between training loads and recovery metrics were identified, it is not possible to definitively conclude that changes in training loads caused the observed changes in recovery. Experimental studies or longitudinal designs that can better control for confounding variables are needed to establish causal relationships. Future research should focus on developing clear monitoring guidelines for the social domain in sports.

This includes identifying key social recovery indicators and establishing best practices for integrating social recovery strategies into training regimens. Finally, while the study provided valuable insights into the relationships between training load and recovery in volleyball players, it did not establish specific thresholds for training loads that may increase the risk of negative outcomes. Future research should focus on identifying these thresholds to provide more precise guidelines for coaches and athletes.

4.7.6. Conclusions

This study explored the relationships between training load metrics and various dimensions of recovery—biological, social, and psychological—in elite volleyball players. The findings underscore the complex interplay between training loads and recovery processes in athletes.

In terms of biological recovery, ETL played a significant role, particularly chronic ETL, which was associated with longer time to take-off and reduced RSI modified. These findings highlight the impact of cumulative external load on neuromuscular efficiency, emphasizing the importance of monitoring time-based metrics such as time to take-off to detect early signs of fatigue.

Social recovery outcomes demonstrated distinct patterns, with acute and chronic ITL both influencing social stress and social recovery. Higher ITL was associated with greater social stress but also improved social recovery, highlighting the dual nature of training-induced stress on social well-being.

For psychological recovery, ITL metrics showed stronger associations compared to ETL. Acute ITL was positively linked to general well-being, self-efficacy, and personal accomplishment while reducing emotional exhaustion, whereas chronic ITL and acute:chronic ITL ratio were both associated with increased emotional exhaustion. These results underline the utility of subjective load monitoring for capturing the psychological responses to training stress, providing actionable insights for managing mental well-being during intensive training phases.

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Chapter V – General Discussion

"We don't rise to the standards we have when others are watching, we fall to the standards we have when no one is watching. The only work that really matters is the work no one sees, it shows who you really are, rather than who you say you are."

Alex Hormozi

This thesis comprises seven studies, each contributing to the overarching aim of understanding and optimizing training load management, recovery, and performance in elite volleyball athletes. Collectively, these studies addressed critical gaps in the literature, offering both theoretical and practical insights into the interplay between ITL and ETL, fatigue, and recovery processes.

The narrative review (Study I) established a foundational understanding of volleyball's unique physical demands, emphasizing the critical role of S&C programs in mitigating injury risks and enhancing performance. It identified the need for tailored training strategies that address position-specific demands, setting the stage for subsequent investigations into training load management.

The scoping review (Study II) highlighted the predominant focus on sagittal plane movements, particularly jumping metrics, in ETL research. While acknowledging the importance of jumping in volleyball, the study revealed a significant gap in understanding non-jumping metrics, position-specific demands, and the role of the libero. This study underscored the necessity of a broader and more holistic approach to ETL monitoring.

Systematic reviews (Studies III and IV) provided valuable insights into ITL monitoring and the interactions between ITL, ETL, and recovery. Study III emphasized the widespread use of the sRPE method while identifying inconsistencies in data collection and interpretation. Study IV explored the relationship between training stress, neuromuscular fatigue, and well-being, advocating for integrated monitoring strategies and highlighting the limitations of current approaches.

Transitioning into empirical research, Study V quantified ITL, ETL, neuromuscular fatigue, and perceptual well-being over a 5-week in-season mesocycle. It revealed that ETL fluctuations significantly influenced fatigue and sleep quality, providing practical insights into load management for optimal recovery.

Study VI examined the impact of congested match schedules on CMJ metrics, identifying significant variability in neuromuscular responses. It demonstrated the utility of CMJ metrics, such as peak propulsive power and jump momentum, in monitoring athlete fatigue and performance during high-demand periods.

Finally, Study VII offered a holistic perspective on recovery, exploring the relationships between training loads and biological, social, and psychological recovery dimensions. It highlighted the detrimental effects of high training loads on recovery metrics and underscored the importance of balanced load management for sustaining athlete readiness and wellness.

5.1. Key results

The findings of this thesis provide insights into the interplay between training load, recovery, and performance in elite volleyball athletes, addressing the core research questions:

1. How do different external and internal loads affect neuromuscular fatigue and subsequent recovery in elite volleyball players?

The systematic review in Study IV revealed that neuromuscular fatigue and recovery are influenced by both ETL and ITL, with specific metrics such as CMJ height and sRPE serving as valuable indicators. Empirical findings from Studies V and VI demonstrated that ETL variations across microcycles and congested match schedules significantly impacted neuromuscular performance, particularly CMJ metrics like propulsive force and velocity. Study VII further emphasized the role of training load balance in optimizing recovery, showing correlations between ETL and biological recovery metrics such as time to takeoff and RSI modified.

2. In what ways can training load monitoring be optimized to maximize performance outcomes in elite volleyball?

The scoping review (Study II) identified a narrow focus on sagittal plane movements and the underrepresentation of non-jumping metrics, highlighting the need for a broader ETL monitoring framework. Study III demonstrated that the sRPE method is a reliable tool for ITL monitoring, though inconsistencies in its application suggest the need for standardized practices. Empirical findings from Studies V and VI underscored the importance of integrating ETL and ITL data for widespread monitoring, with Study VII introducing the ACWR as a valuable metric for managing training loads dynamically.

3. How can chronic and acute training load management improve an athlete's physical readiness and recovery throughout the competitive season?

Study V showed that a progressive decrease in ITL and an undulatory ETL pattern within microcycles helped manage fatigue and optimize readiness for match days. Study VII provided evidence that with higher chronic values of ETL, time to take-off during a CMJ increases. Additionally, acute ETL showed a significant positive association with social stress, indicating that short-term increases in external load may also contribute to negative social interactions.

4. What is the relationship between various training load metrics and recovery indicators in elite volleyball athletes?

Study VII highlighted significant correlations between training loads and recovery across biological, social, and psychological dimensions. Acute ETL showed significant positive associations with both RSI modified and time to take-off. Similarly, Chronic ETL was negatively associated with RSI modified and time to take-off. Acute ETL showed a positive association with social stress.

5. To what extent can effective training load management reduce fatigue accumulation and enhance performance sustainability over a congested period of the season?

Study VI demonstrated that congested match schedules led to significant variability in CMJ metrics, reflecting the cumulative effects of fatigue. However, the study also identified key metrics, such as peak propulsive power and jump momentum, that can be monitored to guide recovery interventions and maintain performance during high-demand periods.

5.2. Interpretation

5.2.1. Integration of external and internal load monitoring strategies

The interplay between ETL and ITL represents a cornerstone of athlete monitoring in high-performance sports [7]. The findings from this thesis reinforce the importance of integrating these two dimensions to optimize training and recovery. While ETL quantifies the mechanical and physical demands placed on athletes, ITL reflects the physiological and psychological responses to those demands [7]. Together, they offer a broad picture of the athlete's workload, bridging objective measures with subjective experiences.

