Monitoring Strategies used by Specialist Tactical Populations: A Systematic Review of the Literature

Sean Richardson

A Dissertation submitted to Auckland University of Technology in partial fulfilment of the requirements for the degree of Master of Sport, Exercise and Health

2023

Abstract

In the field of tactical strength and conditioning, recent research has focused on enhancing operational readiness, preventing injuries, and implementing advanced periodisation models. Tactical populations include operators from law enforcement, military, fire, and emergency response units. Specifically, this dissertation examines the monitoring strategies employed by operators serving in combative environments and proficient in weapons and tactics, referred to as "specialist tactical populations." Combative environments are characterised by high levels of conflict, violence, and danger, requiring operators to face uncertainty, make rapid decisions, and adapt quickly. Examples of units operating in such environments include military, tactical police, and counterterrorism units. Operating in these environments demands exceptional physical and mental capabilities, as the risks of injury or harm are significantly amplified. Therefore, monitoring the physiological and psychological stressors within these high-risk environments becomes crucial for the performance and well-being of specialist tactical operators.

While internal and external load monitoring has been extensively studied in traditional sporting environments, research on monitoring strategies for tactical populations, especially specialist groups, remains limited. This dissertation aims to address this gap by achieving three primary objectives: identifying and analysing monitoring methods applicable to specialist tactical populations, reviewing and critique all available literature on monitoring strategies in these populations, and proposing practical recommendations and a framework for effective load monitoring protocols.

The systematic review conducted for this dissertation included studies primarily conducted in training environments, with limited observation in operational settings. Internal variables were measured in 91% of the studies, with heart rate being the primary method used. External variables were reported in 64% of the studies, with accelerometry being the most common tool. The overall findings highlight the significant physiological and psychological demands placed on specialist tactical operators.

Implementing load monitoring protocols in operational environments requires careful consideration of factors such as validity, wear tolerance, technological constraints, and data security. This dissertation provides valuable insights into the monitoring strategies employed in specialist tactical populations, offering practical recommendations for their implementation in operational settings.

Table of Contents

Abstract **2**

Table of Contents **4**

List of Figures **6**

List of Tables **7**

Attestation of Authorship **8**

Acknowledgements **9**

Chapter 1. Introduction **10**

1.1. Topic and Context *10*

1.2. Significance, Scope, and Focus *11*

1.3. Research Questions *12*

1.4. Overview of Structure *12*

Chapter 2. Inside the Athlete's Toolbox: A Comprehensive Review of Traditional Sport Monitoring Methods **14**

2.2 Discussion *16*

2.3.1. Training Load 16

2.3.2. External Monitoring 18

2.3.3. Internal Monitoring 23

2.3.4. Summary and Conclusion 32

Chapter 3. Beyond the Arena: Exploring Internal and External Load Monitoring Methods in Specialist Tactical Populations **33**

3.1 Research Methods *36*

3.1.1. Search strategy 36

3.1.2. Study Selection 37

3.1.3. Data-evaluation and quality appraisal 38

3.2 Results *39*

3.2.1. Search Results 39

3.2.2. Evidence Quality 39

3.3 Discussion *43*

3.3.1. Training Load 43

3.3.2. Training Load in Tactical Populations 44

3.3.3. Measures of External Load 46

3.3.4. Measures of Internal Load 55

3.3.5. Summary and Conclusion 88

Chapter 4. From Theory to Practice: Practical Applications of Monitoring Methods in Specialist Tactical Populations **99**

4.1 Practical Considerations *99*

4.1.1 Analytical, Technical, and Contextual Considerations 106

4.2 Framework and Recommendations *112*

4.3 Future Research *115*

References **118**

Appendices **164**

Appendix A.. *164*

Appendix B.. *175*

List of Figures

Figure 1. A Comprehensive approach to biomarker analysis, adapted from Lee et al. (2017). 30
Figure 2. PRISMA Selection of Studies Flow Chart 38
Figure 3. Key Considerations for Load Monitoring within Tactical Populations. 113
Figure 4. A Framework of the Key Considerations for Implementing Load Monitoring Protocols in Tactical Environments..114

List of Tables

Table 1. Potential Internal and External Training Load Variables 17
Table 2. Summary of Edward's TRIMP HR Zones and Coefficients...............................29
Table 3. Breakdown of Quality Assessment 41
Table 4. Biochemical Analysis in Specialist Tactical Populations.................................73
Table 5. Hormonal Analysis in Specialist Tactical Populations 77
Table 6. Metabolite Analysis in Specialist Tactical Populations 82
Table 7. Monitoring Methods in Specialist Tactical Populations..................................89
Table 8. Summary of Practical Considerations of Load Monitoring Strategies in Specialist Tactical Populations. Adapted from Michael et al. (2022) 102

Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Name: Sean Richardson

Signature:

Acknowledgements

Firstly, I would like to thank my supervisor. Mike, thank you so much for your unwavering support, guidance, and patience throughout this journey. Your expertise and encouragement have been invaluable, and I am truly grateful for your dedication to helping me reach this milestone.

I am also immensely thankful to my partner, Kelsey, whose support, and understanding have been my rock during the ups and downs of this process. Even though she might not know the intricacies of my research topic, she listened to my rants with a smile and provided me with the much-needed respite and laughter. I cherish the moments of lightheartedness she brought to this challenging endeavour.

Last but not least, I must express my gratitude to my loyal companion, Tari. Despite not being able to comprehend the complexities of this dissertation, Tari's unwavering presence, wagging tail, and occasional mischievous antic brought joy to my writing sessions. Tari, you've been the furry motivator who reminded me to take breaks and enjoy the simple pleasures in life.

To all those who have supported me in various ways throughout this dissertation, whether through friendship, advice, or encouragement, I am incredibly thankful. Your belief in me has made this accomplishment possible.

Chapter 1. Introduction

1.1. Topic and Context

Tactical strength and conditioning has gained significant attention in recent years, as evidenced by the growing body of research and evidence-based practice (Dijksma et al., 2021; Maupin et al., 2019; Michael et al., 2022). This discipline has a rich historical background, with some authors suggesting that the ancient Olympic Games served as a platform to showcase warrior athleticism (Alvar, Sell, & Deuster, 2017). In more recent years, tactical strength and conditioning research has focused on aspects such as periodisation, programming, and injury prevention, with the overarching goal of enhancing operational "readiness" (Maupin et al., 2018). This chapter serves as an introduction to tactical populations as well as introducing important concepts that will be further explored throughout this dissertation.

Tactical populations encompass a diverse range of professionals, including law enforcement, military personnel, firefighters, and emergency response units, and are required to confront life-and-death situations in their line of duty (Alvar et al., 2017; Michael et al., 2022; Maupin et al., 2018). These populations exhibit variations in terms of tactical operators and hierarchical structures, with each group having distinct operational objectives and tasks (Alvar et al., 2017). Therefore, this dissertation will focus on the monitoring strategies employed by operators who may be required to work within combative environments and are proficient in weapons and tactics, referred to as "specialist tactical populations." For this dissertation, combative environments are characterised by high levels of conflict, violence, and danger, where tactical populations may encounter armed individuals or groups, face uncertainty, and require rapid decision-making and adaptability (Alvar et al., 2017; Irving, Orr, & Pope, 2019; Tomes, Schram, & Orr 2021). Notable examples of specialist tactical populations that frequently operate in combative environments as part of their occupational tasks include, military personnel, specialist tactical police units (e.g., SWAT, STG, AOS) and counterterrorism units (Alvar et al., 2017; Michael et al., 2022; Maupin et al., 2018). Operating within these challenging environments demands exceptional physical and mental capabilities as operators navigate through limited visibility, contend with intense emotions, and face various physical hazards. In such austere conditions, the risks of injury or harm are significantly amplified, emphasising the importance and the need for heightened physical fitness, proficient combat skills, and psychological resilience strategies (Michael et al., 2022; Tornero-Aguilera et al., 2017). Furthermore, operators are required to perform at their highest capability under these conditions. Given the heightened physical and mental demands imposed by combative environments, it becomes imperative for practitioners working alongside specialist tactical groups to prioritise the well-being and performance of these operators (Michael et al., 2022; Tornero-Aguilera et al., 2017). In pursuit of this objective, the implementation of monitoring strategies plays a pivotal and indispensable role. As appropriate and effective monitoring strategies allow practitioners to assess operational readiness, through optimising physical fitness, managing stressors, preventing injuries, enhancing performance, and promoting psychological resilience among operators. Essentially, monitoring is a proactive approach that enhances the readiness and effectiveness of specialist tactical populations, enabling them to navigate through the austere environments which they must contend.

The monitoring of internal load (e.g., heart rate (HR), rating of perceived exertion (RPE), and biomarkers), as well as the measurement of external load (e.g., repetition volume, total distance covered, and performance tests), has been extensively investigated within traditional sporting environments (McGuigan, Hassmén, Rosic, & Stevens, 2020). However, the literature on monitoring strategies for tactical populations remains limited in comparison to sports and other populations. Furthermore, there is a paucity of research examining the implementation of monitoring strategies specifically within specialist tactical populations. Consequently, this dissertation aims to provide a comprehensive analysis of the current research in this field, while also identifying and addressing the existing gaps between research and practice.

1.2. Significance, Scope, and Focus

This dissertation aims to identify and analyse the monitoring methods and strategies employed outside the field of tactical populations, that can be relevant and applied to these specialist groups. Additionally, this dissertation aims to review and critique all available literature utilising monitoring strategies in specialist tactical populations. Therefore, this comprehensive examination of monitoring methods employed in non-tactical environments and those implemented within specialist tactical populations will provide a holistic view of the load monitoring landscape across domains. Importantly, this dissertation goes beyond understanding the monitoring strategies themselves and focuses on their practical application within tactical environments. Providing actionable recommendations and a framework for coaches, practitioners, and decision-makers in the tactical field. Finally, the interdisciplinary relevance of this dissertation is noteworthy, as it draws upon knowledge and methods from various fields such as traditional sports, exercise science, and tactical training. This interdisciplinary approach allows for the content of this dissertation to apply to practitioners and researchers from multiple disciplines who are interested in monitoring strategies for tactical populations.

1.3. Research Questions

I. What are the monitoring strategies (outside the field of tactical populations) that are used by coaches and practitioners that are relevant to specialist tactical populations?

II. What are the monitoring strategies implemented within specialist tactical populations?

III. What are the practical applications for specialist tactical populations from the identified monitoring strategies?

1.4. Overview of Structure

The main body of this dissertation is divided into three chapters:

Chapter 2: *Inside the Athlete's Toolbox* provides a comprehensive narrative review and discussion of the literature surrounding monitoring methods employed within traditional sporting environments. This chapter aims to establish a strong foundation of knowledge by reviewing the existing research and highlighting the key monitoring techniques used in sports.

Chapter 3: *Beyond the Arena* builds upon the foundation of internal and external load monitoring methods established in Chapter 2. It systematically presents and explores the current research within the field of specialist tactical populations, while also identifying the current gaps between research and practice. This chapter serves to analyse the current state of monitoring methods beyond traditional sports and provide insight into potential areas of future research.

Chapter 4: *From Theory to Practice* bridges the gap between traditional sport and tactical environments by exploring the practical applications of integrating monitoring methods into specialist tactical populations. This chapter focuses on translating the theoretical knowledge gained from the previous chapters into practical strategies and frameworks for load monitoring in tactical settings.

It is important to note that due to the interrelated topics and structure of the chapters, there may be some repetition between the introductory and summary sections, as well as within the dissertation as a whole. However, efforts have been made to minimise redundancy and ensure that each chapter contributes distinct information and insights to the overall discussion.

Chapter 2. Inside the Athlete's Toolbox: A Comprehensive Review of Traditional Sport Monitoring Methods

Athlete monitoring strategies have become increasingly popular within high-performance and elite athletic populations and are well-established crucial practices for strength and conditioning practitioners and sport scientists (McGuigan et al., 2020; Soligard et al., 2016). Athlete monitoring systems aim to optimise athletic performance, prevent injuries, and safeguard the overall well-being of athletes (McGuigan et al., 2020). With the growing and increasing demands of competitive traditional sport and the perpetual pursuit of *"faster, higher, stronger,"* athletes' and their supporting staff face increasing pressure to enhance performance. In this context, the need for evidence-based decision-making becomes paramount. Over recent years, strength and conditioning practitioners, coaches, and athletes have increasingly adopted a scientific and data-driven approach in the design, monitoring, and implementation of their training programmes (Halson et al., 2014).

The pursuit of athletic excellence necessitates a delicate balance between training stimulus and adequate recovery. Athletes regularly participate in demanding training regimens to enhance their competitive performance (McGuigan et al., 2020). When the balance between stimulus and recovery is appropriately managed, athletes will experience physiological adaptations and improved performance, following the principle of super-compensation (Alvar et al., 2017). However, inadequate training load management can lead to insufficient recovery and maladaptive responses such as injuries, illness, prolonged fatigue, non-functional overreaching, and overtraining syndrome (McGuigan et al., 2020). These maladaptive responses have the potential to negatively influence athletic performance and increase the risk towards athletes' mental and physical well-being (Soligard et al., 2016). Effectively monitoring an athlete's training load and subsequent internal response becomes increasingly important when mitigating these potential negative outcomes. Furthermore, it provides practitioners and coaches objective insight into the understanding of individual adaptations and responses to training load, informing training prescription, and potentially identifying markers of fatigue (Bourdon et al., 2017; Soligard et al., 2016).

Athlete monitoring systems can be expressed as strategies that quantify training load (i.e., external monitoring), and quantify physical status over time (i.e., internal monitoring) (Campbell et al., 2017). External training loads refer to any measurable externally applied stimulus, which is independent of their internal characteristics (e.g., frequency, duration, type of training, time-motion analysis, or Acute:Chronic load ratio) (Maupin et al., 2018; Soligard et al., 2016). These external loads represent the quantity of work completed by athletes. Whereas internal load refers to the measurable "internal response factors within the biological system," and can be expressed as psychological states (e.g., perception of effort, questionnaires, and self-report measures), physiological responses (e.g., HR variables and training impulse), and individual biomarkers (e.g., blood, saliva, and urine analyses) (Soligard et al., 2016). It is well established that no single internal or external marker can accurately detect overtraining and maladaptation in athletes (Bourdon et al., 2017; Greenham et al., 2018; Maupin et al., 2018; Soligard et al., 2016), researchers suggest utilising a multivariate approach and integrate a combination of workload, physiological, psychological, and biochemical markers into athlete monitoring systems (McGuigan et al., 2020).

The monitoring methods and techniques outlined in this chapter are indispensable tools that provide objective insight into athletes' physiological, psychological, and biomechanical responses to the demands of training, recovery, and competition. This chapter aims to explore and provide an overview of the different athlete monitoring methods by examining their significance, methodologies, and practical implications for enhancing performance within the traditional sporting environment. By reviewing and synthesizing current research and practice, this chapter will address the following objectives:

I. Outline the importance of monitoring methods in optimising athletic performance.
II. Discuss the main monitoring methods utilised within traditional sporting environments.
III. Evaluate the strengths and limitations of various traditional sport monitoring techniques, considering their applicability, reliability, and validity.

IV. Identify gaps, challenges, and future directions in the field of athlete monitoring methods.

To achieve these objectives, this chapter is organised into several sections and subheadings. The subsequent section provides a comprehensive review of the relevant and existing literature on training load monitoring methodologies. Followed by an exploration of the two main categories of monitoring methods: external monitoring and internal monitoring, which will examine in detail specific techniques utilised in a traditional sport environment.

2.2 Discussion

2.3.1. Training Load

Strength and conditioning practitioners are responsible for the development and monitoring of periodisation programmes that are designed to elicit specific training adaptations in their athletes' (Campbell et al., 2017). Typically, these professionals monitor athletes' responses to training load and frequently update the programme over time. The process of monitoring individual training responses is essential to understand the individuals' response to training, fatigue, and recovery, whilst mitigating the risk of injury and non-functional overreaching (Campbell et al., 2017). Non-functional overreaching can occur when an athlete undergoes a prolonged and excessive training stimulus, without sufficient recovery (Alvar et al., 2017), and can potentially result in a negative impact on their physical and mental health, as well as performance (McGuigan et al., 2020).

Training load is often referred to within traditional sporting environments as the players' response to the imposed stimulus over time (Soligard et al., 2016). The International Olympic Committee has defined training load as "the cumulative amount of stress placed on an individual from single or multiple training sessions (structured or unstructured) over a period of time" (Soligard et al., 2016). Typically, training load measures have been categorised into internal and external methods (Bourdon et al., 2017; Maupin et al., 2018; McGuigan et al., 2020; Michael et al., 2022; Soligard et al., 2016). For this dissertation, external load will refer to any measurable externally applied stimulus, which is independent of their internal characteristics. Common measures of external load include speed, acceleration, frequency, time-motion analysis, Acute:Chronic workload ratio, and global positioning systems (GPS) parameters (Maupin et al., 2018; Soligard et al., 2016). The externally applied stimulus will result in both physiological and psychological responses within the individual. Therefore, internal load refers to the measurable "internal response factors within the biological system." Measures such as HR, HR variability (HRV), RPE, training impulse (TRIMP), and blood lactate are commonly used to assess internal load (Soligard et al., 2016). A summary of some common internal and external monitoring methods is presented in Table 1.

Table 1.

Potential Internal and External Training Load Variables

Internal load	**External load**
HR	Duration
HR recovery	Distance
Oxygen uptake	Frequency
HRV	Type/Mode
TRIMP	GPS measures
DLW	Accelerometry
Hormone analysis	Power output
Blood lactate/glucose	Speed
RPE/sRPE	Accel/Deceleration
Cognition	Metabolic power
	Time-motion analysis
	Neuromuscular function
	Movement repetition counts
	Acute:Chronic workload ratio
	Training load calculations

HR = Heart rate, HRV = HR variability, TRIMP = Training impulse, GPS = Global positioning system, DLW = Doubly labelled water, RPE = Rating of perceived exertion, sRPE = Session RPE.

External load monitoring provides insight into the work completed, capability, and capacity of the athlete, whereas internal load monitoring establishes how the athlete is adapting physiologically (Maupin et al., 2018). Therefore, to optimise athlete performance, it is critical to integrate both internal and external monitoring methods. This integrated approach to monitoring training loads can provide a more comprehensive analysis of the overall stress experienced by the athlete, as no single variable consistently predicts maladaptation or injury (Borresen et al., 2009; Halson et al., 2014; Meeusen et al., 2013; Soligard et al., 2016). For example, an athlete repeating the same training session may present identical relative power outputs (i.e., same external load), however, their ability to respond to this output (e.g., increased HR, sRPE, or blood lactate; i.e., internal load), may differ significantly between athletes' (Bourdon et al., 2017; Halson et al., 2014). Thus, by taking a comprehensive and integrated approach to athlete monitoring, practitioners can gain greater insight into the athletes' physiological and psychological responses, allowing for more targeted and effective training interventions.

2.3.2. External Monitoring

Although it is desirable to measure both internal and external training loads, this is not always feasible due to the lack of readily available valid indicators of internal load (Impellizzeri et al., 2019). For example, repeated bouts of high-intensity sprint training are thought to elicit higher neuromuscular responses when compared to other forms of running at relatively slower speeds. However, there are no established or validated real-time methods of monitoring this neuromuscular involvement in training environments (Impellizzeri et al., 2019). Conversely, external load indicators such as velocity or time to complete these sprints are easily measurable and commonly employed through GPS tools (Soligard et al., 2016). Furthermore, practitioners typically estimate internal load based on external load variables. However, as explained previously, this approach may have limitations as practitioners prescribe training according to external load to elicit specific internal physiological adaptations.

GPS and Accelerometry

Over the past decade, exercise science research in team sports has developed exponentially, leading to the emergence of novel technologies for monitoring training load in athletes (Bourdon et al., 2017; Rago et al., 2020; Kupperman et al., 2020).

Wearable microtechnology incorporating GPS has become increasingly popular, with four out of the top-five ranked variables used to monitor training load in Football, being derived from GPS technology (Akenhead & Nassis, 2016). These variables included accelerations, total distance, high-speed running distance, and estimated metabolic power (Akenhead & Nassis, 2016). Furthermore, several team sports have adopted the use of wearable microtechnology during competition (e.g., Rugby, Football/Soccer, Basketball, American Football, Cycling, Triathlon etc.). With the development and integration of these micro-technologies in competition and training, research utilising these tools has accelerated over the last decade (Rago et al., 2020).

GPS units are a type of microtechnology worn by athletes that contain sensors which communicate their position and movement through satellites (Bourdon et al., 2017). This allows for the quantification of several external load metrics, including displacement (i.e., distance), velocity inferred from displacement (or more commonly via the Doppler-Shift method), and acceleration obtained by velocity (Bourdon et al., 2017). These metrics lay the foundation to calculate copious amounts of variables for practitioners to analyse and integrate into their athlete monitoring model. Furthermore, the utilisation of triaxial accelerometers is beneficial in the measurement of acceleration quantities executed across all three planes of motion, with the ability to measure impact forces resulting from collisions with other athletes (Scott et al., 2016). The versatility of utilising GPS and accelerometers as a tool to monitor training load have become common practice in high-performance settings as demonstrated by McGuigan et al. (2020), who conducted a systematic review of the training monitoring methods used in the field by coaches and practitioners, reporting all studies to have utilised GPS as a monitoring method.

Despite the abundance of data available from GPS technologies, certain methodological limitations can negatively impact data collection accuracy. The data derived from GPS and accelerometers are susceptible to extraneous variations, often termed "noise," and are typically processed and analysed with algorithms and filtration systems. However, these systems have been reported to be proprietary information, as certain manufacturers do not make them available to the public (Bourdon et al., 2017). The lack of transparency and ambiguity across GPS and accelerometry technology negatively impacts the validity of comparing data across studies and devices, as the data may not be interchangeable. Furthermore, practitioners must be cautious and aware of the data processing techniques employed by their specific devices manufacturer, to maintain methodological consistency in their analyses and interpretations (Bourdon et al., 2017).

Research on the validity and reliability of GPS devices in traditional sports settings has been discussed extensively in previous literature (Kupperman et al., 2020; Rago et al., 2020; Scott et al., 2016). Overall, the findings of Scott et al. (2016) suggest that the interpretation of acceleration, deceleration, and directional change should be approached with caution. As the accuracy of distance and velocity measurements increases with higher sampling frequency, it appears that higher velocity movements decrease GPS accuracy and reliability (Scott et al., 2016). Furthermore, the reliability of GPS data is reduced when assessing sport-specific tasks that involve a change of direction, or variable movement patterns such as kicking a ball, non-contact tackling, or jumping (Kupperman et al., 2020; Scott et al., 2016). Of note, Rago et al. (2020) observed that many practitioners prioritise the exploration of complex variables, over the validation and reliability of the GPS devices. As outlined in Appendix B, there are a copious number of external load variables, however, no current consensus on the most appropriate monitoring system (Gabbett et al., 2017). This presents a challenge for practitioners attempting to effectively monitor their athletes (Rago et al., 2020). As discussed thoroughly by Bourdon et al. (2017), a significant challenge for practitioners collecting GPS data is their ability to make meaningful inferences from the data available, impacting the inferred internal response, and desired adaptation. Furthermore, applied research contexts have developed thorough reporting standards regarding the data collection process, however, practitioners may not be aware of the various factors that can influence the final interpreted result (Rago et al., 2020).

Performance Tests and Neuromuscular Function

Performance tests and measurements of neuromuscular function are frequently reported to be utilised in team sports environments (Aoki et al., 2017; Ferioli et al., 2018;

Halson et al., 2014; McGuigan et al., 2020; Rowell et al., 2017). These types of assessments are often incorporated into athlete monitoring models as they are simple to administer and can be a direct measure of sport-specific improvements (McGuigan, 2017). However, dependent on the test and subsequent parameters, these assessments can be highly fatiguing (McGuigan et al., 2020), or have little to no adverse internal responses (Twist & Highton, 2013). Examples of common performance and neuromuscular function tests include the counter-movement jump (CMJ), reactive strength index (RSI), isometric mid-thigh pull, isokinetic dynamometry, force-velocity profiling, Y-balance test, maximal and repeated sprint performance, and the Yo-yo intermittent recovery test (Halson et al., 2014; McGuigan et al., 2020; Miguel et al., 2021). Each test measures specific variables related to an athlete's performance, such as power output, velocity, endurance, and recovery. Some examples of these variables include mean power, peak velocity, peak force, jump height, fatigue index, rate of force development, ground contact time, and flight time. As discussed previously, there are an increasing number of external monitoring methods at the disposal of sports coaches and strength and conditioning practitioners. This creates a dichotomy between the range of monitoring methods available and the doubts surrounding their efficacy and validity.

The validity and reliability of these performance tests is not the focus of this dissertation as they have been discussed extensively in previous research (Haines, Bourdon, & Deakin, 2016; Louder, Thompson, Banks, & Bressel, 2019; Plisky et al., 2021; Sulaiman et al., 2011). However, one of the more common neuromuscular tests is the CMJ. The CMJ has been utilised as an external monitoring method in team sports to evaluate readiness, performance, and recoverability (Aoki et al., 2017; Rowell et al., 2017; Ferioli et al., 2018). The variables and inferences from CMJ data vary across sports, for example, within basketball settings changes in jump height are the most reported (Heishman, Daub, Miller, Freitas, & Bemben, 2020). However, across Australian Football, rugby, and soccer CMJ has been utilised as a fatigue indicator by analysing specific force-time characteristics that expose compensations in movement strategies (Cormack et al., 2008; Gathercole et al., 2015; Rowell et al., 2017). Where the flight-time to contraction-time ratio as an evaluation of jumping strategy has been validated as a reliable variable in basketball (Heishman et al., 2019). Furthermore, authors have started to integrate other neuromuscular tests with the CMJ to quantify performance changes, such as the modified RSI model (*contraction-time / jump height*) which provides an index of explosiveness (Kipp et al., 2016). Thus, integrating performance and neuromuscular function tests, such as the CMJ, into athlete monitoring models may provide insight into the dose-response relationship of training.

Questionnaires and Self-report Measures

Training load and the subsequent responses to training can also be monitored using questionnaires, diaries, and other self-report tools which can be relatively inexpensive and simple to administer (Borresen & Lambert, 2009). Furthermore, the psychological indicators captured from these tools have been reported to be more sensitive and consistent than physiological indicators within overtraining studies (Meeusen et al., 2013). These psychological inventories can be collected and assessed rapidly (within minutes) compared to other internal and external monitoring methods, such as biochemical blood markers or GPS, which can take up to several days or weeks to evaluate (Bourden et al., 2017). However, one of the main limitations of these self-report tools, is that they rely heavily on subjective information, where athletes can manipulate data, and over- or under-estimate training load (Halson et al., 2014).

Several examples of these questionnaires, self-report tools, and subjective measures that are frequently recommended in the literature and utilised within high-performance settings exist. Such as the Profile of Mood States (POMS) (McNair et al., 1992; Morgan et al., 1987) and its derivatives (Saw et al., 2017), the Recovery-Stress Questionnaire for athletes (RES-Q- Sport) (Kellmann & Kallus, 2000; Kellmann & Kallus, 2001), various Acute Recovery and Stress Scales (Kellmann et al., 2016), Borg RPE (Borg, 1998), Session RPE (sRPE) (Foster, 1998)**,** Daily Analysis of Life Demands for Athletes (DALDA) (Rushall, 1990) and the Total Recovery Scale (TQR) (Kentta & Hassmen, 1998). Determining which subjective instrument to implement can be challenging, as practitioners need to identify not only the insights they wish to obtain but also the method by which they will capture this data. Bourdon et al. (2017) suggest practitioners should consider the following when choosing a questionnaire or self-report tool:

I. The validity and reliability; does the tool come with a detailed manual, theoretical background, and empirical data?
II. Is the tool designed for research purposes or feedback to coaches and athletes?
III. The time frame of the tool; is it more global or specific?
IV. Establish a clear feedback loop and intervention protocol.
V. Avoid using data for selection purposes to prevent undermining compliance.
VI. Display caution when deciding the detail and frequency of measurements (Bourden et al., 2017).

2.3.3. Internal Monitoring

As discussed previously, external load monitoring strategies aim to quantify an athlete’s work completed, capabilities, and capacities. In contrast, internal load refers to the measurable “internal response factors within the biological system” (e.g., HR, biochemical responses, and perception of effort) (Soligard et al., 2016). The monitoring of these internal responses is crucial to understand how individual athletes are adapting physiologically (Maupin et al., 2018). It is important to note, that even when athletes are exposed to the same external stimulus, their internal response can vary. For example, consider two athletes performing identical treadmill-based high-intensity sprint intervals with the same work-to-rest ratio, velocities, and durations for each sprint. However, factors such as fitness level, inherent physiological traits, recovery status, and genetic variability can influence their unique internal response (Impellizzeri et al., 2019). Therefore, it is imperative for coaches and practitioners to directly monitor and assess internal load to induce the desired psychophysiological response.

Perceived Exertion

Perceived exertion is a commonly utilised method of monitoring internal load, as seen in Appendix A. The original 6 to 20 RPE scale was initially designed by Borg (1998) to monitor the physiological stress during exercise and attempted to retrospectively report the perceived effort of athletes after training and competition. This evolved when Foster (1998) proposed the modified sRPE to quantify training load, by multiplying an athlete's RPE (on a scale of 1-10), by the session duration (minutes). For example, if an athlete completed a 30-minute training session and reported the RPE to be an 8 (on the modified 1-10 scale), the athlete would have an sRPE of 240 (30 x 8) arbitrary units. This approach has been demonstrated to be valid and reliable, with individual correlations between sRPE and summated HR zone scores ranging from r = 0.75 to 0.90 (Foster, 1998) and blood lactate concentrations of r = 0.86 (Gabbett & Domrow, 2007). Whilst RPE is well correlated with HR during steady-state exercise and high-intensity intervals, however, it does not transfer over as well into short-duration high-intensity football drills (Borresen & Lambert, 2008). Nonetheless, meta-analyses have reported that RPE is a valid means of assessing exercise intensity, revealing strong weighted mean validity coefficients for HR (r = 0.62), blood lactate (r = 0.57), and percentage of maximal oxygen uptake (VO_2max; r = 0.64). The RPE and sRPE scales were designed to reduce the need for HR monitors or other methods of assessing exercise intensity. While both RPE and sRPE methods are recognised for their simplicity, validity, and reliability, it is important to acknowledge that incorporating HR monitoring, despite its widespread use, may have limitations in explaining some of the variability observed in these measures. HR is often utilised as a criterion for comparison, and can be influenced by factors beyond exercise intensity, such as stress, hydration status, and individual metabolic variability, which may not consistently align with the true physiological demands of the exercise or activity (Halson et al., 2014).