Studies V and VII highlighted the unique contributions of both ETL and ITL in monitoring training loads [137,138]. For example, ITL, measured through sRPE, was found to be more sensitive to cumulative stress and perceived effort, capturing nuanced individual responses that ETL metrics alone might overlook. Conversely, ETL metrics, derived from IMUs, provided detailed insights into biomechanical demands, such as jump counts and intensities, which are particularly relevant for volleyball due to its repetitive and explosive nature.

The thesis findings also emphasize the dynamic interaction between ETL and ITL across different timeframes. For instance, while acute ITL and ETL reflected immediate responses to training sessions, chronic ITL and ETL offered a broader view of training adaptations and readiness over time [137,138]. The relationships observed between ITL and perceptual recovery indicators (e.g., fatigue and sleep quality) in Study V suggest that internal responses are crucial for identifying early signs of maladaptation. Similarly, Study VII demonstrated that acute-to-chronic workload ratios (ACWRs) for both ITL and ETL were predictive of neuromuscular fatigue and recovery metrics, underscoring their value in managing athlete readiness. However, the findings also highlight the limitations of relying on a single dimension of training load. For example, in Study VI, congested match schedules impacted neuromuscular fatigue as evidenced by ETL-derived CMJ metrics, but these effects were more pronounced when interpreted alongside ITL data. This underscores the need for an integrated approach to training load monitoring, where ITL contextualizes the physiological impact of ETL.

The integration of ETL and ITL not only provides an understanding of workload but also facilitates more informed decision-making for coaches and practitioners. By considering both dimensions, training programs can be tailored to the individual needs of players, balancing workload to enhance performance while mitigating the risks of overtraining and injury [139]. Furthermore, this integrative approach aligns with the broader trend in sports science, which advocates for multidimensional monitoring strategies to support athlete development and sustainability [35].

In conclusion, the integration of ETL and ITL is not merely an additive process but a synergistic one that allows for a deeper understanding of the demands and responses in elite volleyball. This thesis contributes to the growing body of evidence supporting the combined use of these metrics, highlighting their complementary nature and practical relevance in the context of high-performance sports.

5.2.2. Neuromuscular fatigue and recovery

Monitoring neuromuscular fatigue and recovery is central to maintaining performance and minimizing injury risk in elite volleyball. Across the studies in this thesis, the complex interactions between training load, fatigue, and recovery were consistently highlighted, offering critical insights into how these processes can be monitored and managed.

The findings underscore that neuromuscular fatigue is influenced by both acute and chronic training loads. For instance, Study V demonstrated that increases in ETL were associated with declines in neuromuscular performance, as evidenced by CMJ metrics [138]. Similarly, Study VI revealed that congested match schedules led to significant variability in key CMJ parameters, such as propulsive force, jump height, and peak power, indicating the cumulative impact of high-intensity competitive periods on neuromuscular fatigue [140]. These results align with previous research, which has shown that these metrics are sensitive to workload fluctuations and can serve as a reliable indicator of athlete readiness [96].

A notable finding from Study VI was the progressive decline in propulsive phase efficiency and peak power during congested schedules, suggesting that athletes adapt their movement strategies to cope with fatigue [140]. These adaptations, while potentially protective in the short term, may compromise performance and increase the risk of overuse injuries over time [141]. Study VII further highlighted the relationship between ACWR and neuromuscular recovery, demonstrating that imbalances in workload could exacerbate fatigue and delay recovery [137].

Recovery strategies play a critical role in mitigating the effects of neuromuscular fatigue. The results from Study V emphasized the importance of adequate sleep and perceptual recovery metrics in supporting neuromuscular performance [138]. Players who reported better sleep quality and lower fatigue levels exhibited improved CMJ performance, reinforcing the interdependence between psychological recovery and physical readiness. Study VII extended this understanding by examining biological recovery metrics, such as jump height and propulsive impulse, and their sensitivity to changes in training load [137]. These findings suggest that recovery strategies should be holistic, addressing both physical and perceptual dimensions.

The variability observed in neuromuscular fatigue and recovery responses across players highlights the need for individualized monitoring and intervention strategies [10]. For example, different player positions in volleyball exhibit unique biomechanical demands, as shown in Study V, where positional differences influenced training and recovery patterns [138]. This underscores the importance of tailoring training and recovery protocols to the specific needs of each athlete, considering factors such as their position, workload history, and individual fatigue thresholds.

Overall, the findings from this thesis contribute to the growing body of evidence emphasizing the role of neuromuscular fatigue as a critical marker of athlete readiness [34]. By integrating neuromuscular assessments, such as CMJ metrics, with training load data, coaches and practitioners can develop more precise and effective strategies to optimize performance and recovery in elite volleyball players. This holistic approach not only enhances athletic performance but also supports long-term athlete health and sustainability in high-performance environments.

5.2.3. Holistic recovery (biological, psychological, and social)

The findings from this thesis underscore the importance of adopting a holistic approach to recovery, which integrates biological, psychological, and social dimensions. Recovery is not merely a physical process; it encompasses a complex interplay of factors that influence an athlete's overall well-being and readiness to perform [100].

The studies revealed that biological recovery metrics, such as CMJ parameters, are closely tied to training load metrics, particularly chronic ETL, which was associated with longer time to take-off and reduced RSI modified [137]. These findings highlight the impact of cumulative external load on neuromuscular efficiency, emphasizing the importance of monitoring time-based metrics such as time to take-off to detect early signs of fatigue. These findings align with the broader sports science literature, which highlights the sensitivity of CMJ metrics to fatigue and their utility in monitoring neuromuscular status [96]. Such data-driven insights can guide training adjustments to optimize recovery and performance.

For psychological recovery, ITL metrics showed stronger associations compared to ETL. Acute ITL was positively linked to general well-being, self-efficacy, and personal accomplishment while reducing emotional exhaustion, whereas chronic ITL and acute:chronic ITL ratio were both associated with increased emotional exhaustion [137]. These results underline the utility of subjective load monitoring for capturing the psychological responses to training stress, providing actionable insights for managing mental well-being during intensive training phases. These results align with prior research suggesting that intense training periods can exacerbate psychological strain, potentially leading to NFO or OTS [102]. Importantly, psychological responses were found to be more sensitive to load variations than some biological markers, highlighting the need for regular psychological assessments [107]. Coaches and sports scientists should incorporate tools like the RESTQ-Sport to capture athletes' subjective experiences, ensuring a widespread understanding of their recovery status.

Social recovery, often overlooked in athletic settings, also played a significant role in the recovery process. Higher ITL was associated with greater social stress but also improved social recovery, highlighting the dual nature of training-induced stress on social well-being [137]. This aligns with the growing recognition of the impact of social stressors on athlete well-being [116]. A supportive social environment, characterized by positive communication and regular interaction with family and friends, can act as a buffer against the stresses of elite sport [118]. Encouraging team-building activities and fostering a culture of openness can enhance social recovery, contributing to better overall performance and resilience [119].

Holistic recovery requires integrating these dimensions into a unified framework. The studies demonstrated that biological, psychological, and social recovery processes are interdependent [100]. For instance, high psychological stress can exacerbate biological fatigue, while a supportive social environment can mitigate psychological strain. Coaches and practitioners should consider these interactions when designing recovery protocols. Strategies such as individualized recovery plans, incorporating both objective metrics (e.g., CMJ performance) and subjective assessments (e.g., well-being scales), can help address the multifaceted nature of recovery.

By emphasizing a holistic approach to recovery, this thesis provides actionable insights for optimizing recovery practices in elite volleyball. These findings highlight the importance of addressing not only the physical but also the psychological and social dimensions of recovery to ensure sustained athlete performance and well-being.

5.2.4. Role of monitoring tools and metrics

Effective monitoring tools and metrics are fundamental to understanding the multifaceted demands of elite volleyball and optimizing performance outcomes. Across the studies in this thesis, a variety of tools and metrics were employed to assess training loads, neuromuscular fatigue, and recovery, each offering unique insights into athlete readiness and resilience.

In monitoring training loads, tools such as the sRPE and IMUs were found to be effective in quantifying internal and external demands [142]. The sRPE provided a practical and cost-efficient way to evaluate ITL, particularly in the context of professional volleyball, where athletes' subjective perceptions of effort offer valuable insights into cumulative stress levels [143]. On the other hand, IMUs allowed precise measurement of ETL variables such as jump count, jump height, and acceleration, making them indispensable for capturing the sport's vertical and multidirectional demands [144]. The combined use of ITL and ETL metrics underscored the importance of integrating subjective and objective data for a comprehensive understanding of training load dynamics.

CMJ tests emerged as a versatile tool for evaluating neuromuscular fatigue. Metrics such as peak power, jump height, and propulsive phase duration provided sensitive indicators of fatigue and recovery status during congested match schedules [140]. The adoption of z-scores for CMJ metrics facilitated meaningful comparisons across players and time points, allowing coaches to identify relative changes in performance [140]. While CMJ tests were effective, incorporating alternative measures, such as isometric force tests or reactive strength indices, could offer additional dimensions to fatigue assessment, as recommended in the broader literature [77,96].

Holistic recovery was assessed through a combination of biological, psychological, and social metrics. Tools such as the RESTQ-Sport-36 provided nuanced insights into recovery states, capturing factors ranging from sleep quality to emotional stress and social recovery [137]. The findings highlighted the importance of integrating recovery monitoring into daily routines, ensuring athletes are supported across all dimensions of well-being. Objective biological markers, such as jump momentum and propulsive impulse, were particularly effective in quantifying recovery in relation to training loads [140].

The thesis also emphasized the potential of emerging technologies, such as advanced IMUs and local positioning systems, for enhancing monitoring practices [144]. While traditional tools remain foundational, these technologies offer opportunities to capture more complex and granular data, particularly for movements in multiple planes or position-specific demands [144]. For instance, tracking upper limb kinetics in setters or lateral movement metrics in liberos could provide valuable insights that are currently underexplored.

The practical utility of monitoring tools lies in their ability to translate data into actionable insights for training and recovery. However, challenges such as data overload, the need for sport-specific calibrations, and ensuring athlete compliance were noted. Coaches and sports scientists must balance the sophistication of monitoring tools with their feasibility in high-performance environments, prioritizing metrics that are both reliable and meaningful.

In conclusion, the studies highlighted the critical role of monitoring tools and metrics in shaping evidence-based training and recovery strategies. By leveraging a mix of established methods and emerging technologies, practitioners can enhance their understanding of athlete performance, reduce injury risks, and optimize overall team success.

5.3. Limitations

This thesis represents a significant step forward in understanding training load management and recovery in elite volleyball athletes. However, several limitations should be acknowledged to contextualize the findings and guide future research.

1. The studies included in this thesis were conducted with specific populations, including professional volleyball players from the Portuguese league. While this provides valuable insights into elite volleyball, the findings may not be directly applicable to athletes from other leagues, levels of play, or regions, where training regimens, competition structures, and cultural contexts may differ.
2. The observational design of the empirical studies precludes establishing causal relationships between training load metrics and recovery or performance outcomes. While correlations provide valuable insights, experimental designs with randomized interventions are needed to confirm causality and refine recommendations for training load management.
3. While the thesis examined biological, psychological, and social recovery dimensions, certain aspects remain underexplored. For instance, the influence of travel schedules, sleep hygiene interventions, and nutritional strategies on recovery were not directly addressed. Additionally, factors such as hormonal responses, neuromuscular biomarkers, and gender-specific recovery processes warrant further investigation.
4. Although the importance of position-specific demands in volleyball was highlighted, the empirical studies did not consistently account for positional differences in the analysis of training loads and recovery metrics. Future research should delve deeper into position-specific adaptations to training and recovery to provide more tailored recommendations.
5. The studies primarily relied on well-established methods and tools, such as IMUs and sRPE. While these methods are reliable and practical, the integration of emerging technologies, such as local positioning systems, advanced machine learning models, and wearable biosensors, was not explored. These technologies could enhance the precision of workload monitoring and predictive analytics in future studies.

5.4. Future directions

The findings and limitations of this thesis highlight several promising avenues for future research. By addressing these gaps, future studies can contribute to a more comprehensive understanding of training load management and recovery in elite volleyball athletes.

1. While this thesis highlighted the importance of position-specific demands, more detailed investigations are needed to develop tailored training and recovery protocols for different positions. Research could explore the specific biomechanical, physiological, and psychological demands of each position and how these influence training load tolerance and recovery.
2. Emerging technologies, such as local positioning systems, wearable biosensors, and machine learning algorithms, hold significant potential for enhancing workload monitoring and predictive analytics. Future studies should assess the validity and feasibility of integrating these tools into volleyball-specific contexts, with an emphasis on improving the precision of load quantification and injury prediction.
3. The physiological and psychological responses to training and recovery can differ significantly between male and female athletes. Research should focus on understanding these differences, exploring factors such as hormonal fluctuations, biomechanical variations, and recovery needs. This would support the development of gender-specific training and recovery strategies.
4. While this thesis explored recovery processes, future research should evaluate the effectiveness of targeted recovery interventions. Studies could assess the impact of strategies such as sleep hygiene programs, nutritional interventions, psychological support, and travel management on recovery and performance outcomes in volleyball athletes.
5. Future studies should work toward the integration of biological, psychological, and social recovery indicators into a single monitoring framework. Such frameworks could leverage multidimensional data to provide a comprehensive assessment of athlete well-being and performance readiness, improving decision-making for coaches and sports scientists.
6. A critical next step is to establish evidence-based thresholds for ITL, ETL, and their ratios (e.g., ACWR) that balance performance optimization with injury prevention.