Heart Rate Variables

The monitoring of HR is a commonly employed method to assess internal load and is utilised across a range of sports and environments, as reflected in Appendix A. HR has been closely linked to metabolic rate (Michael et al., 2022) and has almost a linear relationship with VO_2 during steady-state exercise (Hopkins, 1991; Strath et al., 2000). This provides practitioners with valuable insight into the cardiovascular intensity of training and competition as they can quantify the individual internal response to the imposed training load (Impellizzeri et al., 2004). However, HR can be influenced by non-metabolic factors such as environmental conditions and psychological stress, furthermore, it is not sensitive to rapid changes in metabolic rate (Michael et al., 2022). Typically, the percentage of maximum HR (HR_{max}) is used to prescribe and monitor intensity for endurance and cardiovascular training (Borresen & Lambert, 2008). However, there are several other variables derived from HR data that practitioners can utilise in their toolbox to monitor training loads, such as HR recovery, HR reserve, and HR variability (HRV).

For example, HR recovery has been suggested to be a marker of autonomic function and training status in athletes (Daanen et al., 2012). The theory behind monitoring HR recovery surrounds the indirect relationship between the sympathetic (SNS) and parasympathetic (PNS) branches of the autonomic nervous system (ANS). During exercise, SNS activity increases and is coupled with a reduction in PNS activity, which causes an increase in HR and overall cardiac output to meet the increased demand for oxygen. Once exercise stops, PNS activity increases to return the body to homeostasis, through the decrease of HR and cardiac output. The rate at which HR returns to its resting level during this recovery period (i.e., HR recovery), is directly influenced by the balance between the SNS and PNS relationship. However, it is important to note that HR recovery can also be influenced by various physiological variables, including hydration status, body temperature, and individual genetic factors (Daanen et al., 2012; Halson et al., 2014). These additional factors can contribute to the overall understanding of HR recovery dynamics and should be considered when interpreting HR recovery data. HR recovery is typically measured at the end of exercise and at a specific fixed time interval(s) during the recovery period. The most common HR recovery method is the difference between HR at the end of exercise and HR 30-sec to 2-min post-exercise (Daanen et al., 2012). A faster HR recovery, or a greater decrease in HR during the recovery period, is generally considered to be indicative of enhanced levels of training status (Daanen et al., 2012). Furthermore, some authors discuss the potential use of HR recovery as a tool for monitoring the accumulation of fatigue in sporting populations (Daanen et al., 2012; Halson et al., 2014).

HRV is a non-invasive method to measure the fluctuation of time intervals between heartbeats to evaluate the activity of the ANS in its sympathetic and parasympathetic branches (Plews et al., 2013). Further, it is a useful tool for quantifying ANS function by assessing the balance between SNS and PNS activity (Achten & Jeukendrup, 2003; Aubert et al., 2003; Buchheit et al., 2014; Thayer et al., 2012), which is an essential component of the interindividual variability in physiological responses to training (Buchheit et al., 2014; Chandola et al., 2010; Shaffer et al., 2017). HRV reflects the beat-to-beat variability and is calculated by measuring the time interval between consecutive R waves in an electrocardiogram (Huang et al., 2019). HRV is an indirect measure of SNS activity, due to the inconsistent fluctuations of RR intervals. In clinical settings, a high HRV value is associated with efficient ANS function, healthy cardiac function, reduced inflammation, and cognition flexibility during stress (Draghici & Taylor, 2016; Myllymaki et al., 2012, Plews et al., 2013). Conversely, a low HRV value is associated with inefficient ANS function, an increased potential for cardiac events, maladaptive health outcomes, and reduced cognition in response to threats (Huang et al., 2019). In sport contexts, HRV analysis is considered a useful monitoring method to assess the cardiovascular system's ability to adapt to external and internal loads (Parrado et al., 2010). Furthermore, researchers have demonstrated HRV analysis to be a valuable tool to measure several physiological and performance-related factors, including aerobic fitness (Koenig et al., 2014, Plews et al., 2014, Silva et al., 2013), musculoskeletal injury (Gisselman et al., 2016), illness (Hellard et al., 2011), and stress recovery (Morales et al., 2014) and a useful assessment of internal responses to training loads and recovery adaptations in athletes (Vesterinen et al., 2016; Williams et al., 2017). Additionally, HRV has been examined as a potential marker of overtraining syndrome (Kajaia et al., 2017). Literature suggests enhanced HRV values indicate more PNS than SNS activation, and is indicative of enhanced recovery, “readiness,” and positive adaptations to training which some authors correlate with increased aerobic fitness (Hellard et al., 2011; Kiviniemi et al., 2014; Le Meur et al., 2013; Ortigosa-Márquez et al., 2017; Plews et al., 2013; Tian et al., 2013). However, more research is required as the current body of evidence is inconclusive surrounding the relationship between HRV and overtraining, as evidence reports increases, decreases, and no changes in HRV among overtrained athletes (Halson et al., 2014; Halson & Jeukendrup, 2004; Hedelin et al., 2000; Le Meur et al., 2013; Mourot et al., 2004; Plews et al., 2013; Plews et al., 2014). The inability to distinguish between different stages of overtraining may contribute to the lack of consensus in the literature (Plews et al., 2013).

Several limiting factors may account for these inconsistent findings. HRV analysis is subject to different methodological protocols (e.g., supine, standing, and 24-hr recordings) and analysis techniques (e.g., time domain analysis, frequency domain analysis, and non-linear analysis), which can affect the parameters obtained and the interpretation of the results (Shaffer et al., 2017). Different HRV parameters may be sensitive to different aspects of the HRV signal, resulting in variation across different analysis techniques. This poses a challenge when interpreting and comparing HRV results across different studies that utilise different analysis methodologies (Shaffer et al., 2017). To address these limitations, some researchers have suggested including weekly and seven-day rolling averages as part of athlete monitoring systems, as they have been reported to have superior validity when compared to single-day measurements (Plews et al., 2012). Examining and providing a comprehensive analysis of all possible HRV indices is beyond the scope of this dissertation. However, to summarise, researchers typically prefer the root mean square of successive differences (rMSSD) due to its ease of data collection and calculation, lower coefficient of variation, and lack of breathing frequency influence (Plews et al., 2013). As with most internal and external monitoring methods, it is crucial to monitor HRV longitudinally and understand individual responses to training load (Halson et al., 2014).

Training Impulse

Training Impulse (TRIMP) is frequently used to measure the internal load of athletes during training. It uses a combination of HR and duration to track the internal load and evaluate changes in an individual's training status over time (Borresen & Lambert, 2009). There are two primary TRIMP calculations: Banister's TRIMP and Edward's TRIMP. Banister's TRIMP formula is:

$$TRIMP = D(\Delta\text{HR Ratio})e^{b(\Delta\text{HR Ratio})}$$

D = Training duration

b = Sex-dependent exponential coefficient (Males = 1.92; Females = 1.67)

e = 2.71828

$$\Delta\text{HR Ratio} = \frac{(\text{HR}_{\text{exercise}} - \text{HR}_{\text{rest}})}{(\text{HR}_{\text{max}} - \text{HR}_{\text{rest}})}$$

This model proposed by Bannister (Banister, MacDougall, & Wenger, 1991) multiples an exponentially weighted average HR with the exercise duration, however, it has limitations in accurately representing individual differences, and intermittent or interval sessions. Because it is based on a standard lactate curve and only accounts for a single average HR for an entire training session, it oversimplifies the complex nature of training load (Campbell et al., 2017). The model proposed by Edwards (1993) attempted to rectify this with the below formula:

$$TRIMP = \Sigma\ \frac{(\text{time spent in HR zone } i \times \text{ intensity coefficient } i)}{60}$$

Where Σ represents the sum of the time spent in each HR zone, i represents the specific HR zone, and the intensity coefficient i is derived from regression analysis of HR responses to known exercise intensities. The division by 60 is to convert the TRIMP score to a value per minute (Canino et al., 2020). This method multiplies the sum of time spent in five pre-defined arbitrary HR zones and is multiplied by arbitrary coefficients for each HR zone to quantify training load as presented in Table 2. Both TRIMP calculations provide insight into the internal load experienced by athletes, with Banister's TRIMP being a simple calculation and Edward's TRIMP providing a more nuanced measure of internal load. Practitioners can utilise TRIMP as a useful tool to monitor the intensity of training over time, particularly in traditional sporting contexts (Borresen & Lambert, 2009). The application of Edward's TRIMP model can eliminate the need to calculate individual factors and can account for activity completed in different HR zones.

Table 2.

Summary of Edward's TRIMP HR Zones and Coefficients.

HR Zone	% HR_{max}	Coefficient
1	50-60%	1
2	60-70%	2
3	70-80%	3
4	80-90%	4
5	90-100%	5

HR = Heart rate, HR_{max} = Maximum heart rate

Biochemical monitoring

A plethora of research has emerged on the use of biochemical markers to monitor the internal load of athletes over the last decade (Greenham et al., 2018; Halson et al., 2014; Lee et al., 2017; McGuigan et al., 2020). Biochemical analysis provides objective and quantitative data on the internal physiological response to stress and exercise. This monitoring method involves measurements of various biomarkers in body fluids such as blood, saliva, and urine (Lee et al., 2017). It is beyond the scope of this dissertation to comprehensively review all available literature on the use of biochemical markers within sporting populations. However, Figure 1 presents an approach to biochemical marker analysis adapted from Lee et al. (2017). The approach outlines various biomarkers associated with nutrition and metabolic health, hydration status, muscle status, oxygen transport, injury risk, and inflammation to assist athletes and coaches in interpreting their biochemical data and applying it in a meaningful and practical manner.

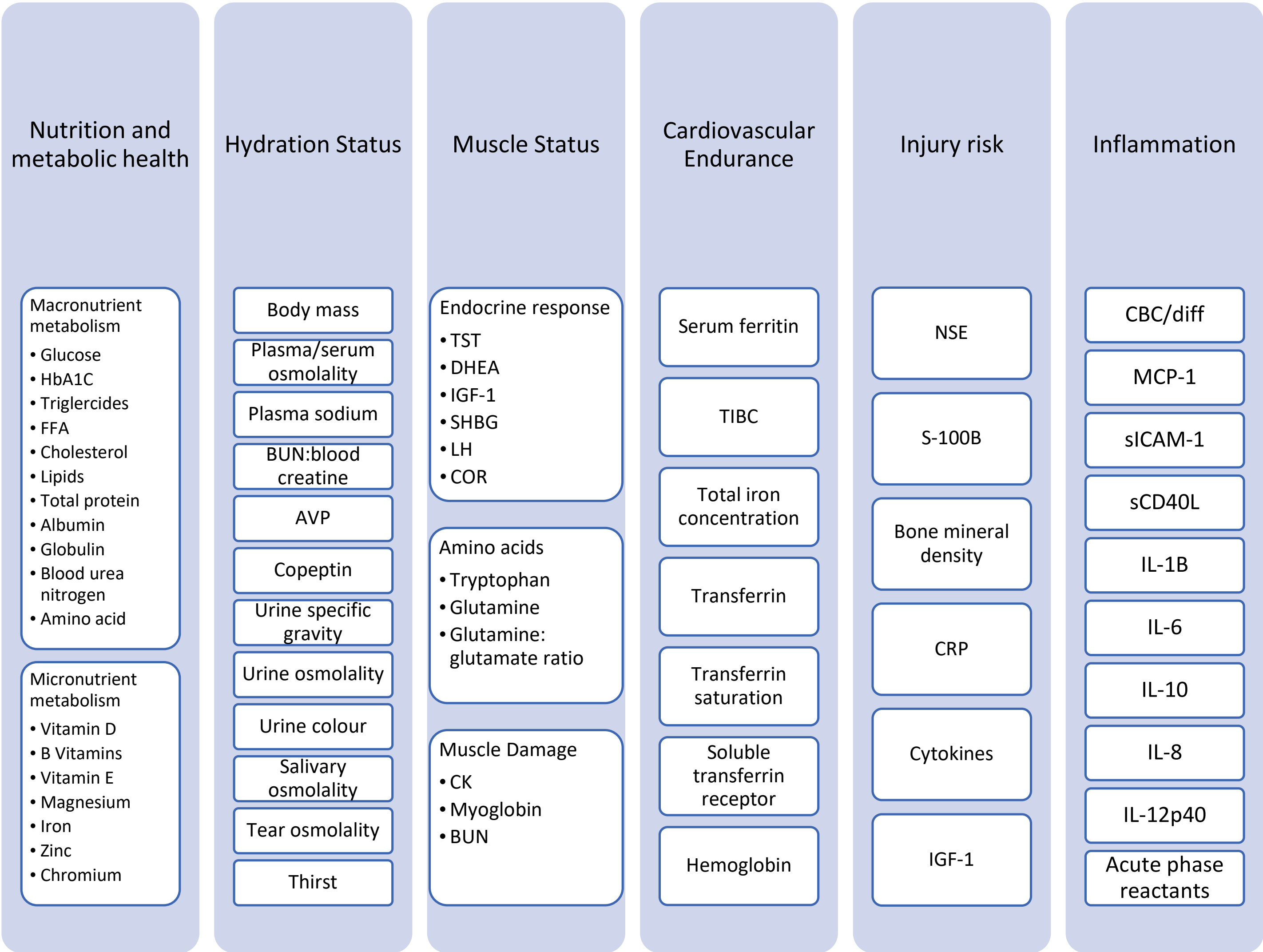

Figure 1. A Comprehensive approach to biomarker analysis, adapted from Lee et al. (2017). Hemoglobin A1c (HbA1C), Free fatty acids (FFA), Blood urea nitrogen (BUN), Arginine vasopressin (AVP), Testosterone (TST), Dehydroepiandrosterone (DHEA), Insulin-like growth factor 1 (IGF-1), Sex hormone-binding globulin (SHBG), Luteinizing hormone (LH), Cortisol (COR), Creatine kinase (CK), Blood urea nitrogen (BUN), Total iron-binding capacity (TIBC), Neuron-specific enolase (NSE), C-reactive protein (CRP), Complete blood count (CBC), Monocyte chemoattractant protein-1 (MCP-1), Soluble intercellular adhesion molecule-1 (sICAM-1), Soluble cluster of differentiation 40 ligand (sCD40L), Interleukin-1 beta (IL-1B), Interleukin-6 (IL-6), Interleukin-10 (IL-10), Interleukin-8 (IL-8), Interleukin-12p40 (IL-12p40).

A recent systematic review and meta-analysis conducted by Greenham et al. (2018) investigated the changes in biochemical markers in response to intensified training periods in athletes. This study aimed to identify the biochemical markers that could serve as indicators of performance and physiological status. Identifying 118 individual biomarkers across 59 studies and 42 meta-analyses further demonstrates the growing interest in biochemical markers as a monitoring method of athletic performance (Greenham et al., 2018). However, the researchers were unable to identify one single biochemical marker that could differentiate between an acute performance reduction (due to an increase in training load/intensity), and non-functional overreaching (caused by maladaptive responses to intensified training loads) (Greenham et al., 2018). Furthermore, there was no clear relationship between the levels of hormone concentrations or metabolite markers and changes in performance, as identified by the inconsistent patterns of change across subgroups (Greenham et al., 2018). However, some biochemical markers demonstrated significant changes in at least one performance subgroup following intensified training and highlighted their potential for monitoring the physiological conditions among well-trained male athletes (Greenham et al., 2018). These markers included the TST:COR ratio, circulating glutamine and urea concentrations, and neutrophil counts. Notably, the TST:COR ratio exhibited sensitivity to performance improvements, as it was observed to increase in studies where performance also improved (Greenham et al., 2018). Suggesting that the TST:COR ratio could potentially serve as a marker to identify positive training adaptations. Whereas, decreased circulating glutamine and increased urea concentrations were observed in studies with decrements in performance (Greenham et al., 2018). The authors suggest that these changes may be attributed to the utilisation of glutamine as a fuel source for immune cells (Castell & Newsholme, 1998), and the increase in urea concentrations is most likely a result of increased deamination of branched-chain amino acids during intensive exercise (Graham, Turcotte, Kiens, & Richter, 1997).

A recent systematic review which aimed to investigate the in-field monitoring methods utilised by coaches and practitioners identified a limited number of studies reporting the utilisation of biochemical markers (McGuigan et al., 2020). Furthermore, the specific markers utilised were often not specified, restricting the understanding of what biochemical markers practitioners value and limiting the scope of future research to enhance and refine these methodologies (McGuigan et al., 2020). However, blood lactate was a specific marker mentioned consistently within the included studies as it is an inexpensive monitoring method suitable for in-field use (McGuigan et al., 2020). The limited use of biochemical analysis in practice can be attributed to several factors, including the complexities and costs associated with sample collection and analysis. In addition to potential confounding variables, such as training schedule, diet, hydration status, and timing of sample collection, these factors should be considered (Halson et al., 2014). There is currently limited literature surrounding the utilisation of biochemical markers in practice. Therefore, it is recommended that coaches and practitioners regularly assess a carefully selected panel of biochemical markers to provide objective insight into the athletes' internal response to training load.

2.3.4. Summary and Conclusion

In conclusion, load monitoring systems within athletic populations play a crucial role in optimising performance and preventing injury. This narrative review discussed the importance of implementing both internal and external monitoring methods when tracking training load. External monitoring methods such as GPS, performance tests, and self-report measures provide insight into the quantity of work completed by athletes. Whereas internal monitoring methods such as HR, RPE, and biochemical analysis can provide valuable insight into how the athlete is responding, recovering, and subsequently adapting to training.

In summary, this chapter has provided a comprehensive overview of the monitoring methods utilised within traditional sport environments and sets a foundation for the following chapters to critically evaluate these methods within specialist tactical populations.

Chapter 3. Beyond the Arena: Exploring Internal and External Load Monitoring Methods in Specialist Tactical Populations

The monitoring of athletes' internal and external loads has been widely studied in traditional sporting populations (McGuigan et al., 2020). However, there is limited research on monitoring tactical groups, including law enforcement, military, fire, and emergency response units, when compared to sport and other populations. Therefore, this chapter builds on the foundation of internal and external monitoring methods of training load established within Chapter 2 and aims to present the current research within this field while identifying the current gaps between research and practice (further elaborated in Chapter 3). Tactical populations have a wide range of tactical operators and hierarchies under their jurisdiction, and the specific operational objectives and tasks vary between groups (Alvar et al., 2017). Therefore, the scope of this chapter will include "specialist tactical populations" that may be required to work within combative environments (i.e., law enforcement, defence forces etc.). The specific operational objectives and tasks vary between specialist groups, however, there are similar metabolic demands as these groups may be required to deploy into copious and varying environmental conditions (Alvar et al., 2017). Furthermore, the bioenergetics, physiological demands, and operational environments of fire and emergency response populations differ significantly from combative roles (Abel, Sell, & Dennison, 2011; Alvar et al., 2017; Perroni et al., 2010; Peterson, Dodd, Rhea, Alvar, & Gray, 2004; Roberts, O'Dea, Boyce, & Mannix, 2002), and a large proportion of the literature surrounding their normative data have been conducted in laboratory settings (Perroni et al., 2010). Therefore, a comprehensive discussion of internal and external monitoring measures in these tactical populations is beyond the scope of this dissertation.

This chapter aims to review all current literature related to the monitoring of internal and external loads in specialist tactical populations. This dissertation identified thirty-three (n = 33) studies which met the inclusion and exclusion criteria and utilised any internal or external monitoring method in specialist tactical populations. These studies reported a variety of outcomes and methodologies, however, all authors reported upon the significant physical and psychological loads these operators tolerate. Specialist tactical populations perform physically and cognitively strenuous tasks in some of the most arduous environmental conditions on the planet (Alvar et al., 2017). Further, they are required to be operationally ready and possess a well-developed range of physiological and technical capabilities to execute their occupational requirements to the highest standard (Anderson, Plecas, & Segger, 2001). The operational demands of specialist tactical populations often include substantial all-terrain hikes, foot and vehicle pursuits, forcible entry, armed and unarmed close-quarter combat, subduing suspects, and fire suppression whilst under substantial external load (Alvar et al., 2017; Anderson et al., 2001; Irving, Orr, & Pope, 2019).

In a study conducted by Irving et al. (2019), specific insights were gained into the operational realities of specialist police within the Australian-New Zealand Counter-Terrorism Committee. The authors reported on the typical operational tasks undertaken by these police officers, highlighting several noteworthy findings. Finding that the most common operational task was "high-risk warrants," accounting for 61% of all operations, followed by "rural operations," which accounted for 11% of all operations. These results suggest that the operational tasks of specialist tactical police units can vary significantly both within and between geographical locations. Furthermore, the study found that during these operations, 84% of police officers were carrying a full operational load and personal protective equipment (PPE), while 74% were carrying external loads in the form of specialist equipment (e.g., ballistic shields, ammunition, and battering rams), in addition to their full operational load and PPE.

The operational environment of the Defence Forces has been referred to as an “anaerobic battlefield” (Mala, Szivak, & Kraemer, 2015), where military personnel are required to perform physically demanding tasks that are often anaerobic, such as load carriage, sprinting, offensive/defensive manoeuvres, evacuation, and heavy and repetitive lifting (Alvar et al., 2017; Friedl et al., 2015; Maupin et al., 2018). While extended load carriage is rarely required beyond 24-km in recent operational conditions (Friedl et al., 2015), it is important to recognise the role of aerobic conditioning during combat scenarios. Optimal aerobic conditioning allows for prolonged task performance at a lower percentage of individual VO_2max (Friedl et al., 2015), reducing the onset of fatigue and preserving cognitive function (Alvar et al., 2017). Additionally, military personnel must be “game-ready” throughout prolonged and often open-ended deployment phases, requiring a well-developed range of physiological and technical capabilities to execute their occupational requirements. Therefore, it is essential operators possess the necessary physical conditioning and technical skills to perform at their best during these demanding and unpredictable operational situations.

During tactical operations, operators are required to perform physical and cognitive tasks to the highest standard. Alver et al. (2017) reported that these tasks often involve carrying an additional load of approximately 80% of their body weight during operations, which can exacerbate the physiological demands of the mission. However, despite the added challenge of this external load, the tasks and objectives do not change. This external load varies in shape, mass, and equipment across the different facets of specialist tactical populations. Often including protective clothing/armour, breathing apparatus, stab-resistant vests, and occupational-specific equipment (e.g., torches, radios, water, medical devices, firearms, ammunition, ballistic shields, forcible entry tools etc.).

It is generally considered that within combat operations, the ability to move quickly under heavy load is advantageous (Mala, Szivak, & Kraemer, 2015). However, the additional load carried by specialist tactical operators can negatively affect their dynamic postural stability and mobility, as demonstrated by Sell et al. (2016) and supported by Carlton et al. (2014). Sell et al. (2016) reported that body armour increased the medial-lateral and anterior-posterior stability index by 10% during single-leg jump landings in soldiers, likely due to increased ground reaction forces when the load was increased. These findings are reiterated by Carlton et al. (2014), who reported an inverse relationship between load and mobility with tactical populations. Similarly, several studies have reported decreased mobility and endurance performance with additional load within tactical populations. Pandorf et al. (2002) identified a 44% increase in 3.2-km run time, with an additional 41-kg load. Harper et al. (1997) identified an increase of 27% in extended endurance tasks (10-km run time) when the load was increased from body weight by 36-kg. Additionally, a New Zealand study conducted on police by Dempsey et al. (2013) found that mobility tasks decreased by an average of 13 to 42% after a 5km loaded run. Suggesting that accumulative fatigue may also play a role in performance under load.

A plethora of studies have shown that energy demand increases with additional load (Beekley, Alt, Buckley, Duffey, & Crowder, 2007; Dempsey et al., 2013; Knapik et al., 2004; Looney et al., 2018; Robinson et al., 2018). For example, Dempsey et al. (2013) reported the effects of police body armour, finding significant increases in subjective fatigue (measured by RPE), oxygen consumption (VO_2max), HR_{max}, and respiratory exchange ratio (RER) ($p < 0.001$ across all measures). Similarly, Beekley et al. (2007) reported that soldiers experienced a linear increase in VO_2max, ventilation, HR, and RER when carrying loads of 30, 50, and 70% of their lean body mass (LBM), to the extent that two subjects could not complete the 6-kmph 30-min loaded march at 70% LBM. Additionally, anaerobic tasks are also impaired during load carriage. Laing Treloar et al. (2011) observed significant increases ($p < 0.01$) in 30-m sprint time between unloaded (combat uniform and boots) and loaded (combat uniform, boots, and 21.6-kg) soldiers. Interestingly, 51.7% of this increase was within the first 5-m. Although this finding is not surprising given the subjects initiated the test from the prone position, it does highlight the significant impact of load on mobility, reiterating the results of Dempsey et al. (2013).

3.1 Research Methods

This systematic review complied with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher et al., 2010).

3.1.1. Search strategy

The search was conducted across PubMed and the Auckland University of Technology Library databases. Pubmed was the primary database utilised as it is the leading source of medical, scientific, and technical research worldwide. Titles, abstracts, and keywords were searched for combinations of the following terms with an "*" indicating a truncation: law enforcement, police*, Military, Defence force*, solider* AND load*, internal load, external load, training load, load monitoring. Databases were searched from 1980 until 11th June 2022 and were required to meet the following inclusion criteria:

I. The study recruited human subjects that were employed as a tactical operator (all ages, sexes, and units will be included), or they were completing the task(s) of these occupations.
II. The study reported using a monitoring method related to internal or external load.
III. The study reported on internal or external load in relation to a stressor.
IV. The study was peer-reviewed and written in the English language.
V. Studies will be included if they are descriptive, correlational, exploratory, or observational.
VI. Additionally, the reference lists of the included studies were searched to collate relevant studies that also met the inclusion criteria.

Exclusion criteria were as follows:

I. Reviews of any kind will be excluded.
II. PhD Dissertations will be excluded.
III. Conference proceedings will be excluded.
IV. Standalone abstracts will be excluded.
V. Unpublished studies will be excluded.
VI. Study cases will be excluded.
VII. Studies will be excluded if primary aim surrounds injuries.
VIII. Studies will be excluded if primary question surrounds nutrition.

3.1.2. Study Selection

Firstly, articles were screened by their title, abstract, and keywords. If no contradiction to the inclusion criteria was present, screening proceeded to full text as represented in Figure 2.

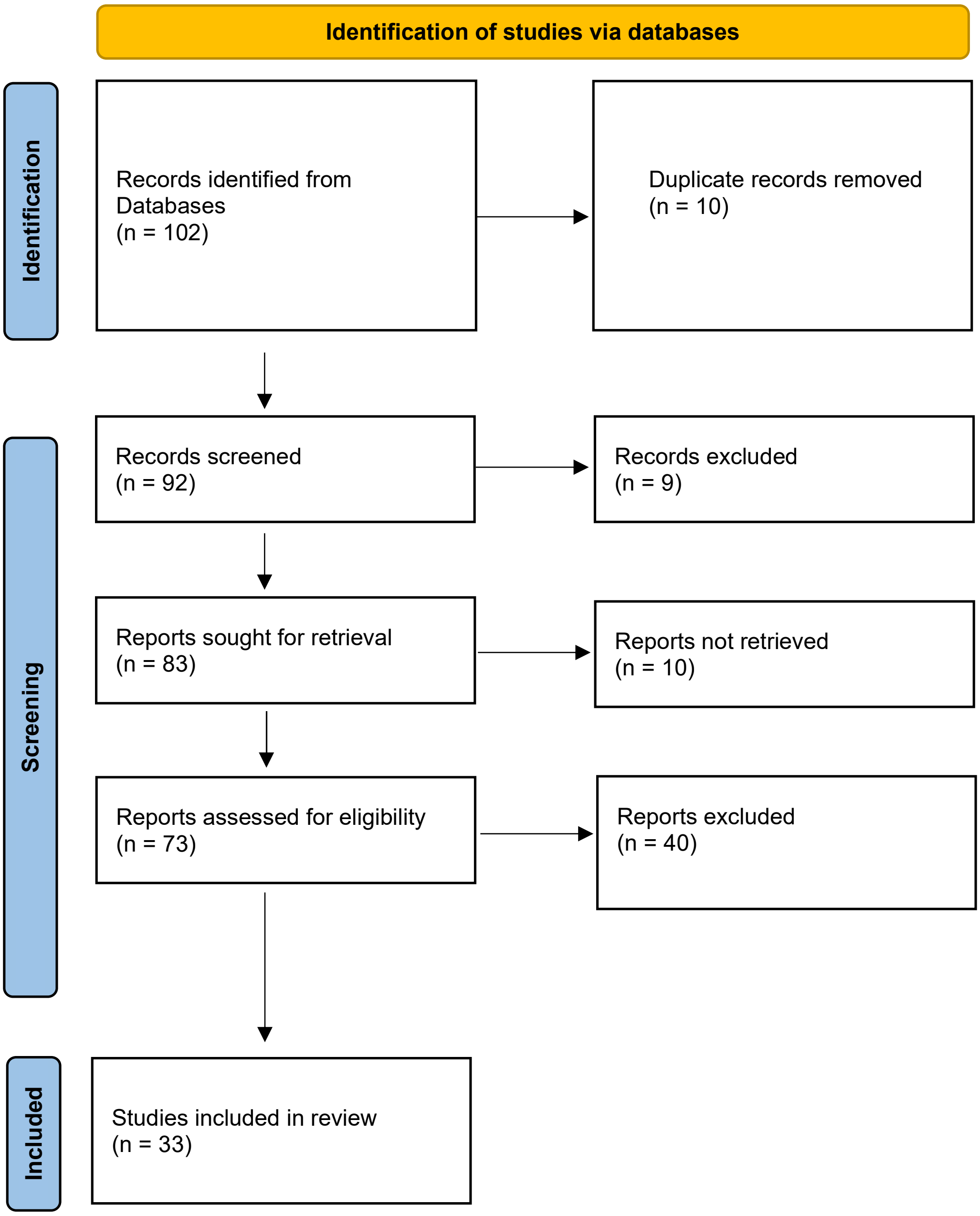

Figure 2. PRISMA Selection of Studies Flow Chart

3.1.3. Data-evaluation and quality appraisal

The quality of each study (including the potential for bias) was assessed using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist (Aromataris et al., 2015).