Research should also aim to identify sport- and position-specific thresholds, ensuring practical relevance for volleyball teams at different levels.

7. Future research should investigate how external factors, such as match schedules, travel, and environmental conditions, interact with training loads and recovery. Understanding these interactions could help develop strategies to mitigate the negative effects of such factors on athlete performance and well-being.
8. The findings related to psychological recovery underscore the importance of mental health support in elite volleyball. Future studies should explore interventions that integrate psychological monitoring and support into regular training and competition routines, particularly during high-stress periods.
9. Although this thesis focused on professional athletes, applying similar methodologies to youth and developmental athletes could yield valuable insights. Research should explore how training load and recovery strategies differ across developmental stages and how early monitoring can support long-term athlete development.

By addressing these future directions, researchers can build on the foundation laid by this thesis to enhance training load management, optimize performance, and safeguard athlete health and well-being in volleyball and other high-performance sports.

5.5. Practical applications

The findings of this thesis provide actionable insights into training load management in elite volleyball, emphasizing the importance of balancing performance optimization with athlete recovery and well-being. By integrating evidence from all seven studies, several practical recommendations emerge for coaches, sports scientists, and practitioners involved in managing elite volleyball teams.

1. Training load management should be tailored to individual athletes, recognizing their unique responses to physical and psychological stressors. The use of tools such as sRPE for ITL and IMUs for ETL enables practitioners to account for both subjective and objective factors, allowing for a holistic view of an athlete's workload. Individualized monitoring is particularly critical during congested match schedules, where recovery demands vary based on position, playing time, and physiological capacities.

2. A mixed-methods approach that combines ITL and ETL metrics with recovery monitoring tools is essential for effective decision-making. For example, CMJ assessments can provide insights into neuromuscular fatigue, while questionnaires like the RESTQ-Sport-36 offer a broader perspective on psychological and social recovery. Integrating these tools within a centralized monitoring system can streamline data collection and interpretation, enhancing the ability to adjust training plans dynamically.
3. The thesis underscores the importance of wave-like distribution of training loads, particularly during the competitive phase. This approach involves alternating periods of higher and lower training intensity to optimize fitness while minimizing the risk of overtraining. Coaches should strategically plan training loads based on match importance, opposition level, and player readiness, ensuring peak performance during critical matches.
4. The unique physical and technical demands of each volleyball position necessitate position-specific training and recovery strategies. For instance, middle blockers require tailored programs focusing on jump volume and landing mechanics. Understanding these nuances allows for the development of more effective training regimens and injury prevention protocols.
5. Recovery strategies must address biological, psychological, and social dimensions. Ensuring adequate sleep, managing pre-match anxiety, and fostering a supportive social environment are all integral to maintaining athlete readiness. Coaches should prioritize recovery modalities that align with the specific needs of their athletes, such as sleep hygiene programs, structured rest days, or team-building activities to reduce stress.
6. During periods of congested match schedules, the findings highlight the need for close monitoring of neuromuscular fatigue and recovery metrics. Adjusting training loads based on CMJ performance data or RESTQ-Sport-36 scores can help mitigate fatigue and maintain performance.
7. Educating athletes about the importance of training load monitoring and recovery is crucial for compliance and long-term success. Transparent communication between coaches, players, and support staff fosters a collaborative environment, ensuring that monitoring practices are effectively implemented. Encouraging athletes to provide

honest feedback through subjective measures, such as RPE or well-being questionnaires, enhances the quality of data collected.

8. As technology continues to evolve, practitioners should consider incorporating advanced tools such as LPS or machine learning algorithms into their monitoring systems. These technologies offer the potential for more precise workload tracking and predictive analytics, allowing for proactive interventions to prevent injury and optimize performance.

Chapter VI – Conclusions

"Without commitment, you'll never start. But more importantly, without consistency, you'll never finish."

Denzel Washington

This thesis provides an exploration of training load, fatigue, and recovery in elite volleyball athletes, addressing critical gaps in knowledge and offering practical insights for optimizing performance and well-being. The findings, derived from seven studies employing both review and empirical methodologies, underscore the multifaceted nature of volleyball's physical, psychological, and social demands. The following conclusions encapsulate the core contributions of this thesis.

The integration of ETL and ITL offers a nuanced understanding of athlete demands. By emphasizing position-specific metrics and holistic monitoring approaches, this thesis establishes a framework for more precise and individualized training load management in elite volleyball.

Monitoring neuromuscular fatigue through objective metrics such as CMJ variables and integrating them with subjective recovery assessments proves critical in evaluating athlete readiness. This thesis highlights the intricate balance between training loads, fatigue, and recovery, providing actionable strategies to optimize performance and reduce injury risks. The exploration of biological, psychological, and social dimensions of recovery demonstrates the importance of a broad monitoring framework. This thesis underscores the interconnectedness of these domains, advocating for an integrated approach that incorporates both objective and subjective measures to enhance athlete recovery and performance.

The thesis provides actionable recommendations for coaches and practitioners, including the importance of tailoring training and recovery protocols to the unique demands of each player's position, managing workloads effectively during congested match schedules, and leveraging innovative monitoring technologies. These insights have direct applications for improving athlete readiness and sustainability throughout the season.

This thesis successfully addresses its central research questions, offering evidence-based answers on the effects of training loads on fatigue and recovery, the optimization of training load monitoring, and the strategies for balancing chronic and acute training loads. The findings reinforce the critical role of effective training load management in minimizing fatigue accumulation and enhancing performance sustainability. Through its combination of review and empirical studies, this thesis contributes to the growing body of knowledge in volleyball science, particularly in the domains of training load monitoring and recovery. The findings not only inform practice at the elite level but also provide a foundation for future research aimed at refining these strategies further.

In conclusion, this thesis represents a significant step forward in understanding the complex interplay between training load, fatigue, and recovery in elite volleyball. By bridging theoretical knowledge with practical applications, it offers a roadmap for optimizing athlete performance while safeguarding their health and well-being. These contributions pave the way for future research and innovation in volleyball and broader high-performance sport contexts.

Chapter VII - References

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Chapter VIII - Appendices

Appendix I – Approval from the ethics committee for the doctoral project.

Appendix II – Supplemental material of Study II.

Appendix III – Supplemental material of Study III.

Appendix IV – Supplemental material of Study IV.

Appendix V – Supplemental material of Study V.

Appendix I – Approval from the ethics committee for the doctoral project.