3.2 Results

3.2.1. Search Results

A total of 92 records were retrieved from the initial search with 10 of these being removed as duplicates. Following this, 61 articles were assessed for eligibility with 52 being sought for retrieval. Of the 73 retrieved, 33 met the inclusion criteria and were included within the systematic review (Figure 2). The participant populations of the 33 included studies were Military/Defence forces (n = 1397), Army (n = 831), Air Force (n = 29), Tactical Police (n = 143), Police (n = 203), Civilians (n = 11). Most studies reported on at least one internal load variable (n = 30). Studies reported using only internal monitoring methods (n = 12) were significantly higher than those incorporating both internal and external (n = 18); three utilised only external measures (n = 3). Table 7 provides a summary of the included studies.

3.2.2. Evidence Quality

To assess the methodological quality of each study, the JBI's critical appraisal checklist was utilised (Aromataris et al., 2015). This checklist consists of several key criteria that were used to evaluate the evidence presented in the studies and is presented in Table 3:

1. Was the study question or objective clearly stated?
2. Was the study design appropriate for the research question?
3. Was the recruitment strategy appropriate to the aim of the research question?
4. Were the study participants and the setting described in detail?
5. Were the exposure factors and the outcomes measured in a valid and reliable way?
6. Was the statistical analysis appropriate for the study design and the research question?
7. Were the results clearly presented?
8. Was the discussion of the results logically organized and well-presented?
9. Was the study free from important biases?

10. Was there a discussion of the limitations of the study?

11. Was the study generalizable to the population from which it was drawn?

12. Are the findings important for clinical practice or health policy?

Table 3.

Breakdown of Quality Assessment

Study	1	2	3	4	5	6	7	8	9	10	11	12	Quality
Blacker et al. (2009)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	Yes	Yes	N/A	10/11
Canino et al. (2020)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	No	Yes	N/A	9/11
Clemente-Suárez et al. (2013)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	N/A	10/11
Conkright et al. (2021)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	N/A	10/11
Drain et al. (2017)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	N/A	10/11
Friedl et al. (1995)	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	N/A	9/11
George et al. (2015)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	N/A	10/11
Grant et al. (2016)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	N/A	10/11
Hormeño-Holgado et al. (2019)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	N/A	10/11
Irvining et al. (2019)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	11/11
Johnson et al. (2018)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	11/11
Jouanin et al. (2004)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	N/A	10/11
Jurvelin et al. (2010)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	11/11
Knapik et al. (2007)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	11/11
Lockie et al. (2020)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	11/11
Nikolova et al. (2007)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	N/A	10/11
O'Leary et al. (2018)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	11/11
Ojanen et al. (2018)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	Yes	Yes	N/A	10/11
Palvina et al. (2021)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	11/11
Richmond et al. (2012)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	N/A	10/11
Richmond et al. (2014)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	N/A	10/11
Salonen et al. (2019)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	No	Yes	N/A	10/11
Sánchez-Molina et al. (2018)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	11/11

Tait et al. (2022)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	11/11
Tanskanen et al. (2011b)	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Unclear	No	Yes	N/A	8/11
Tanskanen et al. (2011a)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	N/A	10/11
Tomes et al. (2021)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	N/A	10/11
Tornero-Aguilera et al. (2017)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	11/11
Tornero-Aguilera et al. (2018)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	11/11
Vikmoen et al. (2020)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	11/11
Wilkinson et al. (2008)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	N/A	10/11
Winters et al. (2021)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	11/11
Wyss et al. (2012)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	11/11

3.3 Discussion

3.3.1. Training Load

Training load is often referred to within traditional sporting contexts as the players' response to the imposed stimulus over time (Soligard et al., 2016). The International Olympic Committee agreed on the definition of training load to be “the cumulative amount of stress placed on an individual from single or multiple training sessions (structured or unstructured) over a period of time” (Soligard et al., 2016). This definition is general and unspecific, to encompass both sports medicine and exercise physiology literature. Furthermore, this definition of training load incorporates the basic principle of General Adaptation Syndrome and subsequently the Stimulus-Fatigue-Recovery-Adaptation response of training theory (Alvar et al., 2017). The accumulation of fatigue is the initial response to an external stimulus resulting in an acute period of reduced performance capacity and operational “*readiness*.” The magnitude of this reduction is primarily dependent on the extent and duration of the external stimulus. Once the acute fatigue response reaches its apex, a recovery phase will occur. Resulting in the dissipation of the accumulated fatigue and subsequent increase in performance capacity and operational readiness of the individual.

To assess, track, and measure training load, it can be divided into internal and external methods (Chapter 2). Typically, the term “load” is used interchangeably with “external load” (Soligard et al., 2016), however, for this dissertation external load will refer to any measurable externally applied stimulus, which is independent of their internal characteristics (e.g., frequency, duration, and type of training, time-motion analysis, or Acute:Chronic load ratio) (Maupin et al., 2018; Soligard et al., 2016). The externally applied stimulus will result in both physiological and psychological responses within the individual. Therefore, internal load refers to the measurable “internal response factors within the biological system” (e.g., HR, biochemical/hormonal/immunological response, perception of effort, or psychological inventories) (Soligard et al., 2016). Monitoring training load through external variables provides insight into the work completed, capabilities, and capacities of the individual. Whereas internal load monitoring is essential to establish how the individual is responding and adapting physiologically (Maupin et al., 2018). As identified in the previous chapter, there are a copious number of variables to measure training load. However, their validity as markers of adaptation and/or maladaptation to training load is limited, as no single response marker consistently predicts injury or maladaptation (Borresen et al., 2009; Halson et al., 2014; Meeusen et al., 2013). Therefore, it is critical to compare and contrast both internal and external monitoring methods against each other in order to ascertain the appropriate Stimulus-Fatigue-Recovery-Adaptation response for the specific training period, as individuals may respond differently to the same external stimulus (Alvar et al., 2017). For example, individuals may present the same relative output (e.g., load-carriage and kilometres travelled) across several operations or training bouts, however, their ability to respond to this output (e.g., RPE and HRV) may differ significantly between individuals (Halson et al., 2014). The individual response differences are of paramount importance for specialist tactical operators. These responses provide insight into overall operational "*readiness*," by providing quantitative and qualitative data to predict whether individuals are in a physiological and psychological state to tolerate high training and operational loads. Additionally, this data can potentially identify individuals with a greater risk of injury and decreased performance (Halson et al., 2014).

3.3.2. Training Load in Tactical Populations

Compared to the traditional sporting context of measuring variables of internal and external load, there are several challenges in capturing this data within tactical populations. Operational (i.e., external) load and therefore demands within tactical environments are often variable and unstructured, with incidental periods of activity across field exercises, physical training, and other operational tasks (Michael et al., 2022). Specific operational tasks and objectives vary between groups. Operational tasks can include substantial all-terrain hikes, foot and vehicle pursuits, forcible entry, armed and unarmed close-quarter combat, subduing suspects, and fire suppression whilst under substantial external load and internal demand (Alvar et al., 2017; Anderson, Plecas, & Segger, 2001; Burley et al., 2020; Irving, Orr, & Pope, 2019; North Atlantic Treaty Organisation, 2009; Schuh-Renner et al., 2017; Wilkinson, Rayson, & Bilzon, 2008). Furthermore, Irving et al. (2019) reported specific insights into the realities of specialist police within the Australian-New Zealand Counter-Terrorism Committee. One finding was that the most common operational tasks were “high-risk warrants” (61%); followed by “rural operations” (11%). Further suggesting that the operational tasks can vary greatly between each specialist police unit and geographical location. Additionally, during 84% of these operations individuals were carrying full operational load and PPE and 74% were carrying external load in the form of specialist equipment (e.g., ballistic shields, ammunition and battering rams) in addition to their full operational load and PPE. These operational tasks are often challenging to quantify due to the varied external and mechanical load, and subsequent physiological (internal) responses. Which are all directly influenced by geographical location, terrain, threat profiles, load carriage, and other operational requirements (North Atlantic Treaty Organisation, 2009). There has been an attempt within the literature to identify the physiological demands of tactical operations. For example, Canino et al. (2020) quantified the metabolic demand of tactical operators utilizing indirect calorimetry, however, these techniques are impractical to implement into typical field usage due to the need for specialised equipment, time-consuming procedures, and the controlled environment required for accurate measurements. Additional research has provided quantitative and qualitative insight into the operational demands of tactical operators utilizing questionnaires, self-reported activity logs, and direct observation (Irving et al., 2019; O'Leary et al., 2018; Redmond et al., 2013; Simpson et al., 2013; Tait et al., 2022; Tanskanen et al., 2011; Trank et al., 2001). However, it should be noted that literature has demonstrated there can be significant variation in genuine activity completed compared to training logs (Moran et al., 2013). Additionally, Redmond et al. (2013) reported manual logs as having inconclusive validity. This further reiterates that whilst these methods are insightful, they cannot provide quantitative data on internal responses and loads. Suggesting, they are not practical for use outside of a controlled training environment (Michael et al., 2022).

There are numerous methods to measure and quantify training and operation load reported within current research (Soligard et al., 2016). However, there is limited incorporation of specialist tactical populations. The following sections will report and explore the various techniques and methods whilst addressing their limitations within a tactical environment.

3.3.3. Measures of External Load

GPS

Over the past ten years, geolocation data obtained from GPS have accelerated the field of athlete monitoring within team-based field sports (Kupperman et al., 2020). Several kinematic variables can be derived from GPS data, primarily distance, speed, acceleration, and deceleration from displacement and velocity (Kupperman et al., 2020). Unfortunately, there are technological and logistical constraints that have significantly restricted the use of GPS within tactical environments (Maupin et al., 2019; Michael et al., 2022). One of the primary risks associated with GPS monitoring surrounds security concerns. Compared to traditional sporting populations, the interception of geolocation data may result in critical security breaches. A recent example of this was identified when GPS tracking company Strava published a "Global Heat Map" that illuminated high-use areas (Sly, 2018). This resulted in the location of secure U.S. Military bases being comprised, due to operators tracking their personal activity. The transmission of data to public servers and social media is a security concern for tactical operators which often embargos the use of GPS devices within deployed and operational environments. This is reflected within the literature, with limited uses of GPS as a monitoring tool outside of a basic-training setting.

There were only three studies (n = 3) identified within this dissertation utilising GPS-derived data as a load monitoring tool. These findings were consistent, however, varied in tactical/operational environments; including basic training (O'Leary et al., 2018), simulation models (Clemente-Suárez et al., 2013), and special forces training (Johnson et al., 2018). One study on special operation forces (SOF), utilised GPS to quantify the external loads (distance, velocity, elevation) undertaken by operators to compare hot and cold environments (jungle and glacial respectively) (Johnson et al., 2018). SOF operators carried on average 23.5–28.6-kg of external load between each exercise, with slightly more weight during the glacial exercise in the form of additional clothing. During the jungle exercise, operators covered 14.4-km with average speeds of 3.9-kmph and an elevation gain of 164-meters. Comparatively, during the glacial exercise, operators covered 13.3-km with average speeds of 0.97-kmph and elevation gain of 1146-m. These findings are reiterated across a 14-week basic training course, where recruits covered approximately 12 to 14-km per day, with the majority of movement speeds (>90%) reported at low to moderate velocities (0 to 10-kmph) (O'Leary et al., 2018). Further, a sex-time interaction for distance was identified, where men completed a significantly greater distance each day (~1.64-km). However, this additional distance was accrued across speeds of ~10-kmph (O'Leary et al., 2018). Furthermore, individualized speed zones were established in relation to individual 2.4-kilometer run speed. It was identified that women completed more distance at speeds of 100% and between 25 to 50% of their 2.4-km run speed. O'Leary et al. (2018) go on to suggest that the least fit individuals within a unit limit the intensity of the activities undertaken, which is supported by the data reporting women completing more distance in the faster individual speed zones, however, completing less distance in the faster arbitrary speed zones. Similarly, Clemente-Suárez et al. (2013) reported soldiers completing maximum speeds of 17.9 ± 2.2-kmph and 10.5 ± 7.6-kmph in asymmetrical and symmetrical combat simulations respectively. This difference between the symmetry of combat simulations is a consequence of soldiers performing fast transitional movements from one piece of cover, position, or room, to the next within asymmetrical combat (Clemente-Suárez et al., 2013). Compared to symmetrical combat, which is typically more continuous in nature, and does not require high changes in speed. However, across both simulations over 50% of the distance covered was performed at relatively low speeds (squatting, walking, or slow marching) further reiterating the findings of O'Leary et al. (2018).

One of the main limitations of primarily relying on GPS-derived data is that it does not provide information surrounding variables which are relevant for tactical-specific operational tasks, such as load carriage, shooting, and other movement types (e.g., crawling, squatting, quartering etc.). Over recent years the accuracy of GPS has improved. However, this is heavily dependent on sampling frequency (Rago et al., 2020; Kupperman et al., 2020), and has exhibited poor validity within sports settings (Bourdon et al., 2017). Furthermore, as discussed in Chapter 2, Bourdon et al. (2017) suggests the different proprietary algorithms from different devices can result in inter- and intra-unit reliability and validity issues, often substantially influencing outcome measures. Additionally, some GPS models (without inbuilt accelerometers) require a satellite connection, and therefore may not be feasible within a tactical environment that often alternates between indoor and outdoor operations.

Accelerometers

Accelerometers are a form of inertial tool that measures *proper acceleration* (the rate of change of velocity on a body's individual rest frame). Accelerometers aid in quantifying external load by reporting on the magnitude and frequency of acceleration on specific body segments. Working in tandem with magnetometers and gyroscopes, accelerometers can provide quantitative insight into several variables within dynamic environments including resistance training monitoring, impact quantification, and movement reconstruction (Adesida et al., 2019; Bourdon et al., 2017; Mavor et al., 2020). The field of accelerometry is rapidly expanding and developing where accelerometers are used across a plethora of industries and sciences, within varying levels of complexity. Within non-combatant environments, accelerometers are frequently used to quantify physical activity and sleep while being cost-efficient and non-invasive on the wearer (Migueles et al., 2017). Within tactical populations accelerometers are often used to quantify general aspects of physical activity, therefore, this will be the focus of this dissertation. For example, Booth et al. (2003) demonstrated that accelerometers can be utilized within tactical settings for prolonged durations (12-day training exercise) and accurately measure sleep fluctuations and physical activity.

This dissertation identified thirteen studies (n = 13) which met the inclusion criteria and utilized accelerometers as part of their research. These studies reported a variety of outcomes and methodologies. Most studies attached via a chest strap (Drain et al., 2017) or alongside a HR monitor (Clemente-Suárez et al., 2013; Jurvelin et al., 2020; O'Leary et al., 2018; Richmond et al., 2012), whilst others attached the device around the “trunk” either at the lumbar spine and waist, (Blacker et al., 2009; Ojanen et al., 2018; Richmond et al., 2014; Wilkinson et al., 2008) or hip (Knapik et al., 2007; Wyss et al., 2012). Only two studies utilised a non-dominant wrist placement (Tanskanen et al., 2011; Vikmoen et al., 2020). It is difficult to collect and interpret data within real-time tactical operations, therefore, all reported studies were either across some form of basic training (Blacker et al., 2009; Drain et al., 2017; Jurvelin et al., 2020; Knapik et al., 2007; O'Leary et al., 2018; Richmond et al., 2012; Tanskanen et al., 2011; Wilkinson et al., 2008; Wyss et al., 2012), field exercise (Ojanen et al., 2018), combat simulation (Clemente-Suárez et al., 2013), or selection course (Richmond et al., 2014; Vikmoen et al., 2020). All studies had a substantial duration of data collection, ranging from 6-days (Vikmoen et al., 2020) to 24-weeks (Wilkinson et al., 2008), whilst the majority were ~8-12 weeks. The collective findings of these studies suggest that specialist tactical populations undertake high external training loads. As reported by multiple studies, the average distance covered across basic training was 11 to 14-km per day (Knapik et al., 2007; O'Leary et al., 2018; Ojanen et al., 2018; Wyss et al., 2012). One study reported an average of 5,632 ± 276 steps during physical training sessions (Drain et al., 2017). Interestingly, when separated by sex, men completed significantly more distance than women; on average 1.6-km per day ($P < 0.001$) as identified by O'Leary et al. (2018). Clemente-Suárez et al. (2013) reported soldiers moving at maximum speeds of 15.5 ± 5.1-kmph with full operational loads, with higher overall impacts, movement, and sprint speeds within asymmetrical combat simulations. This heightened level of physical activity was reiterated within basic training (Wilkinson et al., 2008) and selection courses (Richmond et al., 2014). Wilkinson et al. (2008) reported a mean PAL (average physical activity levels; derived by average daily total EE/BMR [energy expenditure/basal metabolic rate; estimated using Doubly Labelled Water]) value of 2.45 across the duration of the 24-week Parachute Regiment training course. The PAL classification system would consider these values “high” (values greater than 1.85), and almost “very high” (2.5 and above) (Bouten et al., 1996). Westerterp et al. (2001) have suggested civilian populations will have difficulty maintaining energy balance with PAL values over 2.5. These values were reported across an 8-week arduous training course where the average PAL value across weeks two and three was 2.5 ± 0.1, which increased in weeks six and seven to 2.7 ± 0.2 (Richmond et al., 2014), further validating the significant external loads undertaken by specialist tactical populations. However, an important observation from the collated studies was that most physical activity was reported to be low or moderate during operational tasks, of <6 METs (metabolic equivalents) (Jurvelin et al., 2020; Ojanen et al., 2018). This can be identified through the work of Ojanen et al. (2018) who reported shooting training to be the operational task in which operators spent the most time within vigorous activity (>6 METs). Individuals spent 12:50 ± 5:59min >6 METs compared to the 2:34:19hrs within 1.5-3 METs (sedentary or light intensity). Furthermore, during the military field task, operators spent 3:35 ± 1:52min >6 METs compared to 3:03:27 ± 0:23:24hrs at 1.5-3 METs.

As discussed in Chapter 2, there are several limitations to using GPS and accelerometers to measure external load. Similar to GPS, accelerometers only provide information about a kinematic variable (i.e., external load), without indicating the cause or result of the motion (i.e., internal load). This makes it challenging for practitioners to make meaningful inferences from the data available, as it cannot directly be evidence of the physiological internal response associated with motion, such as inter- and intra-muscular reactions, ground reaction forces, and energy expenditure (Bourdon et al., 2017; Michael et al., 2022). Furthermore, the studies identified in this dissertation relied on algorithms and filtering systems to analyse the raw accelerometer and GPS data, which have been reported to be proprietary information (Migueles et al., 2017). The algorithms and filtration systems found in these micro-technologies, are not available to the public and create ambiguity surrounding specific thresholds when capturing slower movements (Migueles et al., 2017). The lack of transparency and ambiguity across accelerometry technology negatively impacts the validity of comparing data across studies and devices, as the data may not be interchangeable. Furthermore, the algorithms have been calibrated for civilian and traditional sports environments and may not accurately capture movement patterns specific to tactical operating environments (Migueles et al., 2017). To address this issue, research has attempted to develop a multivariate model to predict energy expenditure in tactical operating environments (Horner et al., 2013). Future research should focus on developing specific algorithms and filtering systems for tactical operating environments and movements, to enhance the accuracy, reliability, and validity of these devices in operational settings. For example, Garmin has recently marketed their Garmin Tactix 7 as a smartwatch for outdoor and tactical use. At the time of writing, there is currently no available data or information that suggests Garmin have developed or enhanced its previous algorithms and filtering systems to improve the validity within tactical environments. However, this opens the door for future research, innovation, and development of software or firmware to help enhance the utility of these mainstream wearable devices in tactical populations.

Neuromuscular Performance Tests

The utilisation of neuromuscular performance tests has been extensively reviewed in traditional sports environments (Aoki et al., 2017; Ferioli et al., 2018; Halson et al., 2014; McGuigan et al., 2020; Rowell et al., 2017). These evaluations are commonly integrated into athlete monitoring models due to their ease of administration and their potential to directly measure sport specific improvements (McGuigan, 2017). However, the degree of fatigue induced by these assessments can vary depending on the specific test and its associated parameters (McGuigan et al., 2020), with some test eliciting minimal or no adverse internal responses (Twist & Highton, 2013).

This dissertation identified eight studies (n = 8) which met the inclusion criteria and utilised neuromuscular performance tests as part of their research. These studies reported a variety of outcomes and methodologies (Conkright et al., 2021; Hormeño-Holgado et al., 2019; Lockie et al., 2020; Ojanen et al., 2018; Salonen et al., 2019; Tornero-Aguilera et al., 2017; Vikmoen et al., 2020; Winters et al., 2021). The most common monitoring method reported from these studies was lower limb isometric/isokinetic strength (Conkright et al., 2021; Salonen et al., 2019; Winters et al., 2021), vertical jump or CMJ (Conkright et al., 2021: Tornero-Aguilera et al., 2017; Vikmoen et al., 2020), and horizontal jump (Hormeño-Holgado et al., 2019; Ojanen et al., 2018; Winters et al., 2021), other assessments included handgrip strength (Hormeño-Holgado et al., 2019; Salonen et al., 2019), electromyography (EMG) (Lockie et al., 2020; Salonen et al., 2019), shoulder strength (Winters et al., 2021), upper body muscular endurance (Ojanen et al., 2018), upper body muscular power (Vikmoen et al., 2020), and trunk strength (Ojanen et al., 2018; Winters et al., 2021).

The majority of the included studies predominantly reported insignificant changes in neuromuscular performance assessments (Conkright et al., 2021; Hormeño-Holgado et al., 2019; Salonen et al., 2019; Tornero-Aguilera et al., 2017; Winters et al., 2021). For example, lower limb isometric/isokinetic can be affected differently in response to various training scenarios. In short-duration training exercises lasting less than 7-days, studies have shown that strength levels tend to remain relatively unaffected (Conkright et al., 2021; Salonen et al., 2019). However, a separate study conducted by Winters et al. (2021) focused on chronic training adaptation and found that over a 15-month period of Marine Raider Training, there was a significant improvement in strength. This contrast highlights the importance of distinguishing between the short-term effects of training-induced fatigue and the long-term benefits of chronic training adaptation.

One noteworthy finding pertains to vertical jump or CMJ height. Reports on the impact of military training on vertical jump height have been inconclusive. Some authors have reported insignificant changes in performance (Tornero-Aguilera et al., 2017), while others have identified a 6% decrement following a four-day training exercise (Conkright et al., 2021). Notably, significant changes have been observed in special forces selection courses (Vikmoen et al., 2020). Following the selection exercise, vertical jump height significantly decreased in both men and women ($p < 0.001$), corresponding to an 18-19% reduction (Vikmoen et al., 2020). Furthermore, both male and female vertical jump height remained significantly impaired (-6.6 ± 2.8-cm, -16.9 ± 6.0%; and -2.7 ± 2.5-cm, -8.9 ± 8.3% respectively) for the following two-weeks after the selection exercise (Vikmoen et al., 2020). Interestingly, men experienced greater percentage reductions in jump height compared to women 72-hrs post selection (-23.8 ± 6.1% and -14.3 ± 8.0% respectively). While the findings from special forces selection courses provide valuable insights into the physiological response to highly demanding and specialised training, it is essential to acknowledge the unique nature of these training and selection environments. Special forces selection courses and the subsequent exercises/activities are designed to rigorously assess candidates' physical and mental capabilities, often through subjecting them to extreme physical stress. As such, the observed reductions in vertical jump height may not necessarily reflect the typical operational demands of military personnel. Furthermore, the physical demands and tasks of military operations (e.g., load carriage, land navigation, environmental conditions, and combat engagements), may differ and extend beyond the controlled environment of a selection course. Therefore, while the findings of Vikmoen et al. (2020) offer valuable insight into the immediate effects of intense training, their applicability to the long-term physical performance of military personnel in operational contexts requires careful consideration.

Questionnaires

Questionnaires are a subjective self-report tool used to capture and quantify data surrounding both internal and external load. Typically, these self-report measures incorporate perceived efforts, well-being, and psychosocial inventories to ascertain and quantify internal load (Soligard et al., 2016). Questionnaires are not often incorporated to capture external load variables within team-based sports settings, as competition and training load are often captured using performance analysis methods. It would be safe to assume that due to the security and logistical constraints identified previously, the use of questionnaires and surveys would be more common within tactical environments. On the contrary, this dissertation found limited analysis via questionnaires and surveys within tactical settings. Only one study was identified, profiling the occupational tasks of specialist tactical police officers (Irving et al., 2019).

Irving and colleagues (2019) conducted the study on 136 operators apart of the Australian-New Zealand Counter-Terrorism Committee (ANZCTC) via a survey design methodology. The primary aim of this study was to establish the nature and contexts of occupational tasks completed by specialist tactical police officers (Irving et al., 2019). Overall, their findings outline the varying hazardous occupational tasks these operators undertake across their day-to-day operations. A key finding was 61% of participants reported their most common operational task was the execution of high-risk warrants of arrest, whilst the second most common was rural operations (11%). Interestingly, the physical environments of these operations differ significantly. Typically, the execution of high-risk warrants involves systematically transitioning on foot through an urban environment with short explosive movements. Further, operators execute these jobs by working in small teams to enter premises, buildings, and property by utilising MOE (method of entry) tools and specialist equipment. Whereas rural operations often require navigation of rural geographies and landscapes. Typically, during rural operations, officers are required to travel longer durations and distances with full operational external load, PPE (personal protective equipment), specialist equipment, and MOE tools. These specialist police reported performing a variety of these operational tasks whilst carrying a significant external load (Irving et al., 2019). A significant number of participants (84%) reported that during recent operations they carried “full operational load and PPE” with another 74% reporting carriage of specialist equipment (e.g., ballistic shields, ammunition and battering rams) in addition to their typical operational load carriage. Irving et al. (2019) identified the most reported load carriage to be 21 to 25-kilograms, with additional specialist equipment ranging from 10 to 15-kilograms. Of note, these demands share similarities with common infantry soldiers (Orr et al., 2015). The quantity of external load carriage required for rural operations is directly related to the severity of risk for officers with the specific operation. The primary objective of these rural operations can also vary significantly. Objectives range from the apprehension of high-risk offenders located in rural/remote areas to undertaking reconnaissance to gather intelligence on illegal operations (Irving et al., 2019) resulting in vastly different physiological demands.

Another interesting finding from this study was that 8% of the participants reported that they had completed a modality of physical training within one hour of conducting their operation, with 37% reporting they had less than one hour's notice prior to conducting their most recent operational task (Irving et al., 2019). Of note, none of the officers felt that the physical training in such proximity impacted them operationally. Irving et al. (2019) outlined that the potential ramifications of physical training within one hour of commencing an operation have not been previously considered within the available literature and to consider for future research. Questionnaires and other self-report tools are common methodologies used to collect data from participants across academia (APA, 2020; Irving et al., 2019). However, these self-report methodologies have several limitations that should be considered when using them to measure and assess external load in tactical populations. One major limitation is the potential for response bias (Sudman & Bradburn, 1982). This occurs when participants intentionally or unintentionally, do not provide accurate responses. For example, participants may feel pressure to give a socially desirable response, or they may forget certain events. This can lead to overestimation or underestimation of the true external load variable. An obvious limitation of self-report methodologies is that they rely on the participants' subjective interpretation of their own experiences (Nisbett & Wilson, 1977). This can lead to variability in how external load is perceived and reported on the individual level. Additionally, they may not capture all relevant information about the external load variable, as they rely on the participant's ability to recall and report on their experiences (Belli, 1989). This can lead to a lack of accuracy and precision in the measurement of external load. Self-report tools are also limited by their lack of objective measures (Kraemer, 1992). If these self-report methods are not utilized alongside other quantitative metrics, it becomes difficult to verify the accuracy of participant responses, as there is no way to crosscheck the external load experienced by specialist tactical populations. This can make it difficult to draw conclusions about the external load experienced, solely based on self-report data.

In summary, questionnaires and other self-report tools are convenient for collecting data from participants. However, they have several limitations when used to measure and assess external load within specialist tactical populations. It is important to consider their validity and reliability when used to analyse external load in tactical populations, and to consider utilising other quantitative tools to correlate findings; such as direct observation or physiological measures, to supplement the self-report data (Cook & Campbell, 1979).

3.3.4. Measures of Internal Load

Heart Rate

Over recent years, HR has been a widely used metric to assess internal load within specialist tactical populations (Blacker et al., 2009, Canino et al., 2020, Clemente-Suárez et al., 2013, George et al., 2015, Grant et al., 2016, Hormeño-Holgado et al., 2019, Jouanin et al., 2004, Jurvelin et al., 2020, Nikolova et al., 2007, O'Leary et al., 2018, Sánchez-Molina et al., 2018, Richmond et al., 2012, Richmond et al., 2014, Tanskane et al., 2011, Tornero-Aguilera et al., 2017, Tornero-Aguilera et al., 2018, Wilkinson et al., 2008, Winters et al., 2021, Wyss et al., 2012). HR has been closely linked to metabolic rate (Michael et al., 2022), to provide valuable insights into the cardiovascular intensity of exercises and operations. However, it is important to note that HR can be influenced by non-metabolic factors such as environmental conditions and psychological stress, furthermore, it is not sensitive to rapid changes in metabolic rate (Michael et al., 2022). To account for individual differences in age and fitness, HR can be quantified in both absolute units or relative units; beats per minute (bpm), percentage of HR_{max} or HR reserve respectively.

This dissertation identified nineteen (n = 19) studies which met the inclusion criteria and monitored HR as part of their research within specialist tactical populations. These studies reported a variety of outcomes and methodologies, whilst all studies utilised a chest strap to detect ventricular depolarization. The included studies clearly identify HR as a valuable tool for assessing the intensity and demands of training load. Among the studies reviewed, army recruits have been a common population in which HR has been utilised as a measure of internal load. Studies by Blacker et al. (2009), Grant et al. (2016), O'Leary et al. (2018), Richmond et al. (2012), Wilkinson et al. (2008), and Wyss et al. (2012) all used HR to evaluate the internal physiological demand of army and military populations during recruit basic military training (BMT).