UNIVERSIDADE LUSÓFONA
| Faculdade de Educação Física e Desporto

Comissão de Ética da Faculdade de Educação Física e Desporto -ULHT

Parecer M1623

A Comissão de Ética da Faculdade de Educação Física e Desporto – ULHT, em reunião de 16 de Março de 2023, analisou o projeto de Doutoramento em Educação Física e Desporto de **André Gomes Rebelo**, subordinado ao tema *Relationships Between Training Load, Neuromuscular Fatigue, and Well-Being and Their Association with Injury Likelihood in Professional Male Volleyball Athletes*, tendo decidido emitir parecer positivo sem recomendações.

O Diretor da Comissão de Ética da FEFD – ULHT

(José Gregório Viegas Brás)

Appendix II – Supplemental material of Study II.

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
TITLE			
Title	1	Identify the report as a scoping review.	1
ABSTRACT			
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	3-4
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	4
METHODS			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	4
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	4-5
Information sources	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.	5
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	5
Selection of sources of evidence	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	6
Data charting process	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	6-7
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	7-8
Critical appraisal of individual sources of evidence	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate).	8
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	8-9
RESULTS			

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	9
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	9-10
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	N/A
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	10-11
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	11
DISCUSSION			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	11-13
Limitations	20	Discuss the limitations of the scoping review process.	13-14
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	14-15
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	15

Search strategy

PubMed

(("volleyball"[MeSH Terms] OR "volleyball"[All Fields]) AND (("physical exertion"[MeSH Terms] OR ("physical"[All Fields] AND "exertion"[All Fields]) OR "physical exertion"[All Fields] OR ("training"[All Fields] AND "load"[All Fields]) OR "training load"[All Fields]) AND (("measurement"[MeSH Terms] OR "measurement"[All Fields] OR "measure"[All Fields]) OR ("monitoring"[MeSH Terms] OR "monitoring"[All Fields]) OR "assessment"[All Fields])) AND (("athlete performance"[MeSH Terms] OR ("athlete"[All Fields] AND "performance"[All Fields]) OR "athlete performance"[All Fields] OR "performance"[All Fields]) OR ("injury"[MeSH Terms] OR "injury"[All Fields]) OR ("player position"[All Fields] OR "libero"[All Fields] OR "setter"[All Fields] OR "hitter"[All Fields] OR "middle blocker"[All Fields] OR "outside hitter"[All Fields])))

MeSH = Medical Subject Headings

Scopus

(TITLE-ABS-KEY (volleyball) AND TITLE-ABS-KEY ("training load" OR "physical exertion") AND TITLE-ABS-KEY (measurement OR monitor OR assessment) AND TITLE-ABS-KEY (performance OR injury OR "player position" OR libero OR setter OR hitter OR "middle blocker" OR "outside hitter"))

TITLE-ABS-KEY = title, abstract, keywords

Web of Science

(TS=("volleyball") AND TS=("training load" OR "physical exertion") AND TS=(measure* OR monitor* OR assess*) AND TS=(performance OR injury OR "player position" OR libero OR setter OR hitter OR "middle blocker" OR "outside hitter"))

TS = title, abstract, keywords; * = truncation

SPORTDiscus

(MH "Volleyball" OR "Volleyball") AND ("Training Load" OR "Physical Exertion") AND (MH "Measurement" OR "Measurement" OR MH "Monitoring" OR "Monitoring" OR "Assess*") AND ("Performance" OR MH "Injury" OR "Player Position" OR "Libero" OR "Setter" OR "Hitter" OR "Middle Blocker" OR "Outside Hitter")

MH = headings; * = truncation

Appendix III – Supplemental material of Study III.

Search strategy used to locate relevant research articles.

Variable	Search terms
Rating of perceived exertion	(‘internal training load’ OR ‘workload’ OR ‘training impulse’ OR ‘training response’ OR ‘TRIMP’ OR ‘internal load’ OR ‘exposure’ OR ‘RPE’ OR ‘rating of perceived exertion’ OR ‘summated-heart-rate-zone’ OR ‘SHRZ’ OR ‘PlayerLoad’ OR ‘BodyLoad’)
Volleyball	‘volleyball athlete’ OR ‘volleyball player’
Training load AND volleyball (final search)	‘1 AND 2’

Questions from the modified Downs and Black checklist used to evaluate methodological quality of the included articles.

Question no.	Question
	Reporting
1	Is the hypothesis/aim/objective of the study clearly described?
2	Are the main outcomes to be measured clearly described in the introduction or methods section?
3	Are the characteristics of the subjects included in the study clearly described?
4	Are the main findings of the study clearly described?
5	Does the study provide estimates of the random variability in the data for the main outcomes?
6	Have actual probability values been reported (e.g., 0.035 rather than < 0.05) for the main outcomes except where the probability value is < 0.001?
	External validity
7	Were the subjects asked to participate in the study representative of the entire population from which they were recruited?
8	Were those subjects who were prepared to participate representative of the entire population from which they were recruited?
	Internal validity bias
9	If any of the results of the study were based on “data dredging,” was this made clear?
10	Were the statistical tests used to assess the main outcomes appropriate?
11	Were the main outcome measures accurate (valid and reliable)?

Results of methodological quality assessment for included articles.

Study	Downs and Black checklist question number											Total
	Reporting						External validity		Internal validity bias			
	1	2	3	4	5	6	7	8	9	10	11	
Andrade et al.	1	1	1	1	0	1	0	0	1	1	1	**8**
Berriel et al.	1	1	1	1	0	1	0	0	1	1	1	**8**
Brandão et al.	1	1	1	0	0	1	0	0	1	1	1	**7**
Clemente et al.	1	1	1	1	0	1	0	0	1	1	1	**8**
Debien et al.	1	1	1	1	1	1	0	0	1	1	1	**9**
Domingos et al.	1	1	1	1	0	0	0	0	1	1	1	**7**
Duarte et al.	1	1	1	1	0	1	0	0	1	1	1	**8**
Horta et al.	1	1	1	1	0	1	0	0	1	1	1	**8**
Horta et al.	1	1	1	1	0	1	0	0	1	1	1	**8**
Lima et al.	1	1	1	1	0	1	0	0	1	1	1	**8**
Mendes et al.	1	1	1	1	0	1	0	0	1	1	1	**8**
Rabbani et al.	1	1	1	1	0	1	0	0	1	1	1	**8**
Timoteo et al.	1	1	1	1	0	1	0	0	1	1	1	**8**
Ungureanu et al.	1	1	1	1	0	1	0	0	1	1	1	**8**

1 = yes; 0 = no/unable to determine.

Appendix IV – Supplemental material of Study IV.

PRISMA 2020 Checklist.