Overall, HR data collected during BMT provides insight into the physiological demands and training intensities experienced by recruits during their initial training periods. The studies included in this dissertation identified that BMT primarily consists of low-to-moderate intensities, with average daily HR values of ~25 to 35% of HR reserve (Blacker et al., 2009; Grant et al., 2016; O'Leary et al., 2018; Richmond et al., 2012; Wilkinson et al., 2008; Wyss et al., 2012). Unsurprisingly, the physical training sessions were found to be more demanding (Blacker et al., 2009; O'Leary et al., 2018; Richmond et al., 2012). However, these physical training sessions were reported to be highly variable between individuals. Several studies reported recruits accumulated over 20-min at >85% HR reserve, with inter-individual coefficients of variation (CVs) of ~0.5-0.9

for time-in-zone across several days throughout BMT (O'Leary et al., 2018; Richmond et al., 2014; Wilkinson et al., 2008).

Blacker et al. (2009) assessed the differences in physiological demands and adaptations between male and female recruits during BMT when trained during single-sex or mixed-sex platoons. They found that while there was no difference in physical activity between sexes, the males within the mixed-sex platoon operated at a lower HR reserve and subsequently cardiovascular strain when compared to their female peers (24 ± 2 and 33 ± 2% HR reserve respectively, $p < 0.001$) (Blacker et al., 2009). The researchers suggest this was a result of their greater cardiovascular fitness levels ($p < 0.001$), as the cardiovascular strain of the males apart of the mixed-sex platoon was significantly lower than those apart of the male-only platoon (24 ± 2, 33 ± 2% HR reserve respectively, $p < 0.001$). Whilst the female recruits of both platoons experienced similar levels of cardiovascular strain regardless of the designated platoon (33 ± 2 and 33 ± 3% HR reserve, $p = 0.814$) (Blacker et al., 2009). These findings were reiterated by O'Leary et al. (2018) who identified a sex-time interaction for average daily HR ($p < 0.001$). Female recruits had a significantly higher average daily HR compared to males during weeks 12 and 13 ($p < 0.011$) of the 14-week basic training period. Unfortunately, the researchers do not state what activities, exercises, or operations that may have influenced the significant increase in training load and intensity during these two weeks. However, it is important to note that average daily HR was similar between sexes across the duration of training (29 ± 3% and 30% ± 3%, males and females respectively) (O'Leary et al., 2018).

On the contrary, Richmond et al. (2012) reported the physiological demands and progression during BMT for male ($n = 30$) and female ($n = 30$) British Army recruits of single-sex platoons to be similar. The cardiovascular strain measured through average daily %HR reserve (female: 31 ± 4%, male: 32 ± 5%), physical activity levels, and percentage improvements in 2.4-km run time did not differ significantly between males and females ($p > 0.05$). Whilst the total average daily %HR reserve was similar between sexes, under closer inspection, some differences between days and weeks between sexes were identified (Richmond et al., 2012). During the initial week of BMT, female recruits exhibited a lower mean daily %HR reserve in comparison to male recruits. %HR reserve is calculated by subtracting the resting HR from the HR_{max} and then dividing the result by the HR_{max}; serving as an indicator of the level of strain on the cardiovascular system. Thus, a higher %HR reserve suggests a greater level of cardiovascular strain (Richmond et al., 2012). Furthermore, during the final exercise (week 13), female recruits had a higher mean daily %HR reserve compared to male recruits. Potentially indicating that the demands of the final exercise were more physiologically taxing for female recruits than for male recruits. One possible explanation for these differences could be the relative load carried by females. All recruits were required to carry the same load, despite differences in body weight or sex. This may have resulted in female recruits exerting more effort during load carriage tasks, assuming that pace and terrain were comparable between sexes (Richmond et al., 2012). These observations are supported by Wyss et al. (2012) who noted HR values to increase significantly during physical activities such as marching and carrying loads, with no significant differences in HR between sexes. The average HR of male and female recruits was similar throughout the BMT period, with both groups showing a decrease in resting HR over the training period. Another interesting finding reported by Richmond et al. (2012), was that both male and female recruits spent a significant amount of time in the “hard” or “very hard” training zone (Howley et al., 2001) on six days throughout the course. For female recruits, these days were spread out over the 13-week BMT. Yet, these days were concentrated in the first week for male recruits, indicating that this first week period was more physically demanding for males comparatively (Richmond et al., 2012). Additionally, the daily average of absolute physical activity counts (PAC) was higher for male recruits, indicating that they engaged in more physical activity per day compared to females. This is in contrast to the relative total cardiovascular strain shown by the %HR reserve data, which indicated that both sexes experienced the same level of relative physical activity per day (Richmond et al., 2012). While the observations found during BMT provide valuable insights into the physiological responses of recruits, it is important to consider how these findings may relate to the operational demands experienced by military personnel. Typically, specialist tactical operations involve high-intensity physical activities, load carriage, and challenging environmental conditions, which are similar to aspects of BMT (Blacker et al., 2009; Grant et al., 2016; O'Leary et al., 2018; Richmond et al., 2012; Wilkinson et al., 2008; Wyss et al., 2012). Therefore, the understanding gained from studying physiological responses during BMT can inform the preparation and physical conditioning of military personnel for the rigors of military operational demands. However, it is crucial to acknowledge that operational contexts may introduce additional stressors and complexities, necessitating further research to bridge the gap between training and real-world operational demands.

Training Impulse

Training Impulse (TRIMP) is another commonly used index to describe the internal load within specialist tactical populations. It combines HR and duration to produce a unit to track internal load (Borresen & Lambert, 2009) that can be used to monitor and evaluate changes in an individual's training status over time. Recent literature has reported the TRIMP index to provide useful insights into the internal load experienced by specialist tactical populations, during physical activity and training (Jurvelin et al., 2020; O'Leary et al., 2018). Compared to using HR alone, TRIMP acts as an index to describe the internal load in training. Ultimately, providing a more comprehensive assessment of the individual's training status and internal load. By combining HR and duration, TRIMP takes into account not only the intensity of the exercise but also the duration; providing a higher quality measure of overall internal load. Furthermore, the different calculations of TRIMP (i.e., Banister's and Edward's), provide different ways of quantifying the internal load, each with their advantages and disadvantages. For example, Banister's TRIMP provides a simple and straightforward calculation that is easily understood (Exponentially weighted average HR x Duration), whereas, Edward's TRIMP provides a more nuanced and complex measure of the internal load that involves calculating time in different HR zones and applying intensity coefficients to each zone (the exact equation dependent on the specific zones used and the coefficients applied). Furthermore, Edwards' TRIMP was positively correlated with accumulated oxygen uptake ($r = 0.73$-0.84) in tactical populations performing load carriage tasks lasting 5 to 10-min (Canino et al., 2020). Whilst also demonstrating substantial inter-individual variability with CV values ranging from 0.4-0.7 (Jurvelin et al., 2020; O'Leary et al., 2018). However, the HR cut-off points used to determine time-in-zone were considered arbitrary rather than based on physiological principles (Borresen & Lambert, 2009). Although practical challenges may have contributed to a lack of data regarding the demands of tactical-specific tasks in operational settings. The use of TRIMP to monitor and evaluate changes in an individual's training status over time has been shown to provide useful insights into the internal load experienced by specialist tactical populations within both BMT and exercises/operations (Jurvelin et al., 2020; O'Leary et al., 2018).

Heart Rate Variability

In recent years, the concept of "readiness" has become more popular recreationally and within sports settings. One component of this readiness assessment often refers to another HR measure. HRV is the fluctuation and oscillation of time intervals between heartbeats (Buchheit et al., 2014; Shaffer et al., 2017). HRV is an indirect measure of activity levels from the autonomic nervous system (ANS) and has been shown to be a useful marker of ANS function, quantifying insights into the physiological and psychological stress experienced by an individual (Buchheit et al., 2014; Shaffer et al., 2017). HRV reflects the balance between sympathetic (SNS) and parasympathetic (PNS) nervous system contributions to heart rhythm, which result from feedforward (e.g., from the motor cortex) and feedback (e.g., from the baroreflex) inputs to the cardiovascular control centre (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). Some studies have demonstrated the sensitivity of HRV to the work characteristics of tactical populations. This results in the disruption of typical ANS patterns, exemplified by the impact of shift work. Where greater parasympathetic and reduced sympathetic activity has been observed overnight (18:00 to 06:00hrs) (Furlan et al., 1990), while nocturnal night-shift work has been identified to exhibit similar reductions in sympathetic activation compared to morning and evening shifts (Furlan et al., 2000).

One of the main constraints of HRV assessment is that the calculation of HRV is subject to a range of different assessment protocols (e.g., supine, standing, and 24-hr recordings), and analysis techniques (e.g., time domain analysis, frequency domain analysis, and non-linear analysis) (Shaffer et al., 2017). Time domain analysis focuses on the time interval between heartbeats, by measuring HRV parameters including the standard deviation of inter-beat intervals (SDNN), root mean square of successive differences (rMSSD), and percentage of successive intervals differing more than 50-milliseconds (pNN50) (Buchheit et al., 2014). Whilst frequency domain analysis involves the transformation of time series data into a frequency domain representation, it facilitates the estimation of HRV parameters, including low-frequency (LF) power, and high-frequency (HF) power (Buchheit et al., 2014). The non-linear analysis uses complex algorithms to describe the non-linear relationships between different aspects of the HRV signal (Buchheit et al., 2014). These different analysis techniques can affect the HRV parameters obtained, and subsequentially impact the interpretation of the HRV results. As different HRV parameters can respond to various aspects of the HRV signal, this can lead to variations when different analysis techniques are used. This creates challenges when interpreting and comparing HRV results across different studies utilising different analysis methodologies (Shaffer et al., 2017).

This dissertation identified seven (n = 7) studies which met the inclusion criteria and monitored HRV as part of their research within specialist tactical populations, reporting a variety of outcomes and methodologies (George et al., 2015; Grant et al., 2016; Hormeño-Holgado et al., 2019; Jouanin et al., 2004; Nikolova et al., 2007; Sánchez-Molina et al., 2018; Tomes et al., 2021).

Two (n = 2) of the identified studies focused primarily on police/law enforcement personnel (George et al., 2015; Tomes et al., 2021). These studies provide valuable insights into the impact of physiological and psychological stress on the human biological system, by utilising HRV alongside HR recovery to quantify both stress and fitness. George et al. (2015) aimed to quantify the effect of nine (9) months of police recruit basic training on HRV and HR recovery. Interestingly, this was one of the only studies included within this dissertation that solely included female participants within their study. Additionally George et al. (2015) had a secondary objective of identifying whether HRV and HR recovery values could be utilised in part of a complex general algorithm classification system to identify “trained” and “untrained” recruits. The “trained” and “untrained” groups were classified using a complex algorithm and machine learning process. These classifications were established and achieved through the use of two different techniques: the Artificial Neural Network (ANN) and the Support Vector Machine (SVM). The ANN was created using a type of algorithm called the

Levenberg Marquards backpropagation, which was used primarily to train the network by adjusting its internal parameters and values. The input data for the network came from several specific features of the cardiovascular system, that were selected using a technique called genetic algorithm optimisation. The ANN performance was then evaluated using a tenfold cross-validation statistical measure, where the data was split into ten (10) sets and the network was trained and tested using a different set each time. Finally, the results were then measured using four statistical measures: True Positive (correctly identifying a trained individual), False Positive (incorrectly identifying an untrained individual as trained), True Negative (correctly identifying an untrained individual), and False Negative (incorrectly identifying a trained individual as untrained). The implementation of ANN and SVM algorithmic analysis as an internal monitoring method and for physical fitness classification offers a more efficient, less time-consuming, and a more accurate mode to assess physical fitness compared to the traditional HR methods alone (such as graded exercise tests utilising HR to estimate VO_2max).

The main findings from George et al. (2015), demonstrated that police recruit basic training has the ability to effectively alter and change the way the PNS and the non-linear control of the cardiovascular system work. As identified through the changes in HRV and HR recovery measures. Reporting significant differences across all 16 HRV features across the training period ($p < 0.05$) from pre- to post-training. For example, SDNN (Standard Deviation of Normal-to-Normal Intervals; a broader measure of HRV, that calculates the SD of all normal-to-normal intervals within a given time period) was reported to have one of the most significant improvements across the basic-training period ($p = 0.007$). This finding was reiterated by the rMSSD results with significant improvements ($p < 0.001$). This provided a more specific measurement of HRV as rMSSD focuses on the variability between consecutive heartbeats, whereas, SDNN provides a more general measurement (Buchheit et al., 2014). Ultimately, these findings are both linked with the enhanced ANS ability to maintain homeostasis against various internal and external variables. Furthermore, reporting that through the combination of a 5-min supine HRV recordings and post-exercise recovery features (e.g., raw HR, HR recovery, number of beats recovered, HR recovery time constraints etc.) could accurately classify police recruits into the “trained” and “untrained” groupings, with 89.7% being the highest accuracy rating obtained. However interestingly, the HR recovery features (e.g., HR recovery, HR peak, HR recovery time constraints etc.) outperformed the HRV features (e.g., rMSSD, mean HR, mean R-R, LF and HF power etc.) in both classifiers with and without general algorithm optimisation. This study identified the potential for integrating general algorithms into the tactical monitoring environment. Further, through the use of both HRV and HR recovery, George et al. (2015) noted how this methodology could assist traditional internal and external monitoring methods to identify police recruits (or any trainee) that do not respond and/or adapt to the physical training methods within basic training. These insights have the potential to help strength and conditioning professionals adjust and tailor training loads, durations, frequencies, and modes according to the individual. Additionally, this may help strength and conditioning professionals prevent over-stimulus or over-training within these populations to mitigate maladaptation or any adverse health outcomes.

Tomes et al. (2021) utilised HRV in their study to determine the effects of overnight shift work on the specific operational performance of specialist tactical police from a Special Emergency Response Team (SERT). HRV was used within this setting to analyse, measure, and compare the cardio-regulatory stress response of a training day between off-duty operators and those who worked an overnight shift prior to attending training. The participants were classified into two groups: off-duty operators (n = 6), and on-duty operators (n = 5). The off-duty operators, defined as individuals who were able to sleep at their own discretion, were not scheduled to perform any duties/work for 10-hrs prior to attending data collection and training. On the other hand, the on-duty operators were individuals who had just finished a 10-hr overnight shift prior to reporting for training, without the opportunity for sleep. HRV was collected via a three-lead 5-min seated electrocardiograph (ECG) prior to commencing the 8 to 9-hr training day (commencing at approximately 08:00 to 08:30hrs). Operators were wearing full operational load (i.e., helmet, protective plate vest, uniform, boots), therefore, leads were placed as close to the radial artery on both wrists and the left ankle above the medial malleolus. Within this study, short-term HRV was quantified by the number of pairs of consecutive R-R intervals that differed by 50-miliseconds (pRR50). A high pRR50 value indicates a low level of HRV and is associated with increased sympathetic activity and higher levels of overall stress. The firearms qualification shoot is a mandatory certification for operators, as they are expected to maintain and pass to keep their position on the squad; being a pass/fail assessment. The shoot entailed both handgun (Glock 22) and long-barrel rifle (M4) components, where operators were expected to achieve 100% accuracy and proficiency in both firearms.

The firearms qualification shoot was a mandatory certification for operators to maintain their position. While there were no statistically significant differences in pRR50 values at both pre- and post-training measurements for off-duty and on-duty operators (Tomes et al., 2021), there were statistically significant differences in the change of pRR50 values between off-duty (1.27 ± 2.03%) and on-duty (−2.47 ± 3.01%) operators, with a mean difference of 3.73% ($p = 0.037$; 95% CI: 0.29-7.18%) (Tomes et al., 2021). Furthermore, the results revealed that off-duty operators experienced an overall lower cardio-regulatory stress response across the training day. Comparatively, operators who worked an overnight shift prior experienced increased fluctuations in their regulatory capacity during the qualification firearms shoot. These findings are consistent with previous research that found significant changes in short-term HRV following shift work (Furlan et al., 2000). However, an interesting finding outlined by the researchers was that previous research suggested that resting pRR50 values <6.9% are linked with cardiovascular disease (Mietus et al., 2002). Where on average, the on-duty operators that had worked an overnight shift immediately prior exhibited pRR50 values well below this threshold, ranging from ~2.5 to 5% (Tomes et al., 2021). It is important to treat these results with caution given the limited sample size ($n = 11$) and the short duration recordings, compared to 24-hr recordings. However, it is important to note that the observed reductions in pRR50 values following overnight shift work represent an acute physiological response and may not directly imply a chronic risk of cardiovascular disease. To suggest a plausible link between shift work and potential long-term health implications, further research is needed to explore the cumulative effect of shift work on cardiovascular health over an extended career. Such studies would need to consider factors including the duration of shift work, frequency of night/overnight shifts, and other lifestyle and health-related variables that may contribute to cardiovascular risk. While the present study raises questions about the potential impact of shift work on specialist tactical operators' health, a comprehensive understanding of this relationship requires a more extensive investigation with larger sample sizes and long-term data collection.

On the contrary, some research has suggested that HRV may not be a sensitive measure of internal physiological response in specific tactical environments (Hormeño-Holgado et al., 2019). This study aimed to investigate the psychophysiological responses of air combat of fighter pilots, within specific offensive and defensive manoeuvres (Hormeño-Holgado et al., 2019). The main findings of this study identified that both offensive and defensive manoeuvres elicited similar psychophysiological responses of both internal and external measures, including decreased forced vital capacity (i.e., breath muscle strength) (-12.2% change, $p = 0.002$), increased HR (12.4% change, $p = 0.043$), and increased RPE (82.9% change, $p = 0.001$) and stress. The findings of this study suggest that HRV may not be a sensitive measure of physiological response as there were no significant changes in non-linear, temporal, and frequency HRV domains (Hormeño-Holgado et al., 2019). This may have been due to the high anticipatory anxiety response as reported in the low rMSSD, pNN50, and LF results (Offensive: p = 0.92, 0.779, and 0.472 respectively; Defensive: p = 0.067, 0.199, and 0.061 respectively). These values were maintained during both flights, which identifies the significant load and demand of these aircraft combat manoeuvres. Moreover, additional internal load measures, including HR, blood pressure, and leg strength showed significant changes, which was suggested to be due to the activation of the SNS "fight or flight" response (Hormeño-Holgado et al., 2019). An interesting finding from this study, was the importance of considering external and environmental factors, such as hypobaric conditions and G-forces when interpreting HRV data in fighter pilot populations. Reporting that hypobaric conditions resulting in low oxygen pressure can induce hypoxia and subsequently an acute hypoxic-ventilatory response. Where this could lead to modifications of the SNS activation, increased HR, blood pressure, and overall cardiac output. Furthermore, this study reported that G-forces could impact the volume of capillary blood irrigating from the punctured finger used during the data collection process (Hormeño-Holgado et al., 2019). Which has the potential to impact HRV measurements taken utilising photoplethysmography (PPG) methodology. Within this study, HRV was measured using a Polar V800 HR chest strap monitor (POLAR, Finland), therefore, the volume of capillary blood irrigating through the fingers would not directly impact the HRV measurements. However, it is worth considering these external factors when interpreting and collecting HJRV data in fighter pilot populations. The results from Hormeño-Holgado et al. (2019) indicate that HRV may not be a useful measure for detecting changes in overall cortical arousal during combat manoeuvres of fighter pilots. Where HRV may have limited utility for monitoring internal load within these populations during combat, operations, or exercises.

Four (n = 4) studies utilised HRV recordings as part of their internal physiological monitoring method within Military populations (Grant et al., 2016; Jouanin et al., 2004; Nikolova et al., 2007; Sánchez-Molina et al., 2018). These studies investigated the use of HRV whilst focusing on its utility in assessing physical fitness (Grant et al., 2016), fatigue (Jouanin et al., 2004), stress (Nikolova et al., 2007), and performance (Sánchez-Molina et al., 2018).

Both Grant et al. (2016) and Jouanin et al. (2004) investigated HRV and its role in monitoring and assessing physical fitness. Grant et al. (2016) analysed the physical fitness of soldiers (n = 154) who undertook basic training in the South African National Defence Force, whilst measuring exercise-induced cardiac autonomic changes using HRV. This study aimed to investigate whether 20-weeks of basic training compared to 12-weeks elicited greater physical conditioning adaptations, specifically autonomic function (HR and HRV), and exercise ability and endurance (VO_2max indirectly calculated using a validated 2.4-km run test) without the development of overtraining syndrome (OTS) (Grant et al., 2016). The main findings of this study identified that the extended 20-week basic-training programme did not elicit greater responses in exercise capacity (VO_2max), furthermore, there were no identifiers of OTS, as measured by HR and HRV (LF/HF). VO_2max increased predominantly during the first 12-weeks (VO_2max: 49.54 to 54.14; $p < 0.001$), with no significant increases between weeks 12 to 20 (VO_2max: 54.14 to 54.15; $p = 0.44$). These findings were reiterated by soldiers HR decreasing by 11.9% during the first 12-weeks, whilst only declining by 3.7% between weeks 12 to 20. These exercise-induced increases in cardiac function were observed after both 12 and 20 weeks of training, as demonstrated through vagal-induced variability indicators (rMSSD, pNN50, SDNN, and HF). Grant et al. (2016) found that there were significant increases in cardiac control between weeks 1 and 12 ($p < 0.001$ for RMSSD, pNN50, and SDNN), which continued for the additional 8-weeks, although with statistically non-significant changes to autonomic balance (pNN50: $p = 0.083$). Within this study, HRV was utilised to measure and identify OTS. However, the results did not show any early indicators of OTS development. These are thought to lead to an increase in the SNS branch of the ANS, thus changing the ANS balance and leading to minor increases in resting HR and a larger LF/HF ratio (Kuipers et al., 1998). However, within the current study, most supine HRV values (rMSSD, pNN50, SDNN, and HF) consistently progressed toward higher vagal power, confirmed by the LF/HF values; indicators of HRV autonomic balance (Grant et al., 2016). These findings suggest that HRV was a useful tool in monitoring the internal load experienced by these soldiers, whilst helping to identify any early overtraining indicators.

Jouanin et al. (2004) studied whether HRV could serve as an indicator of fatigue, by measuring resting sympathovagal balance across a ranger training course in the French National Centre for Ranger Training ($n = 23$). The ranger training course included instructional education sessions intermittent with intense physical training across the span of 3-weeks, followed by an additional 5-day field exercise. The physical training sessions included a range of both aerobic and anaerobic operationally specific activities (e.g., extended land navigation, water crossings, house-to-house combat etc.). Further, the ranger training course is specifically designed to induce physiological and psychological stress through arduous activity and sleep deprivation, to accumulate fatigue and limit recovery. Overall physical activity was determined as submaximal, corresponding to ~35% of maximal oxygen uptake (Jouanin et al., 2004). After the completion of the 5-day field exercise, soldiers underwent the post-course data collection process between 06:00-08:00hrs, under the same conditions as the baseline assessment prior to the course. Within this study, HRV measurements provided insight into the sympathovagal balance and PNS activity of soldiers recovering from submaximal prolonged fatiguing physical activity induced across the course and 5-day field exercise. Jouanin et al. (2004) identified that fatigue was accompanied by a decrease in testosterone levels (28.6 ± 7%; pre-test: 14.9 ± 0.7 $nmol/L^{-1}$ and post-test: 9.6 ± 0.5 $nmol/L^{-1}$; $p < 0.001$) and an increase in PNS activity. The increased PNS activity was evidenced by a higher TP and standardised HF values in the supine position ($p < 0.001$), a decrease of the standardised LF values in both positions and a change in the LF:HF ratio in the supine position (66.2 ± 12.9% decrease; $p < 0.01$); expressing a decrease in sympathetic activity after physical training.

From a cardiovascular standpoint, this state of prolonged fatigue is expressed by a reduction of resting HR and BP. Resting HR and BP were lower during the post-course stand test compared with the pre-course values, regardless of whether the individual was supine or standing. The data from the time-domain analysis (SD-RRi [standard deviation of RR intervals], pNN50, and rMSSD) provided indices of modulation of PNS activity in the supine position. Moreover, the results suggest that fatigue appears to be accompanied by an increase in PNS activity rather than a decrease in SNS activity (Jouanin et al., 2004). This can be derived from the significantly lower HR and BP following the course and field exercise and is consistent with PNS fatigue (Jouanin et al., 2004). Further, the TP was higher in the supine position at the end of the course ($p < 0.001$), while the standardised HF values were higher for soldiers in both positions, indicating increased PNS activity. In contrast, the standardised LF values (both supine and standing) decreased, expressing a reduction in SNS activity after physical training. This suggested that fatigue may be associated with increased PNS activity rather than a decrease in SNS activity.

Nikolova et al. (2007) and Sánchez-Molina et al. (2018) investigated the impact of stress on the autonomic cardiovascular control and health risks in military populations. Nikolova et al. (2007) analysed the effect of stress on Bulgarian peacekeepers during an operation and utilised HRV in their assessment protocol of psychophysiological stressors to determine the characteristics of stress. Whilst Sánchez-Molina et al. (2018) investigated the psychophysiological response of combat simulations on motor skills, using HRV to assess the sympathetic-vagal interaction of soldiers pre- and post-combat manoeuvres. Sánchez-Molina et al. (2018) explored how individuals’ training levels could affect performance within combat simulations, whilst analysing whether this established training level impacted the stress response.

Nikolova et al. (2007) examined the longitudinal psychophysiological response of peacekeepers to stressors encountered during operations, with a focus on autonomic control, measured through HRV. The results suggest that autonomic control is affected by operational stressors, as they reported a decrease in the mean values of P_{RSA} (spectral power of RR intervals) and STV (standard deviation of R-R intervals, i.e., SD-RRi) during the redeployment phase when operators returned from their mission and were assessed for any changes to their autonomic cardiovascular control and health risk. P_{RSA} is a measure of the spectral power of RR intervals in the respiratory sinus arrhythmia (RSA) frequency range of 0.15 to 0.5 Hz (Nikolova et al., 2007). RSA is the increase in HR during inspiration and decrease during expiration due to changes in parasympathetic tone. P_{RSA} reflects the magnitude of these fluctuations in RR intervals that are related to RSA, which is thought to be primarily mediated by the PNS (Nikolova et al., 2007). Thus, P_{RSA} is typically used as a marker of PNS activity, specifically related to RSA. These results indicate a reduction in parasympathetic function and baroreceptor modulation of heart rhythm. Nikolova et al. (2007) went on to discuss that these findings may be related to cognitive processes, such as self-evaluation of stress and the ability to accomplish the mission. As cognitive appraisal appears to be a mechanism of peacekeeping stress and may play a role in the cumulative effects of stressors on cognition and health (Nikolova et al., 2007).

Additionally, Nikolova et al. (2007) reported stress to be associated with a 50% increase in HR during the redeployment phase. Of note, this increase did not reach the critical 65% value that indicates a risk of cardiovascular disease (Danev et al., 1989), however, it does indicate a risk of a premorbid state. Similar to the findings from Tomes et al. (2021) outlining cardiovascular health risks, these results should be taken into consideration when monitoring tactical populations. Despite the observed autonomic responses, this study did not report any development of PTSD (post-traumatic stress disorder) related to autonomic hyperarousal, as there was no evidence of an increase in sympathetic function or tonic levels across the operation (Nikolova et al., 2007).

Sánchez-Molina et al. (2018) analysed the fine motor skills and the psychophysiological response of two different military units (heavy infantry unit (HIU) and light infantry unit (LIU)) to an asymmetrical combat simulation to analyse whether training and experience influenced performance. Overall, the results indicate that the initial hypothesis was partially correct. The LIU was reported to have a lower psychophysiological response compared to the HIU, however, fine motor skills (as measured by pistol magazine time reload [PMTR]) were not affected in either group. One main finding was that the HR of the LIU (65.1 ± 9.75 to 82.21 ± 10.2bpm; $p = 0.006$) was significantly lower than the HIU (70.91 ± 13.71 to 93.33 ± 9.86ppm) pre- and post-testing. The researchers linked this to the LIUs enhanced physical conditioning, stating it was likely due to the higher physical training conducted by the LIU (Sánchez-Molina et al., 2018). Furthermore, the researchers reported soldiers had conducted the combat simulation with an "optimal" arousal level as evidenced by the correlation analysis between HR and PMTR, however, this correlation is unclear within the results presented in this study. This was suggested to support the Inverted-U Hypothesis that predicts that performance is best at a moderate level of arousal (Neiss et al., 1988; Sánchez-Molina et al., 20187; Vickers et al., 2007). The researchers utilised a self-report questionnaire methodology to measure arousal and anxiety, which asked soldiers to rate their level of alertness and energy pre- and post-combat. As outlined in the above chapter, there are several important biases to consider when interpreting self-report questionnaires. These include but are not limited to: social desirability bias (feeling pressured to report higher levels of alertness, especially after a combat simulation), recall bias (soldiers may not accurately recall their level of alertness before and during the combat simulation, affecting the reliability and validity), subjective interpretation (soldiers with this level of experience within combat roles, may have different interpretations of what constitutes alertness, resulting in inconsistent responses), and response bias (responding in a certain way to please and/or align with the researcher or their own beliefs about the importance of alertness during combat).

When analysing HRV, Sánchez-Molina et al. (2018) identified that the LIU had a significantly higher basal LF prior to conducting the combat simulation (76.6 ± 10.75; $p < 0.001$), which is associated with SNS activation. Immediately following the simulation, both LIU and HIU showed a significant decrease in PNS (rMSSD: 7.62 ± 5.62 and 29.32 ± 9.33 respectively) and an increase in SNS (LF: 90.93 ± 3.42 and 88.68 ± 4.45 respectively) activation, which is suggested to be attributed to the fight-or-flight response mechanism (Sánchez-Molina et al., 2018; Clemente-Suárez et al., 2013; Clemente-Suárez et al., 2015). This decrease in PNS activation was reiterated in a decrease in blood oxygen saturation (BOS) and cognition (cognitive flexibility and fluid thinking [CFFT]). The decrease in CFFT is associated with symptoms of CNS fatigue and weakness in cognitive processing (Sánchez-Molina et al., 2018), ultimately leading to slower and inaccurate responses in critical decision-making ability. These results suggest that maladaptive psychophysiological stress responses during combat can negatively affect soldiers' performance, thus posing an increased risk to their individual and team safety. Overall, Sánchez-Molina et al. (2018) highlight the importance of tailoring training methods according to the demands of the specific infantry units for optimal operative performance. Furthermore, these findings clearly link cognition and psychophysiological associations, suggesting that the incorporation of psychological stressors (i.e., pressure) within the training of specialist tactical populations could enhance operational performance.