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	Page 1
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	Page 2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	Pages 3-4
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Page 4
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Page 5
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	Page 5
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	Pages 5-6
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	Page 6
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	Page 6
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	Pages 6-7
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	Pages 6-7
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	Page 7
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	Page 7
Synthesis	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and	Page 7

Section and Topic	Item #	Checklist item	Location where item is reported
methods		comparing against the planned groups for each synthesis (item #5)).	
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	Page 7
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	Page 7
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	Page 7
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	N/A
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	N/A
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	N/A
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	N/A
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	Page 8
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Page 8
Study characteristics	17	Cite each included study and present its characteristics.	Pages 8-10
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Page 8
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	Pages 10-16
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	Pages 10-16
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	Pages 10-16
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	Pages 10-16
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	Pages 10-16
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	N/A
Certainty of	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	N/A

Section and Topic	Item #	Checklist item	Location where item is reported
evidence			
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	Pages 16-20
	23b	Discuss any limitations of the evidence included in the review.	Pages 21-23
	23c	Discuss any limitations of the review processes used.	Pages 21-23
	23d	Discuss implications of the results for practice, policy, and future research.	Pages 21-23
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	Page 4
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	Page 4
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	Page 4
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	Page 24
Competing interests	26	Declare any competing interests of review authors.	Page 24
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	Page 24

Definition of types of monitoring interventions.

Monitoring intervention	**Definition**
Training stress	Internal training load: physiological stress that a training session induces in the athlete. Common measures include heart rate and rating of perceived exertion. External training load: physical work prescribed in the training plan. The most common method is with time-motion analysis devices, such as GPS, accelerometers, or inertial motion units.
Fitness and fatigue	Low-frequency fatigue: resulted from high-force, high-intensity, or repeated stretch-shortening cycles muscle actions. Vertical jumps are the most used tests to assess neuromuscular fatigue in athletes. Submaximal exercise protocols and physiological markers such as heart rate can also be used as objective markers of fatigue.
Well-being	Wellness inventories and well-being questionnaires are the most common measures to assess metrics such as mood, stress, sleep quality, and muscle soreness in athletes.

Questions from the modified Downs and Black checklist used to evaluate methodological quality of the included articles.

Question no.	Question
	Reporting
1	Is the hypothesis/aim/objective of the study clearly described?
2	Are the main outcomes to be measured clearly described in the introduction or methods section?
3	Are the characteristics of the subjects included in the study clearly described?
4	Are the main findings of the study clearly described?
5	Does the study provide estimates of the random variability in the data for the main outcomes?
6	Have actual probability values been reported (e.g., 0.035 rather than < 0.05) for the main outcomes except where the probability value is < 0.001?
	External validity
7	Were the subjects asked to participate in the study representative of the entire population from which they were recruited?
8	Were those subjects who were prepared to participate representative of the entire population from which they were recruited?
	Internal validity bias
9	If any of the results of the study were based on "data dredging," was this made clear?
10	Were the statistical tests used to assess the main outcomes appropriate?
11	Were the main outcome measures accurate (valid and reliable)?

Results of methodological quality assessment for included articles (1 = yes; 0 = no/unable to determine).

Study	Downs and Black checklist question number											Total
	Reporting						External validity		Internal validity bias			
	1	2	3	4	5	6	7	8	9	10	11	
Rebelo *et al*, 2023	1	1	1	1	1	1	0	0	1	1	1	**9**
Herring and Fukuda, 2022	1	1	1	1	1	1	0	0	1	1	1	**9**
Berriel *et al*, 2022	1	1	1	1	1	1	0	0	1	1	1	**9**
Rabbani *et al*, 2021	1	1	1	1	1	1	0	0	1	1	1	**9**
Haraldsdottir *et al*, 2021	1	1	1	1	1	1	0	0	1	1	1	**9**
Andrade *et al*, 2021	1	1	1	1	1	0	0	0	1	1	1	**8**
Timoteo *et al*, 2021	1	1	1	1	1	1	0	0	1	1	1	**9**
Ungureanu *et al*, 2021	1	1	1	1	0	1	0	0	1	1	1	**8**
Kupperman *et al*, 2021	1	1	1	1	1	0	0	0	1	1	1	**8**
Berriel *et al*, 2020	1	1	1	1	1	1	0	0	1	1	1	**9**
Horta *et al*, 2020	1	1	1	0	1	1	0	0	1	1	1	**9**
García-de-Alcaraz *et al*, 2020	1	1	1	1	0	1	0	0	1	1	1	**8**
Roy *et al*, 2020	1	1	1	1	1	0	0	0	1	1	1	**8**
Clemente *et al*, 2020	1	1	1	1	1	1	0	0	1	1	1	**9**
Lima *et al*, 2020	1	1	1	1	0	1	0	0	1	1	1	**8**
Duarte *et al*, 2019	1	1	1	1	1	1	0	0	1	1	1	**9**
Clemente *et al*, 2019	1	1	1	1	0	1	0	0	1	1	1	**8**
Horta *et al*, 2019	1	1	1	1	0	1	0	0	1	1	1	**8**
Silva *et al*, 2019	1	1	1	1	1	0	0	0	1	1	1	**8**
Roy *et al*, 2019	1	1	1	1	1	0	0	0	1	1	1	**8**
Hyatt and Kavazis, 2019	1	1	1	1	1	0	0	0	1	1	1	**8**
Skazalski *et al*, 2018	1	1	1	1	0	0	0	0	1	1	1	**7**
Castello *et al*, 2018	1	1	1	1	0	1	0	0	1	1	1	**8**
Mendes *et al*, 2018	1	1	1	1	0	1	0	0	1	1	1	**8**
Tavares *et al*, 2018	1	1	1	1	0	1	0	0	1	1	1	**8**
Debien *et al*, 2018	1	1	1	1	1	0	0	0	1	1	1	**8**
Brandão *et al*, 2018	1	1	1	0	0	1	0	0	1	1	1	**6**
Nogueira *et al*, 2017	1	1	1	1	1	0	0	0	1	1	1	**8**
Horta *et al*, 2017	1	1	1	1	0	1	0	0	1	1	1	**8**
Timoteo *et al*, 2017	1	1	1	1	0	1	0	0	1	1	1	**8**
de Freitas *et al*, 2015	1	1	1	1	1	0	0	0	1	1	1	**8**

Appendix V – Supplemental material of Study V.

Wellness questionnaire used to monitor fatigue, recovery, stress, muscle soreness, and sleep perception.