In summary, there are very few studies that appear to be specifically designed to assess the efficacy of utilising HR variables and metrics (e.g., HR, HR-reserve, HR-recovery, TRIMP, and HRV) in controlling training workloads in order to optimise or determine operational performance or readiness. However, research capturing and monitoring HR metrics has provided insight into the physiological demands of military personnel (Blacker et al., 2009; Canino et al., 2020; Clemente-Suárez et al., 2013; Grant et al., 2016; Jouanin et al., 2004; Jurvelin et al., 2020; Nikolova et al., 2007; O'Leary et al., 2018; Sánchez-Molina et al., 2018; Richmond et al., 2012; Richmond et al., 2014; Tanskane et al., 2011; Tornero-Aguilera et al., 2017; Tornero-Aguilera et al., 2018; Wilkinson et al., 2008; Wyss et al., 2012), SOF (Johnson et al., 2018; Winters et al., 2021) law enforcement (George et al., 2015; Tomes et al., 2021), and fighter pilots (Hormeño-Holgado et al., 2019). The included studies have provided practitioners valuable insights into the common HR variables used to monitor internal load within specialist tactical populations, however, there are several limitations to their use in these settings. While metrics such as HR, HR recovery, and HRV have been identified to provide valuable insight into the ANS, and its subsequent response to exercise and stress, there are several limitations to their use in these populations. One limitation is the high inter-individual variability of HR responses, as seen through multiple studies reporting high CV values, indicating significant differences between individuals' time spent in specific HR zones (O'Leary et al., 2018; Richmond et al., 2014). This variability can be influenced by several factors including, age, sex, fitness level, and training status (Buchheit et al., 2014; Migueles et al., 20177; O'Leary et al., 2018). Furthermore, this variability can make it challenging to establish normative values and interpret individual changes over time (Buchheit et al., 2014). Moreover, specialist tactical populations are unique compared to athlete populations, as their environment and stressors are unpredictable by nature. Operators are required to execute specific tasks under extreme, and often arduous conditions, resulting in these populations facing unique physiological and environmental conditions, such as heat (Johnson et al., 2018), cold (Johnson et al., 2018), altitude (Hormeño-Holgado et al., 2019), sleep deprivation (Jouanin et al., 2004; Tomes et al., 2021), and high cognitive demand (Nikolova et al., 2007; Sánchez-Molina et al., 2018; Johnson et al., 2018), all of which can further complicate the interpretation of HR and HRV data (Buchheit et al., 2014). Another limitation is the lack of standardisation in measurement protocols and data analysis methodologies (Buchheit et al., 2014; Horner et al., 2013). This is due to the ability to measure HR and HRV using different devices and software, which have varying sampling rates, recording durations, and filtering algorithms (Bourdon et al., 2017; George et al., 2015; Horner et al., 2013; Migueles et al., 2017). This variability can lead to inconsistency in the quality of data, while also limiting the ability to compare results across studies and subsequent populations/groups (Horner et al., 2013; Migueles et al., 2017). Practitioners must consider these limitations when analysing and comparing HR (and its subsequent variables) data. However, the tracking and monitoring of HR variables have proven to provide useful insight into the internal load of specialist tactical populations. Future research should aim to address and mitigate these limitations, through the development of standardised measurement protocols, and exploring and contrasting HR data with other physiological measures and variables. This will ensure practitioners are able to maximise the benefits of capturing HR data, whilst minimising any potential drawbacks within specialist tactical populations.

Biochemical analysis

Biochemical analysis has emerged as a valuable tool for assessing internal load in specialist tactical populations and has gained popularity in recent years. This monitoring method involves measurements of various biomarkers in body fluids such as blood, saliva, and urine. Utilising biochemical analysis provides objective and quantitative data on the physiological response to stress and exercise. This chapter discusses the use of several biochemical markers (Table 3), including doubly labelled water (DLW), hormonal markers (e.g., TST, COR, IGF-1, and other metabolites (e.g., blood lactate and glucose), as measures of internal load within specialist tactical populations. By examining the strengths and limitations of these markers, this dissertation aims to provide insights into the potential applications of biochemical analysis as a monitoring method of internal load.

Table 4.

Biochemical Analysis in Specialist Tactical Populations

Study	DLW	Hormonal markers	Metabolites	Inflammatory markers
Blacker et al. (2003)	x			
Conkright et al. (2021)		x		
Drain et al. (2017)		x		
Friedl et al. (1995)	x	x		x
Hormeño-Holgado et al. (2019)			x	
Johnson et al. 2018	x			
Jouanin et al. (2004)		x		
O'Leary et al. (2018)	x			
Richmond et al. (2012)	x			
Richmond et al. (2014)	x			
Salonen et al. (2019)		x		
Sánchez-Molina et al. (2018)			x	
Tanskanen et al. (2011a)		x	x	
Tanskane et al. (2011b)		x		
Tornero-Aguilera et al. (2017)		x	x	
Tornero-Aguilera et al. (2018)			x	
Winters et al. (2021)			x	
n =	6	8	5	1

DLW = Doubly labelled water

Doubly Labelled Water

Doubly labelled water (DLW) analysis is considered a gold-standard technique used to measure energy expenditure and water turnover rates (Michael et al., 2022). It involves the consumption of water that contains small amounts of stable hydrogen (^2H) and oxygen (^{18}O) isotopes. The isotopically labelled oxygen exits the body as water and carbon dioxide (e.g., breath), whilst the isotopically labelled hydrogen only exits the body in water (i.e., urine). By measuring the difference of isotope turnover, researchers can measure the elimination rates (typically using isotope ratio mass spectrometry of urine), to calculate an individual's carbon dioxide production, and therefore, total energy expenditure derived by an assumed respiratory quotient (Schoeller et al., 1982). DLW provides a non-invasive and accurate (Michael et al., 2022) method to assess an individual's energy expenditure over a period of several days, or weeks (Blacker et al., 2003; Friedl et al., 1995). DLW can be particularly useful within tactical environments or operations where individuals may not be able to wear HR monitors or other types of activity trackers (Johnson et al., 2018).

This dissertation identified six (n = 6) studies which met the inclusion criteria and utilised the DLW method as part of their research within specialist tactical populations (Blacker et al., 2003; Friedl et al., 1995; Johnson et al., 2018; O'Leary et al., 2018; Richmond et al., 2012; Richmond et al., 2014). Total energy expenditure calculated from DLW has been reported across a range of environments, including BMT (Blacker et al., 2003; O'Leary et al., 2018; Richmond et al., 2012; Richmond et al., 2014), selection and training courses (Friedl et al., 1995), and field exercises (Johnson et al., 2018).

All included studies utilised a similar methodology when administering and collecting their data. Following a baseline urine sample, participants were given a single-weighed oral dose of deuterium (^{2}H) and oxygen-18 (^{18}O) the night before the start of each ~10-day observation period (Blacker et al., 2003; Friedl et al., 1995; Johnson et al., 2018; O'Leary et al., 2018; Richmond et al., 2012; Richmond et al., 2014). There was some variability between morning (Blacker et al., 2003; Richmond et al., 2012; Richmond et al., 2014) and evening (Friedl et al., 1995; O'Leary et al., 2018) samples, however, they were typically within each 24-hour period (Johnson et al., 2018). Additionally, all samples were either stored frozen (Johnson et al., 2018; Richmond et al., 2012; Richmond et al., 2014), or chilled (Blacker et al., 2003; Friedl et al., 1995; O'Leary et al., 2018) until analysis.

The highest reported value of energy expenditure was captured during the initial mountain phase of a U.S. Army Ranger Course, of ~6000-kcal.day^{-1} (Friedl et al., 1995).

However, whilst during BMT the average total energy expenditure was lower than those values reported by Friedl et al. (1995), these are still typically reported to be high, with values ranging from 3530 ± 330-kilocalories per day (Blacker et al., 2003) to 4693 ± 424-kcal.day^{-1} (Richmond et al., 2014) for men, and from 2700-kcal.day^{-1} to 3400-kcal.day^{-1} (O'Leary et al., 2018) for women. Which are similar results to those reported during field exercises (~4600-kcal.day^{-1}; Johnson et al., 2018). Among the studies that utilised DLW at both the onset and conclusion of BMT, as reported by Blacker et al. (2003), O'Leary et al. (2018) and Richmond et al. (2014), only two studies reported significant elevations in energy expenditure values during the latter weeks of training, compared to the initial weeks ($p < 0.001$) (O'Leary et al., 2018; Richmond et al., 2014). Furthermore, as discussed in the previous section, Richmond et al. (2014) reported the average PAL value across weeks two and three of BMT was 2.5 ± 0.1, which further increased in weeks six and seven to 2.7 ± 0.2. These values are considered "very high" by the PAL classification system laid out by Bouten et al. (1996) and is the threshold at which individuals struggle to maintain energy balance. This is supported by several of the included studies reporting significant decreases in body mass across the duration of BMT (Blacker et al., 2003; O'Leary et al., 2018; Richmond et al., 2012; Richmond et al., 2014). On average Richmond et al. (2014) report soldiers to have lost 5.1 ± 2.6-kg, or the equivalent of ~6% body weight.

Overall, DLW analysis has been identified to show promise as a practical tool for monitoring internal load and energy expenditure within specialist tactical populations. The DLW method provides a non-invasive way to track changes in energy expenditure over significant periods of time. This may allow for strength and conditioning practitioners and/or researchers to assess the effectiveness of training interventions and provide insight into the design of hydration and nutritional strategies for operators in high-stress environments (Johnson et al., 2018). However, there are some limitations surrounding the data collection process in the DLW method. Firstly, the cost and logistical challenges associated with DLW analysis can be prohibitive, particularly in governmental settings where resources are often limited. Additionally, DLW analysis requires a relatively long measurement period, typically spanning one to two weeks. This could potentially make it challenging for use in tactical environments where a rapid assessment of energy expenditure is often needed. Furthermore, DLW is limited in its ability to provide daily monitoring, as it cannot provide high-temporal resolution or intensity distributions (Michael et al., 2022). Additionally, the use of DLW may be limited by the need for a high level of participant compliance, as well as the possibility of measurement error associated with changes in body water during the measurement period (Jones et al., 1987). Despite these limitations, DLW analysis remains a valuable tool for monitoring internal load and energy expenditure within specialist tactical populations. Future research should focus on identifying methods to improve the practicality and affordability of DLW analysis, through potentially developing shorter measurement protocols or exploring alternative isotopic tracers. Ultimately, DLW should be used in conjunction with other physiological measures, such as HRV or other biomarkers of metabolic function, to provide a more comprehensive assessment of internal load.

Hormonal Markers

The use of hormone markers to monitor the internal load of specialist tactical populations has been extensively studied, with both acute and chronic exposure to operationally specific activities eliciting marked changes in various physiological processes (Impellizzeri et al., 2019). This dissertation identified eight (n = 8) studies which met the inclusion criteria and utilised the hormone markers to provide insight into the internal load experienced by specialist tactical populations (Conkright et al., 2021; Drain et al., 2017; Friedl et al., 1995; Jouanin et al., 2004; Salonen et al., 2019; Tanskanen et al., 2011a; Tanskanen et al., 2011b; Vikomen et al., 2020). The most common reproductive and metabolic hormones captured by these studies include TST, cortisol (COR), insulin-like growth factor (IGF-1), sex hormone binding globulin (SHBG), thyroid hormones (T3 and T4), and growth hormone (hGH), as presented in Table 5. Hormonal changes have been shown to change in response to military field training (Salonen et al., 2019; Vikomen et al., 2020), operations (Conkright et al., 2021), and BMT or courses (Drain et al., 2017; Friedl et al., 1995; Jouanin et al., 2004; Tanskanen et al., 2011a; Tanskanen et al., 2011b), across various durations, ranging from 5-days (Conkright et al., 2021) to 1-month (Jouanin et al., 2004). These hormonal changes can map periods of physical stress and provide insight to the internal load experienced by these populations.

Table 5.

Hormonal Analysis in Specialist Tactical Populations

Study	COR	TST	IGF-1	SHBG	T3	T4	hGH
Conkright et al. (2021)	x		x				x
Drain et al. (2017)	x	x	x	x			
Friedl et al. (1995)	x	x	x		x		
Jouanin et al. (2004)		x					
Salonen et al. (2019)	x	x		x		x	
Tanskanen et al. (2011a)	x	x					
Tanskanen et al. (2011b)	x	x	x	x			
Vikomen et al. (2020)	x	x	x				
n =	7	7	5	3	1	1	1

COR = cortisol, TST = testosterone, IGF-1 = insulin-like growth factor, SHBG = sex hormone binding globulin, T3 and T4 = thyroid hormones, hGH = growth hormone

TST is an androgenic steroid hormone that plays a crucial role in regulating several physiological processes, including muscle mass, bone density, and immune function. TST is known to fluctuate in response to physical and psychological stress, with acute stressors often resulting in an increase in TST levels (Vingren et al., 2010). Chronic stress or overtraining can lead to a decline in TST levels, resulting in several negative downstream implications for health and performance (Crewther et al., 2011). Further, some authors suggest TST may play a role in cognitive function due to its interaction with the brain (Cherrier et al., 2001; O'Connor et al., 2001; Moffat et al., 2002; Luine et al., 2014), which is of significance for tactical operators due to the importance of decision making within high-stress and arduous situations. Research suggests that TST receptors are present in several areas of the brain responsible for memory and learning (e.g., hippocampus) (Moffat et al., 2002). One theory suggests that TST may increase the number of synapses between neurons and improve communication between the different regions of the brain, allowing for more efficient processing of information (Moffat et al., 2002; Luine et al., 2014). However, it is important to note that the relationship between TST and cognitive function is complex, and more research is needed to fully understand the copious mechanisms involved. Vikomen et al. (2020)

identified a statistically significant effect of time ($p < 0.001$) and a significant sex-time interaction ($p < 0.001$) during a specialist armed forces selection course. The authors also reported initial pre-test TST values to be low (10.6 ± 5.0 nmol.L−1), however, this could be a result of the initial recruit period. These TST values further decreased by 58 ± 11% ($p < 0.001$) 1-day after the selection field exercise and were still reduced by 20 ± 30% ($p < 0.01$) after a 72-hr recovery period. These decreases in TST were also reported across studies, where Salonen et al. (2019) identified a similar significant two-wave decrease in TST values from garrison training to field training exercises ($p < 0.05$–0.001). This significant decrease in TST following arduous selection courses was also reported by Jouanin et al. (2004) who identified plasma TST to have decreased by 28.6 ± 7% ($p < 0.001$). Both Vikomen et al. (2020), Salonen et al. (2019) and Friedl et al. (1994) reported TST concentrations returned to baseline levels following lengthy recovery periods ranging from one (87 ± 75%, $p < 0.001$) to two weeks (Vikomen et al., 2020: 113 ± 73%, $p < 0.001$; Salomen et al., 2019: $p < 0.05$–0.001). As expected, low TST values in women were identified, however, there were no significant changes reported across the duration of the selection course (Vikomen et al., 2020). Conversely, only one study included in this dissertation identified no significant decreases in TST values (Tanskanen et al., 2011b). Reporting increases in basal TST in response to exercise at each time point throughout the study ($p < 0.05$-0.001; Tanskanen et al., 2011b). While there is still much to learn about the relationship between TST, internal load, and performance within specialist tactical populations, early evidence suggests that monitoring TST levels may be useful for optimising performance and reducing the risk of negative health outcomes.

COR is a hormone released by the adrenal glands in response to stress (Gunnar et al., 2007). It is an important component of the body's stress response system, known as the hypothalamic-pituitary-adrenal (HPA) axis, which regulates the body's physiological response to stress (Gunnar et al., 2007). COR plays a critical role in the body’s ability to tolerate stress, and is involved with increasing glucose availability, suppressing immune function, and altering brain function to enhance arousal and vigilance (Gunnar et al., 2007; Liao et al., 2015; Miller et al., 2007). Furthermore, COR has also been implicated in decision-making processes. Some research has identified COR levels to impact components of cognition such as attention, memory, and emotional regulation (Lupien et al., 2009; Schwabe et al., 2013). Specifically, elevated

COR levels have been associated with impaired cognitive performance, particularly in tasks that require executive function and working memory (Lupien et al., 2009; Schwabe et al., 2013), both of which are fundamentally critical in the operational tasks of specialist tactical populations. Tanskanen et al. (2011b) reported a main effect of BMT was the significant TST:COR ratio ($p < 0.05$), which increased from weeks four to seven ($p < 0.01$). Moreover, serum COR increased significantly over this period ($p < 0.01$), however, the individual COR response variations ranged from -48 to 107%. Significant variation in COR response may be due to several factors, including individual baseline differences (Miller et al., 2007), fitness levels (Liao et al., 2015; Miller et al., 2007), and coping mechanisms (Miller et al., 2007). Other COR responses include two studies reporting a significant time interaction for COR to training (Drain et al., 2017: $p < 0.01$; Vikomen et al., 2020: $p < 0.001$), and identified a significant sex-time interaction for COR ($p < 0.001$). Reporting baseline COR levels to be lower in women when compared to men prior to starting an arduous selection course ($p < 0.01$) (Vikomen et al., 2020). Typically, COR levels increase during physical training and exercise, with studies reporting responses ranging from 26% in men ($p < 0.001$) (Vikomen et al., 2020), to 69% when averaged across sex and time ($p < 0.001$) (Conkright et al., 2021), and by 166 ± 93% ($p < 0.001$) in women (Vikomen et al., 2020). Similar to TST, COR levels in men typically returned to baseline or pre-test values following a period of recovery (Salonen et al., 2019; Vikomen et al., 2020). However, Vikomen et al. (2020) reported COR levels in women remained elevated by 153 ± 96% ($p < 0.001$) after the entire two-week recovery period. COR levels may remain elevated following BMT or a selection course due to the body's natural response to stress. The HPA axis is responsible for regulating COR release and can take some time to return to baseline following a stressful event (Gunnar et al., 2007). Additionally, if the body continues to perceive a threat, COR levels may remain elevated as a protective mechanism (Gunnar et al., 2007). Furthermore, some research suggests that females may have stronger COR responses to stress compared to males (Kudielka et al., 2004), which could explain the higher and prolonged COR levels following a selection course.

IGF-1 plays a crucial role in the regulation of cellular growth and metabolism, particularly in skeletal muscle and bone tissue (Bamman et al., 2007). IGF-1 is structurally similar to insulin and is primarily produced in the liver in response to hGH stimulation (Bamman et al., 2007). It is well established that IGF-1 response can be directly impacted by various forms of stress, including physical exercise, psychological stress, and sleep deprivation (McEwen & Karatsoreos, 2015). Given the unique demands and environmental conditions specialist tactical operators are required to work within, tracking IGF-1 may provide critical insight into their internal load and stress levels, particularly in regard to muscular recovery and growth. Similar to TST and COR, multiple studies have reported significant sex-time interactions with IGF-1 (Conkright et al., 2021; Vikomen et al., 2020). Women have been reported to have significantly higher IGF-1 levels prior to starting military field exercises ($p < 0.01$) (Vikomen et al., 2020), and the IGF-1 response to field exercises was significantly different between men and women ($p < 0.001$), with women having a much steeper decline compared to men ($p = 0.001$) (Conkright et al., 2021). The specific response of IGF-1 to stress and exercise varies, but all studies report significant decreases across time ($p < 0.001$-0.01) (Conkright et al., 2021; Drain et al., 2017; Friedl et al., 1995; Tanskanen et al., 2011b; Vikomen et al., 2020). Following a recovery period, IGF-1 typically increases gradually, with studies reporting increases of 46 ± 19% ($p < 0.05$) after one week and 69 ± 29% after two weeks ($p < 0.001$) (Vikomen et al., 2020) and a "substantial" rebound after five weeks (Friedl et al., 1995). Drain et al. (2017) identified an interesting IGF-1 interaction ($p < 0.05$) in operators who completed an experimental physical training regimen during BMT. These operators experienced a decrease in physiological stress, indicated by an attenuated reduction in IGF-1 levels, suggesting a reduced stress response. This observation could potentially translate to enhanced adaptation to training. However, the study also reported other training-induced changes, including a decrease in basal serum IGF-1 levels, increased COR, and increased SHBG, which may reflect a maladaptive physiological state.

One of the main limitations of hormonal monitoring surrounds the controversy of hormone markers as an indicator of internal load. Some authors suggest that these biochemical markers may not always directly measure the internal load of an individual, but instead reflect the downstream responses that occur as a result of training load (Impellizzeri et al., 2019; Michael et al., 2022). Additionally, these hormonal changes can be influenced by other variables, including sleep deprivation, illness, and nutrition, which can potentially affect the interpretation of results (Nindl et al., 2012).

Furthermore, specialist tactical populations often experience multiple stressors simultaneously, including sleep deprivation, inadequate nutrition, and exposure to environmental extremes (Alvar et al., 2017). The interactions between these stressors can have a cumulative effect on the body that may not be reflected solely by hormone markers (Nindl et al., 2012). Therefore, while hormone markers may provide valuable information about the physiological responses to training and stress in tactical environments, it is important to consider the limitations and potential confounding factors associated with their use.

Metabolites

The tracking of blood lactate and glucose levels as a measure of internal load has gained popularity in recent years as a tool for monitoring training load in athletes, as discussed in Chapter 2. The use of this method has expanded beyond traditional sporting contexts and into tactical populations. Lactate and glucose monitoring has been extensively studied in athletes, with several studies demonstrating its effectiveness in monitoring training load and improving performance (Greenham et al., 2018). However, there are only a few studies utilising lactate and glucose levels in specialist tactical populations as presented in Table 6. This dissertation identified seven (n = 7) studies which met the inclusion criteria and utilised lactate and glucose markers to provide insight into the internal load experienced by specialist tactical populations (Hormeño-Holgado et al., 2019; Sánchez-Molina et al., 2018; Tanskanen et al., 2011; Tanskanen et al., 2011; Tornero-Aguilera et al., 2017; Tornero-Aguilera et al., 2018; Winters et al., 2021).

Table 6.

Metabolite Analysis in Specialist Tactical Populations

Study	Lactate	Glucose
Hormeño-Holgado et al. (2019)	x	x
Sánchez-Molina et al. (2018)	x	x
Tanskanen et al. (2011a)	x	
Tanskanen et al. (2011b)	x	
Tornero-Aguilera et al. (2017)	x	
Tornero-Aguilera et al. (2018)	x	x
Winters et al. (2021)	x	
n =	7	3

Typically, studies report significant increases in blood lactate and glucose concentrations following combat simulations (Sánchez-Molina et al., 2018; Tornero-Aguilera et al., 2018), and training exercises (Tanskanen et al., 2011a; Tanskanen et al., 2011b). Specifically, Sánchez-Molina et al. (2018) reported significant blood lactate increases following a combat simulation in both heavy ($p = 0.002$) and light ($p < 0.001$) infantry groups, with blood lactate levels above the anaerobic threshold in both groups. Similarly, Tornero-Aguilera et al. (2018) reported significant increases in blood lactate and blood glucose levels following combat simulations ($p < 0.05$). Additionally, a comparison of physiological responses between lower-trained and highly-trained operators revealed that highly-trained operators had significantly higher blood lactate levels post combat simulation when compared to lower-trained operators (6.8 ± 1.5 $nmol.L^{-1}$ and 1.9 ± 1.7 $nmol.L^{-1}$ respectively ($p < 0.001$)), indicating a higher level of physical intensity during the combat simulation. These results suggest that highly trained operators are more capable of enduring intense physical activity, which is a crucial factor in their ability to perform their duties effectively. Tanskanen et al. (2011a) reported that overreaching subjects had a decrease in the maximal blood lactate:RPE ratio in the VO_2max test, from baseline to the end of BMT, whereas non-overreaching subjects did not experience this change. In contrast, Tanskanen et al. (2011b) found a blunted submaximal exercise-induced increase in blood lactate levels during the second half of BMT. The study suggested that the change in hormone levels, with an increase in basal SHBG and a decrease in COR levels, may have affected the body's response to exercise due to the reduction in glucose availability from the COR decrease.

Furthermore, Tanskanen et al. (2011b) also reported a decrease in HR_{max} during exercise, which may limit the ability to produce lactate and lead to a blunted blood lactate response. Finally, Tornero-Aguilera et al. (2017) found a negative correlation between post-lactate concentrations and pre-HR, indicating that soldiers with higher fitness levels (supported by lower pre-HR) could achieve higher metabolic activation in combat situations. These results highlight the importance of incorporating training principles that improve exercise capacity and efficiency within the overall training program for tactical populations.

Cognition

Specialist tactical populations are tasked with operating in extremely challenging environmental conditions that place significant physiological demands on their bodies, as discussed in the previous sections (Alvar et al., 2017). These conditions often comprise a multitude of stressors, including physical and psychological demands, as well as limited sleep and reduced calorie intake (Friedl et al., 1995; Johnson et al., 2018; Margolis et al., 2014; Nindl et al., 2002; Tait et al., 2022). Furthermore, the occupational tasks of these groups typically require shift/night work, prolonged working hours, with minimal turnaround between shifts and missions (Friedl et al., 1995; Johnson et al., 2018; Tait et al., 2022; Tomes et al., 2021), which can result in inadequate recovery and sleep deprivation (Bannai & Tamakoshi, 2014; Nindl et al., 2007). The ability to maintain high levels of cognitive performance under psychological and physiological duress is of the utmost importance for specialist tactical populations in maintaining their operational readiness (Tomes et al., 2021). Recent research has extensively reviewed the cumulative effect of sleep deprivation on marksmanship. Studies have reported various negative impacts on marksmanship accuracy (Head et al., 2017), impaired target identification (Smith et al., 2019), and an increased likelihood of errors in judgement (Harrison et al., 2017). Furthermore, Thomas and Russo (2007) identified that decrements in cognition could be attributed to approximately 80 to 85% of all accidents in the military. These findings highlight the significant risks associated with fatigue and its impact on cognition, particularly in high-stakes environments. It is crucial for practitioners and decision-makers to understand the intricate relationship between fatigue and cognition in order to effectively monitor and mitigate potential risks, while also recognising the potential for cognitive recovery following periods of prolonged sleep deprivation and stress (Tait et al., 2022).

The process of assessing cognition typically involves the utilisation of various measurement tools such as standardised tests, questionnaires, interviews, and observational measures (Jaarsveld & Lachmann, 2017; Stewart et al., 2012). These assessment instruments vary in complexity and specificity but are designed to measure specific cognitive domains accurately and reliably. Examples of these domains include attention, working memory, language, perception, executive function, processing speed and reaction, visuomotor performance, spatial abilities, reasoning, and problem solving (Almonroeder et al., 2020; Belenky et al., 2003; Harrison & Horne, 2000; Jaarsveld & Lachmann, 2017; Lim & Dinges, 2010; Shattuck et al., 2018; Stewart et al., 2012; Tait et al., 2022; Van Dongen et al., 2003).

The influence of fatigue on decision-making and cognitive processing has been extensively reviewed in athletic populations (Almonroeder et al., 2020). However, there is limited research on cognition as a monitoring tool within tactical populations. This dissertation identified five (n = 5) studies which met the inclusion criteria and utilised cognitive assessment(s) to provide insight into the internal load experienced by specialist tactical populations (Friedl et al., 1995; Hormeño-Holgado & Clemente-Suárez, 2019; Sánchez-Molina et al., 2018; Tait et al., 2022; Tornero-Aguilera et al., 2018). Of these studies, three monitored the cognitive anxiety and emotional response during combat simulations (Hormeño-Holgado & Clemente-Suárez, 2019; Sánchez-Molina et al., 2018; Tornero-Aguilera et al., 2018), two measured memory following combat simulations (Hormeño-Holgado & Clemente-Suárez, 2019; Tornero-Aguilera et al., 2018), and two utilised neurobehavioural tests during and following intensive military training courses (Friedl et al., 1995; Tait et al., 2022). The domains of cognition measured across these two studies include: attention, complex scanning, information processing, perceptual processing, psychomotor speed, reasoning, visual object learning, visual tracking, visuospatial orientation, vigilant attention, and working memory (Friedl et al., 1995; Tait et al., 2022).

Cognitive anxiety is associated with excessive worry, fear, and negative thoughts related to performance or evaluation in a specific task or situation (Gelenberg, 2000; Martens, Vealey, & Burton, 1990). Furthermore, it is a type of anxiety response that primarily affects cognitive functions such as attention, working memory, and decision-making (Eysench et al., 2007). Combat simulations aim to replicate the high-pressure and stressful conditions that operators may experience within real combat environments (Clemente-Suárez et al., 2013; Conkright et al., 2021; Hormeño-Holgado & Clemente-Suárez, 2019; Jouanin et al., 2004; Sánchez-Molina et al., 2018; Tornero-Aguilera et al., 2018). Therefore, cognitive anxiety can be a useful measure of internal load, as it allows for an assessment of how operators are affected by the psychological stressors associated within combat simulations (Tornero-Aguilera et al., 2018). The three studies included in this dissertation utilised the Cognitive State Anxiety Inventory-2 Revised (CSAI-2R) test to assess cognitive anxiety, somatic anxiety, and self-confidence (Cox, Martens, & Russell, 2003; Swann et al., 2012). The CSAI-2R utilises a response scale ranging from 1 to 4, with descriptors ranging from “not at all” to “very much,” to evaluate the intensity of each symptom (Cox, Martens, & Russell, 2003). Higher scores on the response scale for cognitive and somatic anxiety indicate elevated levels of anxiety, while higher scores for self-confidence indicate greater levels of self-confidence (Hormeño-Holgado & Clemente-Suárez, 2019; Sánchez-Molina et al., 2018; Tornero-Aguilera et al., 2018).

All three studies included in this dissertation reported an increase in somatic anxiety following both land and air combat simulations (Hormeño-Holgado & Clemente-Suárez, 2019; Sánchez-Molina et al., 2018; Tornero-Aguilera et al., 2018). Somatic anxiety refers to the physical symptoms of anxiety, such as increased HR or sweating (Tornero-Aguilera et al., 2018), therefore, the observed increase can be attributed to the intense physical and psychological demands of the combat simulations (Hormeño-Holgado & Clemente-Suárez, 2019). However, the findings related to cognitive anxiety among tactical operators varied across the studies. Sánchez-Molina et al. (2018) and Tornero-Aguilera et al. (2018) reported increases in cognitive anxiety, while Hormeño-Holgado and Clemente-Suárez (2019) identified significant decreases. As cognitive anxiety is associated with worry, fear, and negative thoughts related to performance (Gelenberg, 2000), this decease could likely be contributed to the operator’s experience level (Hormeño-Holgado & Clemente-Suárez, 2019). The pilots who exhibited significant decreases in cognitive anxiety were classified as elite, which suggests their expertise and familiarity likely contributed to this result (Hormeño-Holgado & Clemente-Suárez, 2019). This finding is reiterated in the results from Sánchez-Molina et al. (2018), who reported differences in cognitive anxiety responses between units. The authors noted that the unit with the lower anxiety response had trained under similar contexts as the simulation (Sánchez-Molina et al., 2018). These findings collectively suggest that training and experience can influence anxiety levels and overall emotional self-regulation during combat simulations.

Research has established that sleep restriction and total sleep deprivation can have detrimental effects on various aspects of cognitive function including working memory, attention, visuomotor performance, vigilance, reaction time, and decision-making (Belenky et al., 2003; Shattuck et al., 2018; Van Dongen et al., 2003; Lim & Dinges, 2010; Harrison & Horne, 2000). These effects tend to accumulate over consecutive days of insufficient sleep. The two studies included in this dissertation monitored the cognitive function and recovery of the course of an intensive training course (Friedl et al., 1995; Tait et al., 2022). The study conducted by Friedl et al. (1995) aimed to examine the cognitive performance of candidates participating in the U.S. Army Ranger Course, which involves intensive training under demanding conditions. The course consists of four distinct phases spanning approximately two weeks, where candidates undergo rigorous training across a diverse range of environmental settings (forest, desert, mountain, and swamp). The primary objective of the course is to push candidates to their physical, psychological, and emotional limits. To achieve this, the course intentionally restrict sleep (approximately 3.6-hrs per day for 8-weeks) and caloric intake (approximately 1000-kcal.day^{-1}) throughout its duration (Friedl et al., 1995).

During this study, candidates were prescribed a battery of cognitive assessments designed to measure specific cognitive domains including decoding (information processing), pattern analysis (perceptual processing), reasoning (inferential logic), and memory (Friedl et al., 1995). Surprisingly, the ability to memorise and retain words appeared to be relatively unaffected by the severe calorie and sleep deprivation (Friedl et al., 1995). However, tasks requiring higher-order processing, such as decoding and pattern analysis were significantly impaired under these stressors (Friedl et al., 1995). Notably, these cognitive processes demonstrated a capacity for recovery during the brief two-day recovery periods. In contrast, reasoning tasks were significantly impacted from the sleep and caloric restriction ($p < 0.02$) (Friedl et al., 1995). Where performance only returned to baseline levels following the post-training assessment, where sleep and food were unrestricted (Friedl et al., 1995). These findings suggest that while simple cognitive functions exhibit resilience and can recover during short periods, the more complex cognitive processing (e.g., reasoning) are more susceptible to the negative effects of sleep and caloric deprivation.

Similar findings were reported in the study conducted by Tait et al. (2022), who aimed to assess the impact of an intensive training exercise on cognition within Australian Army Soliders (n = 57). The primary training exercise of this study started with four-days living in the field, where soldiers engaged in operational tasks such as digging trenches, simulated contacts, and patrols (Tait et al., 2022). This exercise was intentionally designed to restrict opportunities for sleep and include one night of total sleep deprivation. Following the field training, the exercise transitioned into four-days of simulated combat exercises where soldiers experienced disrupted and restricted sleep (Tait et al., 2022). For the final three-day recovery phase, soldiers returned to their accommodation and participated in light activities with regular sleep opportunities. Neurobehavioral testing of cognition incorporated five tests that measured the following domains: psychomotor speed, visual tracking, working memory, visual object learning, visuospatial orientation, attention, complex scanning, psychomotor speed, and vigilant attention (Tait et al., 2022). Several of these domains were identified to be significantly impaired following the night of total sleep deprivation, including psychomotor speed, reaction time, visual scanning and tracking, visuospatial orientation, and attention tasks (Tait et al., 2022). However, reaction times and visuospatial orientation scores returned to baseline levels within two-days following the field-training phase and during the simulated combat phase of restricted sleep. These findings suggest that accumulating approximately 15-hrs of sleep over a 96-hr period is effective in alleviating most cognitive deficits. (Tait et al., 2022). Furthermore, the authors highlight the significance of reaction time as a critical cognitive ability and suggest its potential as a predictor of operational readiness (Tait et al., 2022).

Understanding the intricate relationship between fatigue, cognition, and performance is essential for practitioners and decision-makers working with specialist tactical populations. Monitoring cognitive performance provides valuable insights into the impact of stressors, recovery, and potentially operational readiness (Tait et al., 2022). By identifying the specific cognitive domains impaired by the realities of operational contexts, practitioners can implement appropriate recovery strategies, and potentially mitigate catastrophic risks.

3.3.5. Summary and Conclusion

This chapter examined the internal and external load monitoring strategies employed within specialist tactical populations. Highlighting the significant physiological and psychological loads specialist tactical populations face during their typical operational tasks. The reviewed literature has provided valuable insight into the importance of implementing both internal and external load monitoring strategies into management systems. As monitoring external load provides valuable insight into the work completed by operators, internal load provides insight into the internal biological response induced by the external stimulus (Soligard et al., 2016). It is worth noting, no single marker can accurately predict or detect overtraining and maladaptation (Bourdon et al., 2017; Greenham et al., 2018; Maupin et al., 2018; Soligard et al., 2016). Therefore, it is recommended to employ a multivariate approach that integrates various internal and external monitoring methods (Bourdon et al., 2017; Michael et al., 2022). This will enable a comprehensive understanding of individual responses and subsequent adaptations and provide practitioners valuable information to guide training prescription and potentially identify markers of fatigue and operational readiness. This comprehensive review of the monitoring strategies utilised within specialist tactical populations provides a foundation for informed decision-making and load management within specialist tactical populations. A summary of these monitoring methods is presented in Table 7.

Table 7.

Monitoring Methods in Specialist Tactical Populations

Authors and year	Study title	Participants	Aim of study/assessment	Monitoring Method	Duration	Main outcomes
Blacker et al. (2009)	Gender differences in the physical demands of British Army recruit training	54 army recruits from 3 different platoons. (male = 26, female = 28)	To examine the difference in physiological demands and adaptations between male and female soldiers during Comprehensive Soldier Fitness (Resilience) in single-gender or mixed-gender platoons, and identify potential reasons for higher injury rates among female soldiers in training.	Internal: HR External: Accelerometers, anthropometrics, DLW	12 weeks	No significant difference in physical activity was observed between platoons or genders ($p > 0.05$). Males in mixed-gender platoons exhibited lower cardiovascular strain compared to females due to higher aerobic fitness ($p < 0.001$). Male recruits in mixed-gender platoons had lower cardiovascular strain than their counterparts in male-only platoons. Female recruits experienced similar levels of cardiac stress, regardless of platoon type ($p = 0.814$). Additional cardiovascular load on female recruits could increase fatigue and predispose them to overuse injuries.
Canino et al. (2020)	Quantifying Training Load During Physically Demanding Tasks in U.S. Army Soldiers: A Comparison of Physiological and Psychological Measurements	61 army soldiers (male = 33, female = 28)	To assess the correlation between total relative oxygen uptake during three “soldiering” tasks and two field-expedient measures of training load: summated HR zone and sRPE.	Internal: HR, oxygen uptake, sRPE	3 activities (<6hrs)	Summated HR zone and sRPE can be used as alternatives to total relative oxygen uptake to measure and monitor training load during soldiering tasks.
Clemente-Suárez et al. (2013)	Mechanical, Physical, and Physiological Analysis of Symmetrical and	20 soldiers from the Spanish Army and Spanish Forces	To assess physical, mechanical, and physiological parameters during both symmetrical	Internal: HR External: GPS	2 days (2x activities)	Differences observed between symmetrical and asymmetrical combat: asymmetrical combat presented higher maximum velocity movement, number of sprints, sprint distance, and average HR. Symmetrical

	Asymmetrical Combat	and Security Corps	and asymmetrical combat simulations.			combat presented higher number of impacts and body load.
Conkright et al. (2021)	Neuromuscular Performance and Hormonal Responses to Military Operational Stress in Men and Women	69 Defence force service members	To compare physical performance and hormone levels in men and women exposed to a 5-day simulated military operational stress and assess the relationship between self-reported and objective measures of allostasis with physical performance.	Internal: Lower-limb strength, Tactical mobility test, Blood biomarkers, Female sex hormones External: Questionnaires, Sleep and caloric intake	5 Days	Significant differences across neuromuscular performance and hormonal responses
Drain et al. (2017)	Hormonal response patterns are differentially influenced by physical conditioning programs during basic military training	75 army recruits (male = 51, female = 24)	To compare the effect of traditional and contemporary military physical training on hormones and body composition in recruits and to determine if high-load/ high-intensity training reduces stress hormone response.	Internal: Hormones concentrations (IGF-I, TST, COR and SHBG) External: Body composition	12 weeks	Significant group × time interaction for IGF-I and COR, main effects over time for IGF-I, COR and SHBG, main effects for time for lean mass and fat mass changes, and a correlation between initial aerobic fitness and TST concentration during weeks 1 & 12. Lower PAC values occurred among those who completed the higher load/intensity program compared to those on traditional military conditioning regimen.
Friedl et al. (1995)	Acute Recovery of Physiological and Cognitive Function in U.S. Army Ranger Students in a Multistressor Field Environment	Unclear	To present the physiological deamands of soldiers during and after completing the U.S. Army Ranger course.	Internal: Cognitive function, Metabolic stress markers, Energy metabolism, Protein status, Immunological function External: Energy expenditure, Caloric intake, Physical load	8 weeks	With a modest increase in sleep and energy intake for 7 days, soldiers demonstrated recovery of some cognitive function and acute metabolic/stress markers.

George et al. (2015)	Assessing the Effect of Long Term Physical Training and Classification of Training Status using HRV and HRR of Female Police Recruits	60 Police recruits	To investigate the impact of nine months of basic police training on HRV and HR recovery in female police recruits, and determine whether HRV/HR recovery measurements could accurately classify trainees as trained or untrained.	Internal: HRV	9 months	Basic police training can alter the cardiovascular system and HRV/HR recovery. Five-min supine HRV recordings and post-exercise recovery features can classify recruits into trained or untrained status with 89.7% accuracy. Genetic algorithm optimization techniques can reduce feature sets for HRV and HR recovery by 50% and 68.5%, respectively while still maintaining high classification accuracy rates.
Grant et al. (2016)	The difference between exercise-induced autonomic and fitness changes measured after 12 and 20 weeks of medium-to-high intensity military training	154 Military recruits	To compare the physical fitness of South African National Defence Force personnel after 12 weeks and 20 weeks of training using VO_2max and HRV as indicators.	Internal: HRV External: PT program components	20 weeks	Significant increase in VO_2max during weeks 1-12 No changes in supine and standing HRV
Hormeño-Holgado et al. (2019)	Effect of different combat jet manoeuvres in the psychophysiologica l response of professional pilots	29 fighter pilots	To investigate the impact of attack and defence air combat manoeuvres on the psychophysiological response of fighter pilots.	Internal: HR, HRV, leg and hand strength, spirometry, temperature, blood oxygen saturation, lactate, hydration, cortical activation, memory and psychological variables	approx. 35min	The defensive manoeuvre produced a decrease in forced vital capacity and an increase in mean HR, Stress Subjective Perception and RPE. It also resulted in a moderate effect in the decrease of cognitive anxiety and an increase in leg strength.

Irving et al. (2019)	Profiling the Occupational Tasks and Physical Conditioning of Specialist Police	Survey: 132 respondents Operational members of the Australian and New Zealand Police Tactical Groups	To investigate the physical fitness regimes undertaken by specialist police officers and establish the nature and context of their assigned tasks.	External: Occupational tasks, nature and environment, external load carriage, physical training [S&C]	N/A	The occupational task most commonly recently undertaken was a high-risk warrant execution followed by rural operations. The external load was carried in all operational circumstances, with loads typically 21-25 kg. All officers undertook regular physical training.
Johnson et al. (2018)	Energy expenditure and intake during Special Operations Forces field training in a jungle and glacial environment	29 Special Forces Operators	The study aimed to compare energy requirements of Special Operations Forces (SOF) in different environments and assess their macronutrient intakes.	External: DLW	3 separate training sessions, 2 in a hot environment (n = 21) and 1 in a cool environment (n = 8). Each mission lasted an average of 4.76 days.	Total energy expenditure was similar in hot and cool environments. Energy intake was higher in the cooler environment. Greater attention should be paid to feeding practices during field training missions for Special Operations Forces.
Jouanin et al. (2004)	Analysis of Heart Rate Variability after a Ranger Training Course	23 cadets of the French military academy	The aim was to investigate whether HRV could indicate fatigue.	Internal: HRV, HR, hormones (TST)	1 month	TST level fell by approximately 28.6 +/- 7%, indicating a high level of fatigue. During the stand test, the total power (TP) of the HRV spectrum increased in a supine position
Jurvelin et al. (2020)	Training Load and Energy Expenditure during Military Basic Training Period	34 male conscripts	The study aimed to compare training load and energy expenditure among individuals with different fitness levels during military basic training.	Internal: Anthropometrics, HR, VO2max External: physical activity, energy expenditure	8 weeks	Training load of BMT was comparable to training of competitive athletes at the highest level. The training groups differed in terms of VO2max to each other. The inactive group were the most loaded during the study period. The PA intensity of different military tasks during the BMT period were low or moderate (<6 METs).

Knapik et al. (2007)	Ambulatory physical activity during United States Army Basic Combat Training	57 army trainees (male = 33, female = 24)	The researchers aimed to investigate ambulatory physical activity during US Army Basic Combat Training, comparing activity levels among trainees in different training phases and genders.	External: accelerometers/ pedometers	61 days	Physical activity levels in US Army Basic Combat Training vary significantly between genders and training phases. Men generally have higher step counts, estimated distances traveled, and average step lengths than women. The highest level of ambulatory physical activity was observed during field exercises.
Lockie et al. (2020)	Training load demands measure by surface electromyography wearable technology when performing law enforcement-specific body drags	11 physically active civilians/students (male = 8, female = 3)	The study aimed to determine if training load and muscle activation patterns required to drag different weight dummies changed during a drag task in recreationally-trained males and females.	Internal: sEMG External: total training load TL	3 days	Quadricep TL was 9% greater, and Gluteus maximus TL was 8% lower in the 90.72 kg body drag compared to the 74.84 kg drag. There were no between-mass differences in time, Bicep femoris TL, total TL, or the ratios. Quadricep TL increased while Glute max TL decreased when participants dragged a 90.72 kg dummy. As drag time was not different between the masses, drag mechanics may have changed leading to increased Quad TL.
Nikolova et al. (2007)	Psychophysiological Assessment of Stress and Screening of Health Risk in Peacekeeping Operations	72 male peace-keepers of the Bulgarian armed forces (w/ a control group [n=61])	To assess the impact of stress on cardiovascular control and health risks among Bulgarian peacekeepers during a PKM in Kosovo.	Internal: HRV, cognitive load (personal interviews), and questionnaires	6 months (pre and post)	Observed reductions in parasympathetic function and baroreceptor modulation of heart rhythm.
O'Leary et al. (2018)	Sex Differences in Training Loads during British Army Basic Training	59 British Army recruits (male = 31, female = 28)	To compare training loads between male and female British Army recruits during 14 weeks of standard entry basic training.	Internal: HR, TRIMP, RPE External: Distance, RPE	14 weeks	Men covered more daily distance, but average daily HR and RPE were similar between men and women. Women had higher daily TRIMP and men had higher total energy expenditure during weeks 1-2 and 12-13. Daily RPE, HR, and TRIMP were related to daily distance, and daily RPE was related to daily TRIMP and HR.

Ojanen et al. (2018)	Changes in Physical Performance During 21 d of Military Field Training in Warfighters	49 male conscripts	To examine neuromuscular performance and physical activity changes among male Finnish Army conscripts during a 21-day military field training, and subsequent recovery over 4 days.	Internal: body composition External: Accelerometery, physical activity, performance measures	21 days	Physical activity levels increased during active duty compared to garrison days, but body mass, skeletal muscle mass, and fat mass decreased during military field training. Muscular endurance declined significantly, while 3.2 km loaded march time remained unchanged.
Palvina et al. (2021)	Antioxidative system capacity after a 10-day-long intensive training course and one-month-long recovery in military cadets	42 cadets (2 females and 40 males)	To evaluate markers of oxidative stress and muscle damage in military cadets after a 10-day intensive training course and a one-month recovery.	Internal: Blood biomarkers	10 days	The intensive training caused increased muscle damage and oxidative stress, but there were no changes in three parameters of antioxidative system.
Richmond et al. (2012)	Comparison of the physical demands of single-sex training for male and female recruits in the British Army	60 army soldiers (male = 30, female = 30)	To compare physical demands and progression of basic training for male and female British Army recruits in single-sex platoons during a 14-week training course.	Internal: HR, physical performance External: Energy expenditure, physical activity, accelerometery	14 weeks	Physical demands and progression of basic training were similar for male and female British Army recruits in single-sex platoons, except for male recruits having 12% higher physical activity counts than females.
Richmond et al. (2014)	Energy balance and physical demands during an 8-week arduous military training course	40 male soldiers	Analyse the physical demands and energy balance of soldiers during the final 8 weeks of the 15-week SCBC	Internal: HR External: DLW, accelerometery, physical activity	8 weeks	Soldiers in Section Commanders' Battles Course experienced high physical demands and energy deficit, resulting in body mass and fat mass loss.
Salonen et al. (2019)	Neuromuscular Performance and Hormonal Profile During Military Training and Subsequent Recovery Period	20 healthy male soldiers	Investigate the effects of garrison and field military service on neuromuscular performance and hormonal profile and	Internal: Hormones (COR, TST, SHBG), neuromuscular	15 days	Neuromuscular performance can be maintained during short-term garrison and field training despite a decrease in hormonal profile, and hormonal responses during field training are greater than garrison training, but three days of recovery

			assess the effects of a 3-day recovery			in free-living conditions are sufficient for hormonal recovery.
Sánchez-Molina et al. (2018)	Assessment of psychophysiological response and specific fine motor skills in combat units	31 male soldiers of the Spanish Army	Analyse psycho-physiological response and specific motor skills in an urban combat simulation with two infantry units	Internal: HR, blood oxygen saturation, metabolites (glucose and lactate), cortical activation, anxiety and HRV	unclear	Combat simulation alters the psycho-physiological basal state in soldiers but has no effect on fine motor skills.
Tait et al. (2022)	Recovery of Cognitive Performance Following Multi-Stressor Military Training	57 Australian Army soldiers (54 men, 3 women)	Assess the impact of an 8-day military training exercise on cognitive performance and track its recovery during reduced training load and partially restored sleep.	Internal: Cognitive function, sleep, RPE	16 days	Cognitive tests are sensitive to sleep restriction and recovery, and they can help assess operational readiness in military personnel.
Tanskanen et al. (2011b)	Serum sex-hormone binding globulin and cortisol concentrations are associated with overreaching during strenuous military training	57 Military males	Investigate the impact of an 8-week Finnish military basic training period (BT) on physical fitness, body composition, mood state, and serum biochemical parameters in new conscripts. Additionally, determine the incidence of overreaching (OR) and evaluate whether initial levels or training responses differ between OR and noOR subjects.	Internal: biochemical markers, mood state, RPE External: training load estimation, RPE	8 weeks	Found that physical demands and progression of basic training were similar between male and female British Army recruits. However, male recruits had higher physical activity counts than females.

Tanskanen et al. (2011a)	Association of Military Training with Oxidative Stress and Overreaching	57 male conscripts	To investigate the effects of an 8-week Finnish military basic training period on physical fitness, body composition, mood state, and serum biochemical parameters, as well as to determine the incidence of overreaching and evaluate the differences in initial levels or training responses between OR and no OR subjects.	Internal: HR, VO2max, Hormone (COR, TST, IGF-1) External: RPE	8 weeks	Improved VO2max during first 4 weeks of BT, with increases in SHBG and decreases in IGF-1 and COR. Blunted submaximal exercise-induced increases in COR, HRmax, and post-exercise increase in blood lactate. 33% of subjects were classified as overreached with higher SHBG and a decrease in maximal La/RPE ratio.
Tomes et al. (2021)	Field Monitoring the Effects of Overnight Shift Work on Specialist Tactical Police Training with Heart Rate Variability Analysis	11 male specialist police officers	Investigate the effects of overnight shift on HRV of specialist police during firearms training and assess the feasibility of using HRV monitoring in tactical police organizations.	Internal: HRV	1 day	HRV may be a useful metric for quantifying load in tactical police organizations and can be measured in situations where data can be used for decision-making in real-time.
Tornero-Aguilera et al. (2017)	Effect of Combat Stress in the Psychophysiological Response of Elite and Non-Elite Soldiers	40 war fighters	Analyse the impact of combat stress on the psychophysiological responses of elite and non-elite soldiers.	Internal: HR, lactate, COR, strength	unclear	Elite soldiers had significantly higher lactate concentration after combat compared to non-elite soldiers. Non-elite soldiers had higher pre- and post-simulation heart rates than elite soldiers. Elite soldiers had higher lower muscular strength than non-elite soldiers in all tests and before/after the combat simulation. Cortical arousal was not significantly different between the two groups.

Tornero-Aguilera et al. (2018)	Use of psychophysiological portable devices to analyse stress response in different experienced soldiers	49 soldiers of Spanish Army	Analyse the effect of experience and training on psychophysiological response, attention, and memory of soldiers in combat.	Internal: Metabolites (lactate, glucose), oxygen saturation, body temp, HR, strength, autonomic modulation, cortical arousal, cognitive and somatic anxiety, and memory	unclear	Higher experienced soldiers showed higher physiological activation and cognitive/memory impairment than lower experienced soldiers after a combat simulation. Memory function was affected by the nature of the stimulus.
Vikmoen et al. (2020)	Sex differences in the physiological response to a demanding military field exercise	35 Forces Special Command Conscripts (male = 23, female = 12)	Investigate sex differences in acute effects of military field exercise on explosive strength, anaerobic performance, body composition, and blood biomarkers, and examine recovery in both men and women.	Internal: neuromuscular, physical performance, hormones (COR, TST, IGF-1) External: body composition	6 weeks	Military field exercises result in significant losses in body mass, fat and muscle mass. The impact is greater on women than men in terms of explosive strength and anaerobic performance. Recovery process is slower in females than males. Monitoring methods used included anthropometric measurements, DXA scans, and blood biomarkers.
Wilkinson et al. (2008)	A physical demands analysis of the 24-week British Army Parachute Regiment recruit training syllabus	50 Parachute Regiment recruits	The aim of this study was to assess the physical demands of the 24-week Combined Infantryman's Course (CIC) for Parachute Regiment (Para) recruits, develop physical selection standards, and recommend modifications to reduce injury rates and maximize benefits.	Internal: DLW, %HR reserve External: Accelerometery	24 weeks	No overall progression in physiological stress during the first 9 weeks of training. 2.4 km run time and static lift strength predicted 10 mile loaded march performance. Job-related selection procedures and a more progressive approach to training reduced medical discharge rates from 14.4% to 5.1% and increased pass rates from 43% to 58%.

Winters et al. (2021)	Altered Physical Performance Following Advanced Special Operations Tactical Training	73 United States Marine Corps Forces Special Operations Command (MARSOC) students	The aim of this study was to determine how specific military tactical training phases influence overall physical performance characteristics and identify any deficits that may occur during certain stages, so that human performance programs can be tailored accordingly with evidence-based modifications.	Internal: HR, blood lactate, aerobic power, anaerobic capacity, neuromuscular power, maximal oxygen uptake, leg strength, shoulder strength and trunk extension/flexion strength External: percent body fat (%BF)	15 months	Significant changes were observed in broad jump, 5-10-5 agility time, %BF, AP, VO2 max, 300-yard shuttle run time, AC, left knee extension strength, trunk flexion strength, and left shoulder external rotation strength during two distinct tactical training phases. These changes were identified by post hoc Bonferroni pairwise comparisons analysis.
Wyss et al. (2012)	Ambulatory physical activity in Swiss Army recruits	50 male army recruits	The aim of this study was to objectively assess and compare the type, intensity, and duration of physical activity during basic training provided by each of 5 selected Swiss Army occupational specialties, and describe and compare physical activity levels among different military occupations in terms of energy expenditure and time spent performing physically demanding activities.	Internal: HR External: Accelerometery	10 weeks	Physical activity levels during basic training vary significantly among different military occupations Estimated energy expenditure (TEE) values ranged between 16.8-17.1 MJ/d, which is comparable to the recommended daily intake for adults of similar age and gender according to WHO guidelines Time spent marching or performing physically demanding activities such as lifting/carrying loads varied greatly across occupational specialties with some requiring more than double the amount compared to others.

Chapter 4. From Theory to Practice: Practical Applications of Monitoring Methods in Specialist Tactical Populations

Chapter 4 aims to bridge the gap between traditional sport and tactical environments by exploring the practical applications of integrating monitoring strategies with specialist tactical populations. Drawing upon the findings and insights from the previous chapters, which examined athlete monitoring methods of traditional sport (Chapter 2) and the monitoring methods utilised in tactical environments (Chapter 3), this chapter aims to synthesize the knowledge from these distinct domains and achieve the following objectives:

I. Examine the practical considerations and challenges involved in measuring work and training loads in tactical environments.
II. Propose practical recommendations and a framework for developing effective load monitoring protocols tailored, specifically to the needs of specialist tactical populations.
III. Contribute to the broader understanding and knowledge base on load monitoring practices within specialist tactical populations, emphasising the importance of evidence-based approaches in optimising performance.

Through achieving these objectives, this chapter hopes to provide researchers and practitioners working alongside and in tactical groups with a framework to enhance the effectiveness of load monitoring protocols to optimise performance.

4.1 Practical Considerations

In traditional sports environments, the primary goal of load monitoring protocols is to facilitate the decision-making process of coaches and managerial staff regarding the availability of individual players for training and competition (Bourdon et al., 2017). However, load monitoring protocols within tactical populations cannot be easily distilled to one goal. The primary objectives of implementing load monitoring within tactical populations are multifaceted and complex, and should surround optimising performance, enhancing operational readiness, and mitigating the risk of injuries (Dijksma et al., 2021; Michael et al., 2022; Vrijkotte et al., 2019). While individual availability for training is an important aspect, it forms part of a broader objective aimed at safeguarding the overall physical and psychological well-being of operators. In the review by Michael et al. (2022), it was emphasised that practitioners working within the tactical field should prioritise the identification of the overarching purpose behind their monitoring protocols. As load monitoring fundamentally functions as a scientific feedback mechanism, practitioners may become entangled in the intricacies of specific variables and emerging technologies (Michael et al., 2022). This reiterates the significance of informed decision-making in the selection of monitoring tools and strategies, it is recommended practitioners consider the following questions:

I. What are the practical and scientific objectives of implementing load monitoring protocols?
II. What analytical and interpretive strategies will be employed to develop conclusions and insights?
III. What are the criteria for selecting a valid and reliable monitoring tool?
IV. What is the appropriate timeframe for data collection (e.g., global, or specific time frames)?
V. How can a clear feedback loop be established between practitioners and operators?

(Bourdon et al., 2017; Michael et al., 2017)

Furthermore, establishing and implementing load monitoring strategies within tactical operating environments presents practitioners with unique challenges. These challenges encompass the dynamic and unpredictable nature of the environment, safety and security concerns, data accessibility and infrastructure, ethical considerations, participant heterogeneity, and psychological factors. To effectively address these challenges a multidisciplinary approach is necessary, involving practitioners and experts in sport and exercise science, medicine, human performance, tactical operations, and data analytics.

Chapter 3 provides a comprehensive overview of the internal and external load monitoring strategies utilised in studies on specialist tactical populations. This Chapter provides valuable insight into the distinct physiological and psychological demands faced by operators within training environments, combat simulations, and specific operations. Furthermore, the findings in Chapter 3 emphasise several practical considerations and limitations of specific monitoring methods. To assist practitioners in understanding these advantages and disadvantages, a summary in Table 8 adapted from the work of Michael et al. (2022) has been provided. It is important to note that each monitoring tool carries varying advantages and critical limitations. As a result, practitioners must evaluate them on a case-by-case basis, considering their specific operating constraints and environments (Michael et al., 2017). Therefore, while this chapter offers general recommendations and a framework for practitioners to consider when designing and implementing their monitoring protocol, it is crucial to tailor the approach to individual circumstances.

As discussed above and alluded to in Table 8, there are copious challenges and limitations when implementing a load monitoring protocol in tactical environments. The following discussion will critically examine analytical, technical, and contextual considerations. With the aim to provide practitioners with a comprehensive understanding of the key factors and associated implications of specific load monitoring tools.

Table 8.