	-3	**-2**	**-1**	**0**	**1**	**2**	**3**
Fatigue	Very tired	Tired	Fairly tired	Neutral	Fairly fresh	Fresh	Very fresh
Sleep quality	Very restless	Restless	Fairly restless	Neutral	Fairly restful	Restful	Very restful
Sleep time	0-3 hours	4 hours	5 hours	6 hours	7 hours	8 hours	9+ hours
Soreness	Very tight/sore	Tight/sore	Fairly tight/sore	Neutral	Fairly good	Good	Very good
Mood	Very unpleasant	Unpleasant	Fairly unpleasant	Neutral	Fairly pleasant	Pleasant	Very pleasant
Stress	Very anxious	Anxious	Fairly anxious	Neutral	Fairly calm	Calm	Very calm

Analysis of correlation between training loads, neuromuscular fatigue, and well-being parameters during the five microcycles.

Microcycle 1													
Variables	sRPE	wITL	Strain	Monotony	wETL	CMJ height	CMJ PP	Fatigue	Sleep quality	Sleep time	Soreness	Mood	Stress
sRPE	1.000												
wITL	0.397	1.000											
Strain	-0.375	0.271	1.000										
Monotony	**-0.745**	-0.293	**0.793**	1.000									
wETL	0.240	-0.453	-0.431	-0.060	1.000								
CMJ height	-0.138	0.033	-0.002	-0.037	0.275	1.000							
CMJ PP	-0.259	-0.433	-0.173	0.149	0.428	0.261	1.000						
Fatigue	0.118	0.353	-0.072	-0.213	-0.320	0.307	-0.448	1.000					
Sleep quality	-0.077	0.192	0.333	0.061	**-0.747**	0.189	-0.375	**0.599**	1.000				
Sleep time	-0.014	0.393	0.181	0.017	-0.238	-0.461	-0.389	0.323	0.248	1.000			
Soreness	-0.264	0.061	0.111	0.113	-0.440	0.085	-0.441	**0.677**	**0.750**	0.254	1.000		
Mood	-0.284	-0.150	0.166	0.194	-0.405	0.476	-0.183	0.415	**0.685**	-0.413	**0.648**	1.000	
Stress	-0.160	-0.030	0.166	0.100	-0.418	0.483	-0.226	0.318	**0.569**	-0.510	**0.570**	**0.955**	1.000
Microcycle 2													
Variables	sRPE	wITL	Strain	Monotony	wETL	CMJ height	CMJ PP	Fatigue	Sleep quality	Sleep time	Soreness	Mood	Stress
sRPE	1.000												

wITL	**0.863**	1.000											
Strain	0.337	0.391	1.000										
Monotony	-0.502	-0.428	**0.634**	1.000									
wETL	0.360	0.451	-0.218	-0.433	1.000								
CMJ height	0.091	0.169	-0.201	-0.218	0.178	1.000							
CMJ PP	0.342	0.121	-0.400	**-0.681**	**0.697**	0.380	1.000						
Fatigue	**-0.690**	**-0.579**	-0.114	0.511	**-0.789**	0.110	-0.472	1.000					
Sleep quality	-0.151	-0.100	0.501	0.193	**-0.703**	-0.269	-0.482	**0.641**	1.000				
Sleep time	0.110	0.122	0.418	0.087	-0.259	-0.346	-0.141	-0.061	0.318	1.000			
Soreness	-0.482	-0.489	-0.373	-0.145	**-0.734**	-0.148	-0.302	**0.725**	**0.655**	-0.104	1.000		
Mood	-0.090	-0.107	0.087	-0.159	-0.315	0.171	-0.273	0.364	0.465	-0.470	0.441	1.000	
Stress	0.008	-0.059	-0.115	-0.332	-0.158	0.048	-0.056	0.282	0.481	-0.443	**0.542**	**0.895**	1.000
Microcycle 3													
Variables	sRPE	wITL	Strain	Monotony	wETL	CMJ height	CMJ PP	Fatigue	Sleep quality	Sleep time	Soreness	Mood	Stress
sRPE	1.000												
wITL	**0.868**	1.000											
Strain	0.387	0.392	1.000										
Monotony	-0.318	-0.229	**0.734**	1.000									
wETL	-0.267	-0.275	-0.156	0.120	1.000								
CMJ height	0.008	0.104	-0.263	-0.209	0.496	1.000							
CMJ PP	0.088	-0.148	-0.089	-0.079	**0.591**	0.294	1.000						
Fatigue	-0.374	-0.384	-0.121	0.166	-0.568	-0.042	-0.209	1.000					
Sleep quality	0.225	0.073	0.004	-0.038	-0.421	0.134	0.015	0.504	1.000				
Sleep time	-0.240	**-0.542**	-0.419	-0.077	0.326	-0.154	0.163	-0.038	0.092	1.000			
Soreness	0.002	0.143	0.200	0.267	-0.399	-0.066	-0.064	0.404	0.372	-0.241	1.000		
Mood	0.394	0.492	0.488	0.202	-0.480	0.254	-0.214	0.421	**0.635**	-0.427	0.404	1.000	
Stress	0.246	0.532	**0.630**	0.337	-0.548	0.151	-0.263	0.324	0.372	**-0.614**	0.221	**0.720**	1.000
Microcycle 4													
Variables	sRPE	wITL	Strain	Monotony	wETL	CMJ height	CMJ PP	Fatigue	Sleep quality	Sleep time	Soreness	Mood	Stress
sRPE	1.000												
wITL	**0.904**	1.000											
Strain	0.438	0.270	1.000										
Monotony	0.218	0.026	**0.968**	1.000									
wETL	-0.052	-0.016	-0.093	-0.077	1.000								
CMJ height	-0.208	-0.286	0.029	0.114	0.471	1.000							

CMJ PP	0.023	0.053	0.207	0.198	0.126	0.252	1.000						
Fatigue	-0.006	0.071	-0.291	-0.269	-0.049	-0.230	**-0.536**	1.000					
Sleep quality	-0.314	-0.282	-0.115	0.071	-0.553	-0.321	-0.517	0.484	1.000				
Sleep time	0.331	0.301	0.260	0.122	0.207	0.025	-0.176	0.151	0.392	1.000			
Soreness	-0.470	-0.378	**-0.695**	**-0.575**	-0.218	-0.177	-0.305	0.467	0.301	-0.304	1.000		
Mood	-0.526	**-0.537**	**-0.534**	-0.304	-0.229	0.154	-0.427	0.273	**0.582**	0.081	**0.640**	1.000	
Stress	-0.455	-0.454	-0.337	-0.112	-0.213	0.127	-0.292	0.467	**0.580**	0.112	**0.623**	**0.686**	1.000
Microcycle 5													
Variables	sRPE	wITL	Strain	Monotony	wETL	CMJ height	CMJ PP	Fatigue	Sleep quality	Sleep time	Soreness	Mood	Stress
sRPE	1.000												
wITL	**0.887**	1.000											
Strain	0.397	**0.687**	1.000										
Monotony	0.110	0.485	**0.941**	1.000									
wETL	0.321	0.338	0.029	-0.078	1.000								
CMJ height	-0.244	-0.150	0.273	0.294	0.054	1.000							
CMJ PP	0.209	-0.027	-0.293	-0.476	**0.663**	0.268	1.000						
Fatigue	-0.027	0.111	0.201	0.158	**-0.612**	0.123	-0.361	1.000					
Sleep quality	-0.174	-0.031	0.253	0.332	-0.179	0.321	**-0.601**	0.187	1.000				
Sleep time	-0.096	-0.093	-0.131	-0.166	0.270	0.095	-0.153	0.119	**0.609**	1.000			
Soreness	-0.425	-0.429	-0.359	-0.322	-0.340	-0.231	0.000	0.352	-0.040	-0.093	1.000		
Mood	0.022	0.192	0.307	0.333	-0.361	**0.620**	-0.099	**0.555**	0.356	0.047	0.184	1.000	
Stress	0.039	0.176	0.197	0.228	-0.393	0.519	-0.049	**0.689**	0.249	0.002	0.330	**0.897**	1.000