Summary of Practical Considerations of Load Monitoring Strategies in Specialist Tactical Populations. Adapted from Michael et al. (2022)

Monitoring Method	Load measure	Advantages	Disadvantages
GPS	External	- Provides accurate and objective gross movement characteristics - Can identify discrete activities - Allows for real-time training modification - Enables analysis of training patterns and progress over time - Can be integrated with other monitoring methods	- Security concerns - Requires equipment for data handling and analysis - Requires satellite (outdoors only) - Signal can be affected by environmental factors (buildings, tree coverage) - Limited indoors use - Battery life limitations - Lacks qualitative context
Accelerometry	External	- Relatively non-invasive - Low cost - Can be integrated into wearable devices or smartphones - Can identify discrete activities	- Requires equipment for data handling and analysis - Limitations distinguishing tactical specific tasks - Requires calibration and validation - Placement and adherence may vary - No real-time insights
Performance tests and neuromuscular function	External	- Identifies specific strengths and weaknesses - Allow for targeted training interventions	- Often require specialist equipment and personnel - May be invasive - May not translate to operational tasks
Questionnaires and self-report measures	External	- Cost effective - Easy to administer - Minimal equipment required - Captures insights and perspectives - Tailored to specific research or monitoring objectives	- Subjective, relies on individual recall accuracy - Potential for biased or inconsistent answers - Undefined/non-specific physiological meaning - Interpretation requires caution due to potential social desirability bias - Limited actionability for most measures

Diaries and training logs	External	- Minimal data input - Low cost - Allows for self-reflection and tracking of progress - Capture qualitative information - Guide and monitor training progression - Promotes accountability and adherence to training plans - Can be stored on user devices	- Not always reflective of actual activity - Reliance on individual consistency and accuracy - Time-consuming and prone to errors - Subjective and lacks standardisation
Direct observation	External	- Low participant burden - Provides real-time, objective assessment - Allows for immediate feedback, coaching or correction - Capture details not easily measured by other monitoring methods (joint angles, body positioning) - Potential for highly detailed qualitative information	- High staff burden (observation, data entry) - Requires trained observers - Potential for observer bias, or subjective interpretation of movements - Limited applicability to large-scale monitoring or real-world settings
Perceived exertion	Internal	- Non-invasive - Low cost - Simple to administer - Direct measure of physiological response - Strong relationship with metabolic rate - Can identify discrete activities - Real-time assessment - Allows individuals to self-regulate	- Subjective - May not accurately reflect physiological response - Limited actionability over extended tactical operations

Heart rate	Internal	- Non-invasive - Low cost - Simple to administer - Direct measure of physiological response - Strong relationship with metabolic rate - Can identify discrete activities - Can prescribe and modify training in real time - Allows individuals to self-regulate	- Data handling/analysis requirements - Battery life limitations - User comfort unsuitable for long-term use - Potential for external influence (caffeine, hydration, stress etc.) - Changes in HR may lag behind changes in exercise intensity, limiting real-time feedback - HR alone may not capture other important aspects of physical performance - Physiological interpretation of TRIMP metrics unclear
Heart rate variability	Internal	- Non-invasive - Quantifies holistic stress/readiness	- Requires further evidence from well controlled training studies - Requires expertise to interpret raw data - Data handling/analysis requirements - Requires standardised day-to-day measurements - Requires longitudinal monitoring for effective insights
Oxygen consumption	Internal	- Provides a direct measure of metabolic demand, and energy expenditure - Real-time feedback - Precise determination of metabolic intensity - Can be measured via laboratory-based techniques or estimated through wearable devices	- Laboratory-based measurements require specialist equipment and personnel - Expensive and impractical for field use - Calculations via wearable devices may lack accuracy - Does not directly provide detailed insight into anaerobic metabolism or specific performance measures
Training impulse	Internal	- Considers both exercise intensity and duration - Non-invasive - Low cost	- Requires accurate and consistent records - Varying results based on models - Unclear overall metrics

Biochemical markers	Internal	- Provide insights into physiological responses - Allows for individualised interventions or adjustments - Useful in clinical or research settings	- Requires specialist testing and equipment - Expensive and invasive - Timing of sample collection, standardisation, and storage conditions are critical for accurate results - May not correlate with performance outcomes - Cannot be used to prescribe training
Doubly labelled water	Internal	- Accurate measurement of total energy expenditure - Reliable assessment of metabolic rate - Valuable for long-term research on energy expenditure - Non-invasive and simple to administer	- Requires specialist equipment and expertise for analysis - Expensive and time-consuming - Limited practicality for individual monitoring - Does not reflect discrete activities - Does not provide real-time or detailed information on specific physiological responses
Hormonal markers	Internal	- Provide insights into physiological response and adaptations - Can potentially identify hormonal imbalances/abnormalities	- Expensive and requires specialist laboratory testing and personnel - Cannot be used to prescribe training - Hormone levels fluctuate throughout the day, making it challenging to obtain accurate and representative measurements - Hormonal responses may not directly correlate with performance outcomes
Metabolites	Internal	- Provide insight into metabolic response - Can identify metabolic thresholds and training zones - Relatively non-invasive	- Expensive and requires specific equipment or laboratory analysis - Requires expert personnel for interpretation - Can be influenced by other variables (nutrition, hydration, environmental conditions)
Cognition	Internal	- Potential early detector of fatigue - Non-invasive - Relatively low cost - Provides an objective measure of decision-making and working memory capability	- Limited contextual information - Lack of standardisation - Time and resource intensive - Individual variability - Ethical considerations for some tests - Lack of long term monitoring

4.1.1 Analytical, Technical, and Contextual Considerations

Validity and Practicality

Researchers evaluate the validity and reliability of emerging technologies and monitoring tools through rigorous scientific tests and procedures (Greenham et al., 2018; Kupperman et al., 2020; Migueles et al., 2017; Rago et al., 2020). However, it is the responsibility of the practitioner to interpret and evaluate the practicality of these technologies and tools within their specific operating environment. Additionally, practitioners are responsible for identifying how the monitoring method will align with their overarching objective(s) and determine if it will provide meaningful insights (Michael et al., 2022). Further, practitioners often encounter external constraints which impact their decision-making process, some examples include lack of funding, limited resources, logistical challenges, and operational conditions.

The initial concern practitioners must consider is the validity of each monitoring method (Bourdon et al., 2017). Validity is critically important, as it serves as a foundation for whether the monitoring method measures what it is intended to measure (Alvar et al., 2017; Bourdon et al., 2017; Impellizzeri et al., 2019). Evaluating the validity of a test or tool allows practitioners to ensure the collected data accurately reflects the intended variable and provides a solid foundation for informed decision-making. Essentially, validity acts as the cornerstone for evidence-based decision-making.

As reported in Chapters 2 and 3, the validity and reliability of certain monitoring techniques and methods have been extensively reviewed in controlled settings. However, their implementation in tactical environments necessitates a critical evaluation of their practicality considering logistical, operational, and time-sensitive constraints. For example, DLW is a well-established and validated (Capling et al., 2017; Michael et al., 2022) monitoring technique that demonstrates high validity and reliability in quantifying total energy expenditure and water turnover rates across sport (Capling et al., 2017; Parker et al., 2022) and tactical settings (Blacker et al., 2003; Friedl et al., 1995; Johnson et al., 2018; O'Leary et al., 2018; Richmond et al., 2012; Richmond et al., 2014). While DLW is considered a *gold standard* method of measurement (Michael et al., 2022), its practical implementation within tactical environments poses some of the following challenges:

1. Laboratory requirements: DLW analysis requires specialist laboratory equipment and personnel to process and assess the isotopes found within urine samples (Schoeller et al., 1982). However, these laboratory facilities are rarely available or accessible within tactical operational or training environments. Furthermore, the costs associated with this analysis can be prohibitive, particularly in governmental settings where resources are often limited.
2. Sample collection: DLW analysis involves multiple urine sample collections over a relatively long measurement period, typically spanning one to two weeks (Blacker et al., 2003; Johnson et al., 2018; O'Leary et al., 2018; Richmond et al., 2012; Richmond et al., 2014). Furthermore, collecting and storing urine samples in the field can be logistically challenging and time-consuming. As seen in the study by Johnson et al. (2018) where researchers travelled a total of 27.7-km over 9-days with SOF through both glacial (cold) and jungle (hot) environments, whilst collecting and storing urine samples.
3. Result timeline: Due to the requirement of a laboratory for processing and analysis, obtaining results can take days or weeks (Johnson et al., 2018; O'Leary et al., 2018). This constraint may not align with the need for immediate decision-making, and may not be practical in dynamic tactical environments.

Ultimately, certain monitoring methods have been extensively established as valid and reliable tools within controlled research settings, such as the DLW method (Capling et al., 2017; Johnson et al., 2018). However, the practical implementation of these methods within tactical environments may not be feasible and pose significant constraints, as discussed in the above example. Practitioners may need to explore other *field-friendly* alternatives that are more practical, portable, and provide real-time feedback. For example, in the case of DLW analysis, field-friendly alternatives encompass wrist-mounted wearable sensors (Argent et al., 2022), and urine-specific gravity tests (Chapelle et al., 2020). However, these field-friendly advantages come at the cost of validity. There is contention surrounding the accuracy and reliability of consumer wrist-mounted wearables in estimating energy expenditure, with various results and methodologies in the current research landscape (Fuller et al., 2020; O'Driscoll et al., 2020). Whereas, urine-based hydration assessments are established as reliable and practical, however, they can be heavily influenced by external variables such as the timing of fluid intake, nutrition, and the impact of renal responses during physical activity (Chapelle et al., 2020; Hew-Butler et al., 2018). In the selection of a monitoring method, practitioners must carefully evaluate the balance between practicality and validity, considering the constraints and limitations of each method and determining the tool or strategy that best meets the needs of their unit or team.

Wear tolerance

Another concern practitioners must consider is the durability and robustness of the employed monitoring method. Tactical operational environments are some of the most austere and hazardous conditions on the planet (Alvar et al., 2017; Tornero-Aguilera et al., 2017). Therefore, the monitoring devices or tools need to be highly durable and resistant to physical impacts, moisture, dust, extreme temperatures, and other environmental factors that operators may encounter (Alvar et al., 2017). Furthermore, these devices must be able to withstand these demanding conditions without compromising functionality or performance.

User comfort and ergonomics are confounding factors in terms of wear tolerance. For example, Beeler et al. (2018) reported that chest-worn devices were more likely to have a negative impact on operational performance in military populations compared to devices mounted on the extremities (e.g., foot, arm, or wrist). Anecdotal observations from Michael et al. (2022) support these findings, noting several issues from the prolonged wearing of chest-worn monitoring devices, such as:

- Skin irritation,
- Discomfort under PPE (e.g., body armour),
- Difficulties during sleep and prone activities,
- Devices catching on obstacles and equipment.

These limitations in wear tolerance, including issues related to user comfort both in rest and tactical-specific tasks can significantly impact user compliance and result in sporadic data collection. These patterns are evident in the context of BMT, where HR monitoring has been observed to be conducted across a range of 25 to 50% of the total duration (Blacker et al., 2009; O'Leary et al., 2018; Richmond et al., 2014; Wilkinson et al., 2008). These reports emphasise the need for practitioners to prioritise freedom of movement and minimise discomfort when employing or designing monitoring devices that will be worn concurrently with PPE or uniforms. The integration of functionality and equipment is often highlighted as an important criterion for wear tolerance. However, the diverse range of apparel, PPE, and equipment utilised across tactical populations poses a significant challenge in standardising monitoring strategies. Therefore, practitioners should work with their end-users to evaluate the efficacy of the proposed monitoring strategy. Additionally, practitioners with adequate time and resources could engage and collaborate with manufacturers and industry stakeholders to develop tailored monitoring strategies that seamlessly integrate with the existing gear of their specific unit or team. This collaborative approach, combined with in-house validation of practices, may ensure optimal implementation and effectiveness (Bourdon et al., 2018).

Battery life

One important technical concern in wearable technology within tactical environments is battery life and power management. Extending battery life has emerged as a key technological focus in various wearable domains, such as phones and smartwatches (Argent et al., 2022). The integration of load management systems and technology has raised concerns for practitioners about the accessibility to power for those working within tactical environments (Michael et al., 2022). Table 8 highlights several monitoring methods that are limited by battery life such as GPS, accelerometry, and HR tools. While some devices have the capability to manipulate sampling frequency which may conserve power (Dlugosz & Iniewski, 2006), this may result in a trade-off by compromising data granularity, as evidenced by variations in GPS wearable devices (Kupperman et al., 2020; Rago et al., 2020). Furthermore, devices such as HR chest straps and smartwatches that require frequent recharging or battery replacement pose practical challenges for monitoring prolonged periods of tactical activities or operations.

This can be particularly problematic in environments with limited or impractical access to power sources, hindering continuous data collection and monitoring. Therefore, practitioners need to carefully consider the battery life limitations of specific monitoring devices and align them with the needs and requirements of their unit or team.

However, while technological monitoring methods may seem appealing, it is critical for practitioners to consider the earlier question: *"What are the practical and scientific objectives of implementing load monitoring protocols?"* (Bourdon et al., 2017; Michael et al., 2017). Validity and practicality should be compared between technological methods and simpler approaches (Windt et al., 2020). For example, perceptual measures such as the talk test and RPE are equally effective in developing cardiopulmonary adaptation compared to HR-guided training (Foster et al., 2018). Importantly, these perceptual measures do not present the limitations associated with technological methods, offering a viable alternative for practitioners.

Logistics and Resources

Several of the *gold-standard* monitoring methods discussed in the previous chapters require significant financial resources to acquire the necessary equipment and technology. For example, out of the sixteen monitoring methods outlined in Table 8, ten involve associated costs. Even wearable devices with relatively lower financial burdens such as HR monitors, come with certain expenses. It is important to note that these costs are dependent on individual circumstances. While practitioners working with small units or teams may be able to manage these expenses, those operating within larger groups (e.g., many military settings) may face multiplied financial burdens (Michael et al., 2022). Additionally, there can be added costs, such as software and data analysis tools that are required to interpret and analyse the results. Where the scale of the group or population being monitored can amplify the financial challenges associated with implementing these load-monitoring strategies.

Furthermore, there are logistical challenges in monitoring and collecting data from large groups. The collection, inspection, and cleaning of substantial amounts of data generated by wearable devices requires careful allocation of resources, as well as time and expertise (Michael et al., 2022). Additionally, certain monitoring methods, as discussed in Chapter 3, restrict access to raw data (e.g., GPS) and utilise proprietary analysis algorithms that are not publicly available (Bourdon et al., 2017; Migueles et al., 2017). While these approaches may offer convenience and visually appealing data, it limits practitioners' ability to conduct independent analysis (Michael et al., 2022). Alternatively, practitioners can utilise written logs or direct observation methods. However, it is important to acknowledge that these approaches are labour-intensive and require substantial amounts of time for data input (Michael et al., 2022). Furthermore, relying solely on subjective and qualitative observation methods introduces the potential for inter-rater variability and may lack the quantitative validity sought by practitioners, decision-makers, and operators.

Data Security and Analysis

Data security is a significant risk and limitation associated with load monitoring strategies within tactical environments. Many of the wearable devices commercially available for practitioners and operators, utilise and rely on wireless transmission, GPS, and third-party cloud systems that necessitate an internet connection. However, these data transmission methods can be vulnerable to interception, leading to critical security breaches. A notable example was the recent "Global Heat Map" that publicly compromised and exposed several secure U.S. Military bases (Sly, 2018), consequently, resulting in the restriction of personal GPS transmission during deployments across several militaries (Michael et al., 2022). Therefore, it is imperative practitioners thoroughly assess the security measures associated with data upload, location, and transmission before undertaking any data collection and management within tactical environments.

In addition to data security concerns, the volume of data generated from various monitoring methods during prolonged operational tasks presents challenges in data cleaning and interpretation. The process of reducing the data to summary measures inherently involves a loss of information. Thus, practitioners should consider the strategy and approach for presenting this data and finding a balance between simplicity and complexity (Michael et al., 2022). For example, it would be misleading to present a single mean HR value to represent an activity lasting over a 10-hr period, as it oversimplifies the representation. This approach would fail to capture intensity fluctuations over time and may mask the physiological implications of intermittent high-intensity activity (Michael et al., 2022). By focusing solely on the mean value, the dynamic nature of physiological responses and the cumulative effect of intense periods can be overlooked.

Michael et al. (2022) also advise caution when interpreting summary metrics (e.g., TRIMP and sRPE) as the weightings of intensity and duration used in these arbitrary units and equations may not be adequately validated to reflect meaningful physiological constructs of tactical environments (Borresen & Lambert, 2009). For instance, the TRIMP values observed during BMT are approximately 1400 AU (arbitrary units) per week, and thus comparable to elite athletes ranging from 800 to 2000 AU per week (Jurvelin et al., 2020). However, the physiological demands placed on these groups and contexts differ significantly. BMT typically involves 10 to 16-hr days at predominantly low-to-moderate intensities with significant load carriage components (Blacker et al., 2009; Grant et al., 2016; O'Leary et al., 2018; Richmond et al., 2012; Wilkinson et al., 2008; Wyss et al., 2012), whereas athletic populations engage in 1 to 5-hrs of specific and relatively intense training per day (Borresen & Lambert, 2008; Daanen et al., 2012; Impellizzeri et al., 2004; Michael et al., 2022). This example underscores the significance of contextualising datasets to specific events or activities, emphasising the need for practitioners to carefully consider the presentation and reporting of data to operators and decision-makers (Michael et al., 2022). Furthermore, practitioners should establish clear connections between specific physiological constructs and the load unit or measure employed.

4.2 Framework and Recommendations

As outlined in the previous discussion, the development and implementation of load monitoring strategies in specialist tactical populations poses numerous practical considerations and challenges that differ from those found in traditional sports environments (Bourdon et al., 2017; Michael et al., 2022). To ensure the effectiveness and practicality of implementing a monitoring system into tactical environments, it is crucial to address the limitations and challenges associated with each monitoring method. However, this evaluation process can be challenging. Therefore, Figure 3 presents an outline of the five key considerations for developing and implementing a load monitoring strategy or system that is specifically designed for specialist tactical environments. These considerations encompass practices and recommendations found within traditional sporting environments (Bourdon et al., 2017), whilst also applying the limitations and practical considerations of the previous discussion.

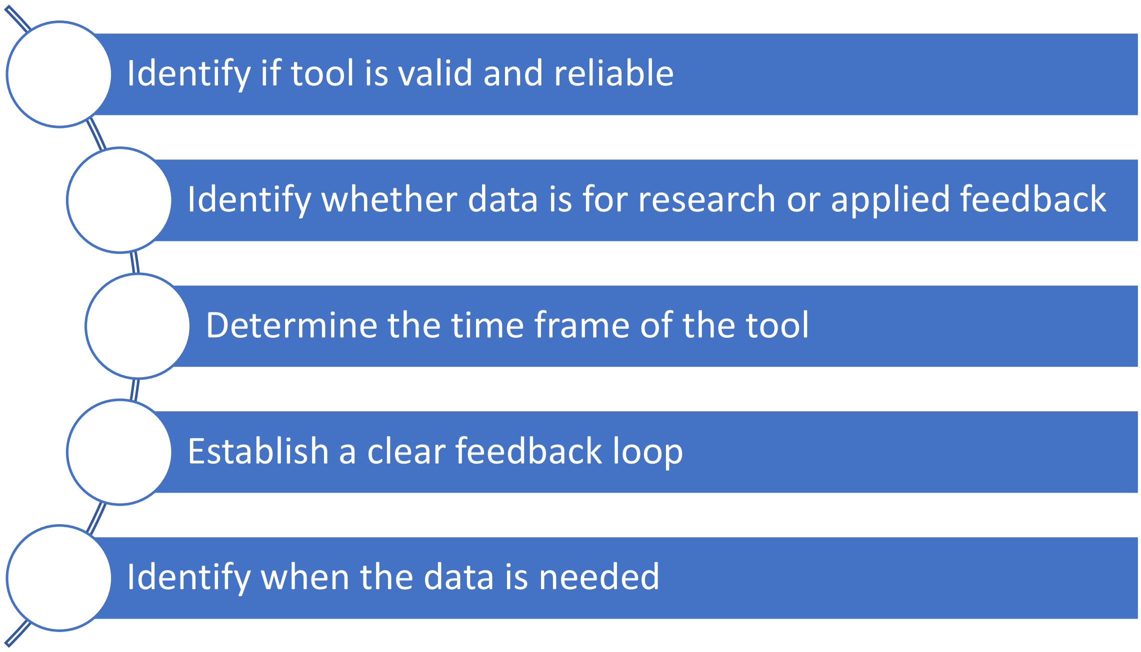

Figure 3. Key Considerations for Load Monitoring within Tactical Populations.

Furthermore, due to the disparity of available literature between traditional sports and tactical populations, Figure 4 presents a framework and summary that integrates findings and common practices from both domains. It draws upon traditional sports monitoring methodology (Bourdon et al., 2017) and current practices observed within specialist tactical environments (Michael et al., 2022). However, it is essential for practitioners who wish to apply the findings presented in this dissertation to consider, adapt, and tailor the evidence-based practices to their specific unit or team.

Figure 4. A Framework of the Key Considerations for Implementing Load Monitoring Protocols in Tactical Environments

Practitioners should adapt and modify the considerations presented in Figure 4 based on the unique characteristics of their operational environment. Contextual factors such as specific operational demands, physical profiles, available resources, technological advancements, operational needs, and objectives should be considered when implementing and utilising this framework (Bourdon et al., 2017; Dijksma et al., 2021; Michael et al., 2022; Vrijkotte et al., 2019). Furthermore, the purpose of this framework is to synthesize the primary considerations for practically implementing load monitoring strategies and to encourage practitioners to critically evaluate their applicability to their specific circumstances. Additionally, it is crucial to recognise that the field of load monitoring across sport and tactical environments is dynamic, with regular technological advancements and emerging research (Dijksma et al., 2021; Michael et al., 2022). Therefore, practitioners should continuously evaluate and update their protocols to incorporate promising methodologies and technology (Bourdon et al., 2017). Furthermore, the collaboration with interdisciplinary teams, units, and groups between tactical and sports domains will help contribute to the evolution of load monitoring practices across tactical populations.

In summary, this framework serves as a valuable tool for practitioners when developing and implementing load monitoring strategies within specialist tactical populations, providing guidance and insight from both the sports and tactical domains. Practitioners are encouraged to adapt and refine these considerations based on their individual needs and objectives, while also staying informed about emerging research and technological advancements across both fields.

4.3 Future Research

This dissertation has made substantial contributions to the understanding and knowledge base on load monitoring practices and their application within specialist tactical populations. However, there are several areas of research that warrant further investigation. The following suggestions aim to inspire future scholars and researchers to delve deeper into the complexities of load monitoring within specialist tactical populations, in order to expand our collective knowledge and enhance the training and performance optimisation strategies for these groups.

1. Identification of physiological and psychological demands during operational environments: While there is a growing body of research conducted in training

environments and field exercises, there is a lack of data coming from operational settings.

2. Load monitoring and cognitive performance: Currently, there is a growing body of research surrounding the impact of sleep deprivation on cognition (Tait et al., 2022). However, there is limited evidence surrounding cognitive skills training within tactical environments.
3. Data surrounding the use of a multivariate load model: This information would enhance the clarity of the internal and external physiological and psychological demands.
4. Development of advanced load monitoring technologies: Current monitoring devices have several limitations in practicality within tactical environments. Future research should focus on the development of technology specifically designed to tolerate the demands of tactical environments.
5. Longitudinal studies on load management and performance outcomes: Long-term studies that tack load patterns, training responses, injury occurrences, and performance metrics over extended periods would provide valuable insights into the dose-response relationship and the impact of load monitoring protocols on long-term performance outcomes.
6. Investigations of load monitoring strategies across different tactical populations: The demands and operational contexts vary across different tactical populations. Future research should examine the applicability and effectiveness of load monitoring strategies across these populations. Furthermore, comparative studies that explore similarities and differences in load profiles, injury risk factors, and performance outcomes would enable the development of tailored load monitoring protocols specific to each tactical population.
7. Validate load-outcome models: Michael et al., (2022) highlighted the need for validating the use of load data in predicting health and performance outcomes. Suggesting a three-step process involving mechanistic exploration, hypothesis testing, and controlled trials to establish the predictive value of load metrics and assess the benefits of modifying prescriptions based on the feedback of load data.

References

Abbott, W., Brickley, G., & Smeeton, N. J. (2018). Positional Differences in GPS Outputs and Perceived Exertion During Soccer Training Games and Competition. *Journal of Strength and Conditioning Research, 32*(11), 3222-3231. https://doi.org/10.1519/jsc.0000000000002387

Abdullahi, Y., Coetzee, B., & van den Berg, L. (2019). Relationships Between Results of an Internal and External Match Load Determining Method in Male, Singles Badminton Players. *Journal of Strength and Conditioning Research, 33*(4), 1111-1118. https://doi.org/10.1519/jsc.0000000000002115

Abel, M. G., Sell, K., & Dennison, K. (2011). Design and implementation of fitness programs for firefighters. *Strength and Conditioning Journal, 33*(4), 31-42. doi:10.1519/ssc.0b013e318212f412

Achten, J., & Jeukendrup, A. E. (2003). Heart rate monitoring: Applications and limitations. *Sports Medicine, 33*(7), 517-538. https://doi.org/10.2165/00007256-200333070-00001

Adesida, Y., Papi, E., & McGregor, A. H. (2019). Exploring the role of wearable technology in sport kinematics and kinetics: A systematic review. *Sensors, 19*(7), 1597. doi:10.3390/s19071597

Akenhead, R., & Nassis, G. P. (2016). Training load and player monitoring in high-level football: Current practice and perceptions. *International Journal of Sports Physiology and Performance, 11*(5), 587–593.

Akiyama, K., Sasaki, T., & Mashiko, M. (2019). Elite Male Lacrosse Players' Match Activity Profile. *Journal of Sport Science and Medicine, 18*(2), 290-294.

Akubat, I., Barrett, S., Sagarra, M. L., & Abt, G. (2018). The Validity of External:Internal Training Load Ratios in Rested and Fatigued Soccer Players. *Sports (Basel), 6*(2). https://doi.org/10.3390/sports6020044

Alder, D. B., Broadbent, D. P., Stead, J., & Poolton, J. (2019). The impact of physiological load on anticipation skills in badminton: From testing to training. *Journal of Sports Sciences, 37*(16), 1816-1823. https://doi.org/10.1080/02640414.2019.1596051

Almonroeder, T. G., Tighe, S. M., Miller, T. M., & Lanning, C. R. (2018). The influence of fatigue on decision-making in athletes: A systematic review. Sports Biomechanics, 19, 76-89. https://doi.org/10.1080/14763141.2018.1465451

Altmann, S., Neumann, R., Härtel, S., Woll, A., & Buchheit, M. (2021). Using Submaximal Exercise Heart Rate for Monitoring Cardiorespiratory Fitness Changes in Professional Soccer Players: A Replication Study. *International Journal of Sports Physiology and Performance, 16*(8), 1096–1102. https://doi.org/10.1123/ijspp.2020-0554

Alvar, B., Sell, K., & Deuster, P. (2017). NSCA'S essentials of tactical strength and conditioning. Champaign, IL: Human Kinetics.

American Psychological Association. (2020). Publication manual of the American Psychological Association (7th ed.). https://doi.org/10.1037/0000165-000

Anderson, T., Adams, W. M., Martin, K. J., & Wideman, L. (2021). Examining Internal and External Physical Workloads Between Training and Competitive Matches Within Collegiate Division I Men's Soccer. *Journal of Strength and Conditioning Research, 35*(12), 3440-3447. https://doi.org/10.1519/jsc.0000000000004149

Angius, L., Merlini, M., Hopker, J., Bianchi, M., Fois, F., Piras, F., Cugia, P., Russell, J., & Marcora, S. M. (2022). Physical and Mental Fatigue Reduce Psychomotor Vigilance in Professional Football Players. *International Journal of Sports Physiology and Performance*, 1-8. https://doi.org/10.1123/ijspp.2021-0387

Aoki, M. S., Ronda, L. T., Marcelino, P. R., Drago, G., Carling, C., Bradley, P. S., & Moreira, A. (2017). Monitoring Training Loads in Professional Basketball Players Engaged in a Periodized Training Program. *Journal of Strength and Conditioning Research, 31*(2), 348-358. https://doi.org/10.1519/jsc.0000000000001507

Aoki, M. S., Ronda, L. T., Marcelino, P. R., Drago, G., Carling, C., Bradley, P. S., & Moreira, A. (2017). Monitoring training loads in professional basketball players engaged in a periodized training program. *Journal of Strength and Conditioning Research, 31*(2), 348–358.

Argent, R., Hetherington-Rauth, M., Stang, J., Tarp, J., Ortega, F. B., Molina-Garcia, P., Schumann, M., Bloch, W., Cheng, S., Grøntved, A., Brønd, J. C., Ekelund, U., Sardinha, L. B., & Caulfield, B. (2022). Recommendations for determining the validity of consumer wearables and smartphones for the estimation of energy expenditure: Expert statement and checklist of the INTERLIVE Network. *Sports Medicine, 52*, 1817-1832. https://doi.org/10.1007/s40279-022-01665-4

Aromataris E, Fernandez R, Godfrey C, Holly C, Kahlil H, Tungpunkom P. (2015). Summarizing systematic reviews: methodological development, conduct and reporting of an Umbrella review approach. *Int J Evid Based Health 13*(3):132-40.

Askow, A. T., Lobato, A. L., Arndts, D. J., Jennings, W., Kreutzer, A., Erickson, J. L., Esposito, P. E., Oliver, J. M., Foster, C., & Jagim, A. R. (2021). Session Rating of Perceived Exertion (sRPE) Load and Training Impulse Are Strongly Correlated to GPS-Derived Measures of External Load in NCAA Division I Women's Soccer Athletes. *J Funct Morphol Kinesiol, 6*(4). https://doi.org/10.3390/jfmk6040090

Aubert, A. E., Seps, B., & Beckers, F. (2003). Heart rate variability in athletes. *Sports Medicine, 33*(12), 889-919. https://doi.org/10.2165/00007256-200333120-00003

Azcárate, U., Los Arcos, A., Jiménez-Reyes, P., & Yanci, J. (2020). Are acceleration and cardiovascular capacities related to perceived load in professional soccer players? *Research in Sports Medicine, 28*(1), 27-41. https://doi.org/10.1080/15438627.2019.1644642

Banister, E. W., MacDougall, J. D., & Wenger, H. A. (1991). Modeling elite athletic performance: Physiological testing of the high-performance athlete. Human Kinetics.

Bannai, A., & Tamakoshi, A. (2014). The association between long working hours and health: A systematic review of epidemiological evidence. *Scandinavian Journal of Work, Environment & Health*, 40, 5-18. https://doi.org/10.5271/sjweh.3388

Barnes, M. R., Guy, J. H., Elsworthy, N., & Scanlan, A. T. (2021). A Comparison of PlayerLoad(TM) and Heart Rate during Backwards and Forwards Locomotion during Intermittent Exercise in Rugby League Players. *Sports (Basel), 9*(2). https://doi.org/10.3390/sports9020021

Beato, M., & Drust, B. (2021). Acceleration intensity is an important contributor to the external and internal training load demands of repeated sprint exercises in soccer players. *Research in Sports Medicine, 29*(1), 67-76. https://doi.org/10.1080/15438627.2020.1743993

Beato, M., Coratella, G., Schena, F., & Hulton, A. T. (2017). Evaluation of the external and internal workload in female futsal players. *Biol Sport, 34*(3), 227-231. https://doi.org/10.5114/biolsport.2017.65998

Beeler, N., Roos, L., Delves, S. K., Veenstra, B. J., Friedl, K., Buller, M. J., & Wyss, T. (2018). The wearing comfort and acceptability of ambulatory physical activity monitoring devices in soldiers. *IISE Transactions on Occupational Ergonomics and Human Factors, 6(*1), 1-10.