Note: Significant differences ($p \leq 0.05$) are highlighted in bold. sRPE = session rating of perceived exertion; wITL = weekly internal training load; wETL = weekly external training load; CMJ = countermovement jump; PP = peak power.

Analysis of correlation between training loads and well-being parameters during the matchday minus.

Matchday-6									
Variables	sRPE	ITL	ETL	Fatigue	Sleep quality	Sleep time	Soreness	Mood	Stress
sRPE	1.000								
ITL	**0.971**	1.000							
ETL	0.340	0.391	1.000						
Fatigue	0.119	0.000	-0.503	1.000					

Sleep quality	-0.161	-0.149	-0.274	-0.250	1.000				
Sleep time	0.101	0.049	0.089	-0.340	-0.049	1.000			
Soreness	-0.597	-0.591	-0.540	0.110	0.446	-0.542	1.000		
Mood	0.020	-0.045	-0.217	0.454	0.378	**-0.725**	**0.614**	1.000	
Stress	-0.048	-0.077	-0.464	**0.582**	0.264	**-0.765**	**0.616**	**0.844**	1.000
Matchday-5									
Variables	sRPE	ITL	ETL	Fatigue	Sleep quality	Sleep time	Soreness	Mood	Stress
sRPE	1.000								
ITL	**0.995**	1.000							
ETL	0.295	0.293	1.000						
Fatigue	0.110	0.097	-0.397	1.000					
Sleep quality	0.108	0.148	-0.147	0.272	1.000				
Sleep time	0.188	0.199	-0.052	-0.128	0.436	1.000			
Soreness	-0.138	-0.080	-0.512	0.514	0.496	-0.260	1.000		
Mood	0.472	**0.558**	-0.393	0.303	0.268	-0.162	0.533	1.000	
Stress	0.348	0.435	-0.398	0.291	0.286	-0.204	**0.563**	**0.953**	1.000
Matchday-4									
Variables	sRPE	ITL	ETL	Fatigue	Sleep quality	Sleep time	Soreness	Mood	Stress
sRPE	1.000								
ITL	**0.984**	1.000							
ETL	0.099	0.057	1.000						
Fatigue	-0.153	-0.207	-0.262	1.000					
Sleep quality	0.053	0.016	**-0.577**	0.172	1.000				
Sleep time	0.263	0.295	0.084	-0.486	0.073	1.000			
Soreness	-0.024	-0.054	-0.538	0.325	0.322	-0.063	1.000		
Mood	-0.219	-0.237	-0.011	0.246	0.235	-0.395	-0.194	1.000	
Stress	0.125	0.081	-0.151	0.241	0.241	-0.124	0.284	**0.677**	1.000
Matchday-3									
Variables	sRPE	ITL	ETL	Fatigue	Sleep quality	Sleep time	Soreness	Mood	Stress
sRPE	1.000								
ITL	**0.999**	1.000							
ETL	0.047	0.049	1.000						
Fatigue	-0.078	-0.062	**-0.821**	1.000					
Sleep quality	0.151	0.177	**-0.733**	**0.667**	1.000				

Sleep time	0.277	0.220	0.286	-0.113	0.159	1.000			
Soreness	-0-285	-0.251	-0.378	0.507	0.430	-0.222	1.000		
Mood	0.184	0.240	-0.476	**0.663**	**0.685**	-0.240	**0.555**	1.000	
Stress	0.168	0.207	**-0.643**	**0.755**	**0.556**	-0.323	0.450	**0.825**	1.000
Matchday-2									
Variables	sRPE	ITL	ETL	Fatigue	Sleep quality	Sleep time	Soreness	Mood	Stress
sRPE	1.000								
ITL	**0.987**	1.000							
ETL	-0.072	-0.132	1.000						
Fatigue	-0.235	-0.323	-0.327	1.000					
Sleep quality	0.210	0.147	-0.265	0.501	1.000				
Sleep time	0.296	0.336	0.361	0.138	0.521	1.000			
Soreness	-0.361	-0.415	-0.225	0.163	0.317	-0.058	1.000		
Mood	0.096	0.003	0.175	0.106	0.449	-0.070	**0.625**	1.000	
Stress	0.008	-0.100	0.128	0.247	0.202	-0.164	**0.611**	**0.737**	1.000
Matchday-1									
Variables	sRPE	ITL	ETL	Fatigue	Sleep quality	Sleep time	Soreness	Mood	Stress
sRPE	1.000								
ITL	**0.953**	1.000							
ETL	0.372	0.397	1.000						
Fatigue	0.048	-0.018	-0.515	1.000					
Sleep quality	0.103	0.175	-0.088	**0.643**	1.000				
Sleep time	0.198	0.372	**0.597**	-0.065	0.046	1.000			
Soreness	-0.174	-0.187	-0.154	0.524	**0.754**	-0.294	1.000		
Mood	0.070	0.012	-0.120	0.286	**0.634**	-0.430	0.414	1.000	
Stress	0.028	-0.016	-0.295	0.404	**0.629**	-0.428	0.378	**0.881**	1.000
Matchday									
Variables	sRPE	ITL	ETL	Fatigue	Sleep quality	Sleep time	Soreness	Mood	Stress
sRPE	1.000								
ITL	**0.983**	1.000							
ETL	**0.716**	**0.711**	1.000						
Fatigue	-0.191	-0.159	-0.109	1.000					
Sleep quality	0.137	0.270	-0.237	0.282	1.000				
Sleep time	0.475	0.470	0.160	-0.328	0.496	1.000			

Soreness	-0.127	-0.051	-0.092	**0.644**	0.468	-0.115	1.000		
Mood	-0.043	0.100	-0.114	0.216	0.377	-0.100	0.402	1.000	
Stress	-0.225	-0.047	-0.164	0.344	0.455	-0.263	**0.597**	**0.745**	1.000