Belenky, G., Wesensten, N. J., Thorne, D. R., Thomas, M. L., Sing, H. C., Redmond, D. P., Russo, M. B., & Balkin, T. J. (2003). Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: A sleep dose-response study. *Journal of Sleep Research, 12*(1), 1-12. https://doi.org/10.1046/j.1365-2869.2003.00337

Bělka, J., Hulka, K., Machová, I., Šafář, M., Weisser, R., Bellar, D. M., Hoover, D. L., & Judge, L. W. (2017). Effects of Environmental Context on Physiological Response During Team Handball Small Sided Games. *International Journal of Exercise Science, 10*(8), 1263-1274.

Belli, R. F. (1989). The structure of autobiographical memory and the event history calendar: Potential improvements in the quality of retrospective reports in surveys. *Public Opinion Quarterly, 53*(4), 542-566. https://doi.org/10.1086/269071

Benjamin, C. L., Sekiguchi, Y., Morrissey, M. C., Butler, C. R., Filep, E. M., Stearns, R. L., & Casa, D. J. (2021). The effects of hydration status and ice-water dousing on physiological and performance indices during a simulated soccer match in the heat. *Journal of Science and Medicine in Sport, 24*(8), 723-728. https://doi.org/10.1016/j.jsams.2021.05.013

Bigg, J. L., Gamble, A. S. D., & Spriet, L. L. (2021). Internal Physiological Load Measured Using Training Impulse in Varsity Men's and Women's Ice Hockey Players Between Game Periods. *Journal of Strength and Conditioning Research, 35*(10), 2824-2832. https://doi.org/10.1519/jsc.0000000000004120

Birdsey, L. P., Weston, M., Russell, M., Johnston, M., Cook, C. J., & Kilduff, L. P. (2019). Neuromuscular, physiological and perceptual responses to an elite netball tournament. *Journal of Sports Sciences, 37*(19), 2169-2174. https://doi.org/10.1080/02640414.2019.1625613

Birdsey, L. P., Weston, M., Russell, M., Johnston, M., Cook, C. J., & Kilduff, L. P. (2022). The neuromuscular, physiological, endocrine and perceptual responses to different training session orders in international female netball players. *European Journal of Sport Science, 22*(3), 314-325. https://doi.org/10.1080/17461391.2020.1869837

Bjørndal, C. T., Bache-Mathiesen, L. K., Gjesdal, S., Moseid, C. H., Myklebust, G., & Luteberget, L. S. (2021). An Examination of Training Load, Match Activities, and Health Problems in Norwegian Youth Elite Handball Players Over One Competitive Season. *Front Sports Act Living, 3*, 635103. https://doi.org/10.3389/fspor.2021.635103

Blacker, S. D., Wilkinson, D. M., Rayson, M. P., Blacker, S. D., Wilkinson, D. M., & Rayson, M. P. (2009). Gender differences in the physical demands of British Army recruit training. *Military Medicine, 174*(8), 811-816. https://doi.org/10.7205/milmed-d-01-3708

Blair, M. R., Elsworthy, N., Rehrer, N. J., Button, C., & Gill, N. D. (2018). Physical and Physiological Demands of Elite Rugby Union Officials. *International Journal of Sports Physiology and Performance, 13*(9), 1199-1207. https://doi.org/10.1123/ijspp.2017-0849

Booth, C. K., Coad, R. A., Forbes-Ewan, C. H., Thomson, G. F., & Niro, P. J. (2003). The physiological and psychological effects of combat ration feeding during a 12-day training exercise in the tropics. *Military Medicine, 168*(1), 63–70.

Borg, G. (1998). Borg's perceived exertion and pain rating scales. Human Kinetics.

Borresen, J., & Lambert, M. I. (2008). Quantifying training load: a comparison of subjective and objective methods. *International journal of sports physiology and performance, 3*, 16-30.

Borresen, J., & Lambert, M. I. (2009). The quantification of training load, the training response and the effect on performance. *Sports Medicine, 39*, 779–795. https://doi.org/10.2165/11317780-000000000-00000

Bourdon, P. C., Cardinale, M., Murray, A., Gastin, P., Kellmann, M., Varley, M. C., ... Cable, N. T. (2017). Monitoring athlete training loads: Consensus statement. International *Journal of Sports Physiology and Performance, 12*, 161–170.

Bourdon, P., Cardinale, M., Murray, A., Gastin, P., Kellmann, M., Varley, M. C., Gabbett, T. J., Coutts, A. J., Burgess, D. J., Gregson, W., Cable, N. T., & Coutts, A. (2017). Monitoring athlete training loads: Consensus statement. *International Journal of Sports Physiology and Performance*, 12, 161-170. https://doi.org/10.1123/IJSPP.2017-0208

Bouten, C.V.C., Verboeket-Van Der Veene, W.P.H.G., Westerterp, K.R., Verduin, M., and Janssen, J.D., (1996). Daily physical activity assessment: comparison between movement registration and doubly labeled water. *Journal of Applied Physiology, 81*, 1019–1026.

Bozzini, B. N., McFadden, B. A., Scruggs, S. K., & Arent, S. M. (2021). Evaluation of Performance Characteristics and Internal and External Training Loads in Female Collegiate Beach Volleyball Players. *Journal of Strength and Conditioning Research, 35*(6), 1559-1567. https://doi.org/10.1519/jsc.0000000000004051

Brandes, M., & Elvers, S. (2017). Elite Youth Soccer Players' Physiological Responses, Time-Motion Characteristics, and Game Performance in 4 vs. 4 Small-Sided Games: The Influence of Coach Feedback. *Journal of Strength and Conditioning Research, 31*(10), 2652-2658. https://doi.org/10.1519/jsc.0000000000001717

Branquinho, L., Ferraz, R., Travassos, B., & M, C. M. (2020). Comparison between Continuous and Fractionated Game Format on Internal and External Load in Small-Sided Games in Soccer. *Int J Environ Res Public Health, 17*(2). https://doi.org/10.3390/ijerph17020405

Branquinho, L., Ferraz, R., Travassos, B., Marinho, D. A., & Marques, M. C. (2021). Effects of Different Recovery Times on Internal and External Load During Small-Sided Games in Soccer. *Sports Health, 13*(4), 324-331. https://doi.org/10.1177/1941738121995469

Bredt, S. G. T., Torres, J. O., Diniz, L. B. F., Praça, G. M., Andrade, A. G. P., Morales, J. C. P., Rosso, T. L. N., & Chagas, M. H. (2020). Physical and physiological demands of basketball small-sided games: the influence of defensive and time pressures. *Biol Sport, 37*(2), 131-138. https://doi.org/10.5114/biolsport.2020.93038

Brisola, G. M. P., Claus, G. M., Dutra, Y. M., Malta, E. S., de Poli, R. A. B., Esco, M. R., & Zagatto, A. M. (2020). Effects of Seasonal Training Load on Performance and Illness Symptoms in Water Polo. *Journal of Strength and Conditioning Research, 34*(2), 406-413. https://doi.org/10.1519/jsc.0000000000003358

Bruno, S., Gonçalo, C., Sílvia, R.-R., & Filipe Manuel, C. (2021). Monitoring physical performance and training load in young surf athletes. *Journal of Human Sport and Exercise, 16*(2), 261-272. https://doi.org/10.14198/jhse.2021.162.03

Buchheit, M. (2014). Monitoring training status with HR measures: do all roads lead to Rome? *Frontiers in Physiology, 5*, 73.

Buchheit, M., Lacome, M., Cholley, Y., & Simpson, B. M. (2018). Neuromuscular Responses to Conditioned Soccer Sessions Assessed via GPS-Embedded Accelerometers: Insights Into Tactical Periodization. *International Journal of Sports Physiology and Performance, 13*(5), 577-583. https://doi.org/10.1123/ijspp.2017-0045

Bunn, J. A., Myers, B. J., & Reagor, M. K. (2021). An Evaluation of Training Load Measures for Drills in Women's Collegiate Lacrosse. *International Journal of Sports Physiology and Performance, 16*(6), 841-848. https://doi.org/10.1123/ijspp.2020-0029

Burley, S. D., Drain, J. R., Sampson, J. A., Nindl, B. C., & Groeller, H. (2020). Effect of a novel low volume, high intensity con- current training regimen on recruit fitness and resilience. *Journal of Science and Medicine in Sport, 23*(10), 979–984.

Campbell, B. I., Bove, D., Ward, P., Vargas, A., & Dolan, J. (2017). Quantification of training load and training response for improving athletic performance. *Strength and Conditioning Journal, 39*(5).

Campbell, P. G., Peake, J. M., & Minett, G. M. (2018). The Specificity of Rugby Union Training Sessions in Preparation for Match Demands. *International Journal of Sports Physiology and Performance, 13*(4), 496-503. https://doi.org/10.1123/ijspp.2017-0082

Campbell, P. G., Stewart, I. B., Sirotic, A. C., & Minett, G. M. (2020). The Effect of Overreaching on Neuromuscular Performance and Wellness Responses in Australian Rules Football Athletes. *Journal of Strength and Conditioning Research, 34*(6), 1530-1538. https://doi.org/10.1519/jsc.0000000000003603

Campos-Vazquez, M. A., Toscano-Bendala, F. J., Mora-Ferrera, J. C., & Suarez-Arrones, L. J. (2017). Relationship Between Internal Load Indicators and Changes on Intermittent Performance After the Preseason in Professional Soccer Players. *Journal of Strength and Conditioning Research, 31*(6), 1477-1485. https://doi.org/10.1519/jsc.0000000000001613

Canino, M. C., Foulis, S. A., Cohen, B. S., Walker, L. A., Taylor, K. M., Redmond, J. E., & Sharp, M. A. (2020). Quantifying Training Load During Physically Demanding Tasks in U.S. Army Soldiers: A Comparison of Physiological and Psychological Measurements. *Military Medicine, 185*(5/6), e847-e852. https://doi.org/10.1093/milmed/usz445

Capling, L., Beck, K. L., Gifford, J. A., Slater, G., Flood, V. M., & O'Connor, H. (2017). Validity of Dietary Assessment in Athletes: A Systematic Review. *Nutrients, 9*(12), 1313. https://doi.org/10.3390/nu9121313

Castell, L. M., & Newsholme, E. A. (1998). Glutamine and the effects of exhaustive exercise upon the immune response. *Canadian Journal of Physiology and Pharmacology, 76*(5), 524–532.

Castillo-Rodríguez, A., Cano-Cáceres, F. J., Figueiredo, A., & Fernández-García, J. C. (2020). Train Like You Compete? Physical and Physiological Responses on Semi-Professional Soccer Players. *Int J Environ Res Public Health, 17*(3). https://doi.org/10.3390/ijerph17030756

Castillo, D., Weston, M., McLaren, S. J., Cámara, J., & Yanci, J. (2017). Relationships Between Internal and External Match-Load Indicators in Soccer Match Officials. *International Journal of Sports Physiology and Performance, 12*(7), 922-927. https://doi.org/10.1123/ijspp.2016-0392

Chandola, T., Heraclides, A., & Kumari, M. (2010). Psychophysiological biomarkers of workplace stressors. *Neuroscience & Biobehavioral Reviews, 35*, 51-57. doi: 10.1016/j.neubiorev.2010.01.008

Chapelle, L., Tassignon, B., Rommers, N., Mertens, E., Mullie, P., & Clarys, P. (2020). Pre-exercise hypohydration prevalence in soccer players: A quantitative systematic review. *European Journal of Sport Science, 20*(6), 744-755. https://doi.org/10.1080/17461391.2019.1669716

Cherrier, M. M., Asthana, S., Plymate, S., Baker, L., Matsumoto, A. M., Peskind, E., Raskind, M. A., & Brodkin, K. (2001). Testosterone supplementation improves spatial and verbal memory in healthy older men. *Neurology, 57*(1), 80-88.

Cirer-Sastre, R., Legaz-Arrese, A., Corbi, F., López-Laval, I., Puente-Lanzarote, J., Hernández-González, V., & Reverter-Masià, J. (2019). Effect of Training Load on Post-Exercise Cardiac Troponin T Elevations in Young Soccer Players. *Int J Environ Res Public Health, 16*(23). https://doi.org/10.3390/ijerph16234853

Clemente-Suárez, V. L., & Robles-Pérez, J. J. (2013). Mechanical, physical, and physiological analysis of symmetrical and asymmetrical combat. *Journal of Strength and Conditioning Research, 27*(9), 2420-2426-2426. https://doi.org/10.1519/JSC.0b013e31828055e9

Clemente-Suárez, V., & Robles-Perez, J. (2013). Psycho-physiological response of soldiers in urban combat. *Anales de Psicología, 29*(2), 598–603. https://doi.org/10.6018/analesps.29.2.150691

Clemente-Suarez, V., & Robles-Pérez, J. (2015). Acute effects of caffeine supplementation on cortical arousal, anxiety, physiological response, and marksmanship in close quarter combat. *Ergonomics, 58*(11), 1842–1850. https://doi.org/10.1080/00140139.2015.1036790

Clemente, F. M. (2018). Associations between wellness and internal and external load variables in two intermittent small-sided soccer games. *Physiol Behav, 197*, 9-14. https://doi.org/10.1016/j.physbeh.2018.09.008

Clemente, F. M., Nikolaidis, P. T., Rosemann, T., & Knechtle, B. (2019a). Shorter Small-Sided Game Sets May Increase the Intensity of Internal and External Load Measures: A Study in Amateur Soccer Players. *Sports (Basel), 7*(5). https://doi.org/10.3390/sports7050107

Clemente, F. M., Nikolaidis, P. T., Rosemann, T., & Knechtle, B. (2019b). Variations of Internal and External Load Variables between Intermittent Small-Sided Soccer Game Training Regimens. *Int J Environ Res Public Health, 16*(16). https://doi.org/10.3390/ijerph16162923

Coelho, A. B., Nakamura, F. Y., Morgado, M. C., Holmes, C. J., Baldassarre, A., Esco, M. R., & Rama, L. M. (2019). Heart Rate Variability and Stress Recovery Responses during a Training Camp in Elite Young Canoe Sprint Athletes. *Sports (Basel), 7*(5). https://doi.org/10.3390/sports7050126

Coker, N. A., Wells, A. J., & Gepner, Y. (2020). Effect of Heat Stress on Measures of Running Performance and Heart Rate Responses During a Competitive Season in Male Soccer Players. *Journal of Strength and Conditioning Research, 34*(4), 1141-1149. https://doi.org/10.1519/jsc.0000000000002441

Colby, M. J., Dawson, B., Peeling, P., Heasman, J., Rogalski, B., Drew, M. K., & Stares, J. (2018,). Improvement of Prediction of Noncontact Injury in Elite Australian Footballers With Repeated Exposure to Established High-Risk Workload Scenarios. *International Journal of Sports Physiology and Performance, 13*(9), 1130-1135. https://doi.org/10.1123/ijspp.2017-0696

Colosio, A. L., Lievens, M., Pogliaghi, S., Bourgois, J. G., & Boone, J. (2020). Heart rate-index estimates aerobic metabolism in professional soccer players. *Journal of Science and Medicine in Sport, 23*(12), 1208-1214. https://doi.org/10.1016/j.jsams.2020.04.015

Comyns, T., & Hannon, A. (2018). Strength and Conditioning Coaches' Application of the Session Rating of Perceived Exertion Method of Monitoring within Professional Rugby Union. *J Hum Kinet, 61*, 155-166. https://doi.org/10.1515/hukin-2017-0118

concentrations are associated with overreaching during strenuous military training. *Journal of Strength and Conditioning Research, 25*(3), 787-797. https://doi.org/https://doi.org/10.1519/JSC.0b013e3181c1fa5d

Conkright, W. R., Beckner, M. E., Sinnott, A. M., Eagle, S. R., Martin, B. J., Lagoy, A. D., Proessl, F., Lovalekar, M., Doyle, T. L. A., Agostinelli, P., Sekel, N. M., Flanagan, S. D., Germain, A., Connaboy, C., & Nindl, B. C. (2021). Neuromuscular Performance and Hormonal Responses to Military Operational Stress in Men and Women. *Journal of Strength and Conditioning Research, 35*(5), 1296-1305.

Conlan, G., McLean, B., Kemp, J., & Duffield, R. (2021). Effect of Training/Competition Load and Scheduling on Sleep Characteristics in Professional Rugby League Athletes. *Journal of Strength and Conditioning Research*. https://doi.org/10.1519/jsc.0000000000004111

Conte, D., Arruda, A. F. S., Clemente, F. M., Castillo, D., Kamarauskas, P., & Guerriero, A. (2022). Assessing the Relationship Between External and Internal Match Loads in Elite Women's Rugby Sevens. *International Journal of Sports Physiology and Performance, 17*(4), 634-639. https://doi.org/10.1123/ijspp.2021-0097

Conte, D., Kamarauskas, P., Ferioli, D., Scanlan, A. T., Kamandulis, S., Paulauskas, H., & Lukonaitienė, I. (2021). Workload and well-being across games played on consecutive days during in-season phase in basketball players. *J Sports Med Phys Fitness, 61*(4), 534-541. https://doi.org/10.23736/s0022-4707.20.11396-3

Conte, D., Kolb, N., Scanlan, A. T., & Santolamazza, F. (2018). Monitoring Training Load and Well-Being During the In-Season Phase in National Collegiate Athletic Association Division I Men's Basketball. *International Journal of Sports Physiology and Performance, 13*(8), 1067-1074. https://doi.org/10.1123/ijspp.2017-0689

Cook, T. D., & Campbell, D. T. (1979). Quasi-experimentation: Design and analysis issues for field settings. Houghton Mifflin.

Coppalle, S., Ravé, G., Moran, J., Salhi, I., Abderrahman, A. B., Zouita, S., Granacher, U., & Zouhal, H. (2021). Internal and External Training Load in Under-19 versus Professional Soccer Players during the In-Season Period. *Int J Environ Res Public Health, 18*(2). https://doi.org/10.3390/ijerph18020558

Coppus, T. A., Anderson, T., Hurley, E., Gill, D. L., & Brown, P. K. (2022). The Practical Utility of Objective Training Load Indices in Division I College Soccer Players. *Journal of Strength and Conditioning Research, 36*(4), 1026-1030. https://doi.org/10.1519/jsc.0000000000004227

Cormack, S., Newton, R., & McGuigan, M. (2008). Neuromuscular and endocrine responses of elite players to an Australian rules football match. *International Journal of Sports Physiology and Performance, 3*(3), 359–374.

Corrigan, S. L., Bulmer, S., Roberts, S. S. H., Warmington, S., Drain, J., & Main, L. C. (2022). Monitoring Responses to Basic Military Training with Heart Rate Variability. *Medicine and Science in Sports and Exercise, 54*(9), 1506-1514. https://doi.org/10.1249/MSS.0000000000002930

Costa, J. A., Brito, J., Nakamura, F. Y., Dores, H., & Rebelo, A. (2022). Associations between 24-h heart rate variability and aerobic fitness in high-level female soccer players. *Scand J Med Sci Sports, 32 Suppl 1*, 140-149. https://doi.org/10.1111/sms.14116

Costa, J. A., Brito, J., Nakamura, F. Y., Oliveira, E. M., Costa, O. P., & Rebelo, A. N. (2019). Does Night Training Load Affect Sleep Patterns and Nocturnal Cardiac Autonomic Activity in High-Level Female Soccer Players? *International Journal of Sports Physiology and Performance, 14*(6), 779–787. https://doi.org/10.1123/ijspp.2018-0652

Costa, J. A., Figueiredo, P., Nakamura, F. Y., Rebelo, A., & Brito, J. (2021). Monitoring Individual Sleep and Nocturnal Heart Rate Variability Indices: The Impact of Training and Match Schedule and Load in High-Level Female Soccer Players. *Frontiers in Physiology, 12*, 678462. https://doi.org/10.3389/fphys.2021.678462

Costa, J. A., Figueiredo, P., Prata, A., Reis, T., Reis, J. F., Nascimento, L., & Brito, J. (2022). Associations between Training Load and Well-Being in Elite Beach Soccer Players: A Case Report. *Int J Environ Res Public Health, 19*(10). https://doi.org/10.3390/ijerph19106209

Costa, J., Figueiredo, P., Nakamura, F., Rago, V., Rebelo, A., & Brito, J. (2019). Intra-individual variability of sleep and nocturnal cardiac autonomic activity in elite female soccer players during an international tournament. *PLoS One, 14*(9), e0218635. https://doi.org/10.1371/journal.pone.0218635

Cox, R. H., Martens, M. P., & Russell, W. D. (2003). Measuring anxiety in athletics: The revised competitive state anxiety inventory. Journal of Sport and Exercise Psychology, 25(4), 519-533. https://doi.org/10.1123/jsep.25.4.519

Coyne, J. O. C., Coutts, A. J., Newton, R. U., & Gregory Haff, G. (2021). Relationships Between Different Internal and External Training Load Variables and Elite International Women's Basketball Performance. *International Journal of Sports Physiology and Performance, 16*(6), 871-880. https://doi.org/10.1123/ijspp.2020-0495

Crang, Z. L., Hewitt, A., Scott, T. J., Kelly, V. G., & Johnston, R. D. (2020). Relationship Between Preseason Training Load, Match Performance, and Match Activities in Professional Rugby League. *Journal of Strength and Conditioning Research*. https://doi.org/10.1519/jsc.0000000000003891

Crouch, A. K., Jiroutek, M. R., Snarr, R. L., & Bunn, J. A. (2021). Relationship between pre-training wellness scores and internal and external training loads in a Division I women's lacrosse team. *Journal of Sports Sciences, 39*(9), 1070-1076. https://doi.org/10.1080/02640414.2020.1857106

Cruz, I. F., Pereira, L. A., Kobal, R., Kitamura, K., Cedra, C., Loturco, I., & Cal Abad, C. C. (2018). Perceived training load and jumping responses following nine weeks of a competitive period in young female basketball players. *PeerJ, 6*, e5225. https://doi.org/10.7717/peerj.5225

Cullen, B. D., Roantree, M. T., McCarren, A. L., Kelly, D. T., O'Connor, P. L., Hughes, S. M., Daly, P. G., & Moyna, N. M. (2017). Physiological Profile and Activity Pattern of Minor Gaelic Football Players. *Journal of Strength and Conditioning Research, 31*(7), 1811-1820. https://doi.org/10.1519/jsc.0000000000001667

Curtis, R. M., Huggins, R. A., Benjamin, C. L., Sekiguchi, Y., Adams, W. M., Arent, S. M., Jain, R., Miller, S. J., Walker, A. J., & Casa, D. J. (2020). Contextual Factors Influencing External and Internal Training Loads in Collegiate Men's Soccer. *Journal of Strength and Conditioning Research, 34*(2), 374-381. https://doi.org/10.1519/jsc.0000000000003361

da Silva, C. D., Machado, G., Fernandes, A. A., Teoldo, I., Pimenta, E. M., Marins, J. C. B., & Garcia, E. S. (2021). Muscle Damage-Based Recovery Strategies Can Be Supported by Predictive Capacity of Specific Global Positioning System Accelerometry Parameters Immediately a Post-Soccer Match-Load. *Journal of Strength and Conditioning Research, 35*(5), 1410-1418. https://doi.org/10.1519/jsc.0000000000002922

Daanen, H. A., Lamberts, R. P., Kallen, V. L., et al. (2012). A systematic review on heart-rate recovery to monitor changes in training status in athletes. *International Journal of Sports Physiology and Performance, 7*, 251–260. https://doi.org/10.1123/ijspp.7.3.251

Dalen, T., & Lorås, H. (2019). Monitoring Training and Match Physical Load in Junior Soccer Players: Starters versus Substitutes. *Sports (Basel), 7*(3). https://doi.org/10.3390/sports7030070

Danev, S. S. (1989). Informativeness of Heart Rhythm in Occupational Physiological Aspect [in Bulgarian] (D.Sc. Thesis). Sofia, Bulgaria

Daniel, F., David, M., Joan, A. C., & Gerard, C. (2021). Integrating External and Internal Load for Monitoring Fitness and Fatigue Status in Standard Microcycles in Elite Rink Hockey. *Frontiers in Physiology, 12*. https://doi.org/10.3389/fphys.2021.698463

de Dios-Álvarez, V., Alkain, P., Castellano, J., & Rey, E. (2021). Accumulative Weekly External and Internal Load Relative to Match Load in Elite Male Youth Soccer Players. *Pediatr Exerc Sci*, 1-6. https://doi.org/10.1123/pes.2021-0048

de Dios-Álvarez, V., Suárez-Iglesias, D., Bouzas-Rico, S., Alkain, P., González-Conde, A., & Ayán-Pérez, C. (2021). Relationships between RPE-derived internal training load parameters and GPS-based external training load variables in elite young soccer players. *Research in Sports Medicine*, 1-16. https://doi.org/10.1080/15438627.2021.1937165

Delecroix, B., Delaval, B., Dawson, B., Berthoin, S., & Dupont, G. (2019). Workload and injury incidence in elite football academy players. *Journal of Sports Sciences, 37*(24), 2768-2773. https://doi.org/10.1080/02640414.2019.1584954

Dello Iacono, A., Martone, D., Cular, D., Milic, M., & Padulo, J. (2017). Game Profile-Based Training in Soccer: A New Field Approach. *Journal of Strength and Conditioning Research, 31*(12), 3333-3342. https://doi.org/10.1519/jsc.0000000000001768

Dlugosz, R. T., & Iniewski, K. (2006). Ultra Low Power Current-mode Algorithmic Analog-to-digital Converter Implemented in 0.18 µm CMOS Technology for Wireless Sensor Network. In Proceedings of the International Conference on Mixed Design of Integrated Circuits and Systems, MIXDES 2006 (pp. 67-72). IEEE. https://doi.org/10.1109/MIXDES.2006.1706608

Dobbin, N., Thorpe, C., Highton, J., & Twist, C. (2020). Sex-Related Changes in Physical Performance, Well-Being, and Neuromuscular Function of Elite Touch Players During a 4-Day International Tournament. *International Journal of Sports Physiology and Performance, 15*(8), 1138-1146. https://doi.org/10.1123/ijspp.2019-0594

Doeven, S. H., Brink, M. S., Huijgen, B. C. H., de Jong, J., & Lemmink, K. (2021). Managing Load to Optimize Well-Being and Recovery During Short-Term Match Congestion in Elite Basketball. *International Journal of Sports Physiology and Performance, 16*(1), 45-50. https://doi.org/10.1123/ijspp.2019-0916

Douchet, T., Humbertclaude, A., Cometti, C., Paizis, C., & Babault, N. (2021). Quantifying Accelerations and Decelerations in Elite Women Soccer Players during Regular In-Season Training as an Index of Training Load. *Sports, 9*(8). https://doi.org/10.3390/sports9080109

Draghici, A.E., & Taylor, J.A. (2016). The physiological basis and measurement of heart rate variability in humans. *Journal of Physiology and Anthropology, 35*, 1-8. doi: 10.1186/s40101-015-0094-5

Drain, J. R., Groeller, H., Burley, S. D., & Nindl, B. C. (2017). Hormonal response patterns are differentially influenced by physical conditioning programs during basic military training. *Journal of Science and Medicine in Sport, 20*, S98-S103-S103. https://doi.org/10.1016/j.jsams.2017.08.020

Dubois, R., Paillard, T., Lyons, M., McGrath, D., Maurelli, O., & Prioux, J. (2017). Running and Metabolic Demands of Elite Rugby Union Assessed Using Traditional, Metabolic Power, and Heart Rate Monitoring Methods. *Journal of Sport Science and Medicine, 16*(1), 84-92.

Duthie, G. M., Thornton, H. R., Delaney, J. A., Connolly, D. R., & Serpiello, F. R. (2018). Running Intensities in Elite Youth Soccer by Age and Position. *Journal of Strength and Conditioning Research, 32*(10), 2918-2924. https://doi.org/10.1519/jsc.0000000000002728

Edwards, S. (1993). High performance training and racing. In The Heart Rate Monitor Book. Feet Fleet Press. pp. 113-123. Sacramento, CA.

Enes, A., Oneda, G., Alves, D. L., de P. Palumboa, D., Cruz, R., Moiano Junior, J. V. M., Novack, L. F., & Osiecki, R. (2021). Determinant Factors of the Match-Based Internal Load in Elite Soccer Players. *Research Quarterly for Exercise & Sport, 92*(1), 63-70. https://doi.org/10.1080/02701367.2019.1710445

Enes, A., Oneda, G., Alves, D. L., Palumbo, D. P., Cruz, R., Moiano Junior, J. V. M., Novack, L. F., & Osiecki, R. (2021). Determinant Factors of the Match-Based Internal Load in Elite Soccer Players. *Research Quarterly for Exercise & Sport, 92*(1), 63-70. https://doi.org/10.1080/02701367.2019.1710445

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: Attentional control theory. Emotion, 7(2), 336-353.

Ferioli, D., Bosio, A., Bilsborough, J. C., La Torre, A., Tornaghi, M., & Rampinini, E. (2018). The Preparation Period in Basketball: Training Load and Neuromuscular Adaptations. *International Journal of Sports Physiology and Performance, 13*(8), 991-999. https://doi.org/10.1123/ijspp.2017-0434

Ferioli, D., Bosio, A., Bilsborough, J. C., Torre, A. La, Tornaghi, M., & Rampinini, E. (2018). The preparation period in basketball: training load and neuromuscular adaptations. *International Journal of Sports Physiology and Performance, 13*(1), 42–49.

Ferioli, D., Scanlan, A. T., Conte, D., Tibiletti, E., & Rampinini, E. (2021). The Business End of the Season: A Comparison Between Playoff and Regular-Season Workloads in Professional Basketball Players. *International Journal of Sports Physiology and Performance, 16*(5), 655-662. https://doi.org/10.1123/ijspp.2020-0405

Fernandes, R., Brito, J. P., Vieira, L. H. P., Martins, A. D., Clemente, F. M., Nobari, H., Reis, V. M., & Oliveira, R. (2021). In-Season Internal Load and Wellness Variations in Professional Women Soccer Players: Comparisons between Playing Positions and Status. *Int J Environ Res Public Health, 18*(23). https://doi.org/10.3390/ijerph182312817

Fernandes, R., Ceylan, H., Clemente, F. M., Brito, J. P., Martins, A. D., Nobari, H., Reis, V. M., & Oliveira, R. (2022). In-Season Microcycle Quantification of Professional Women Soccer Players-External, Internal and Wellness Measures. *Healthcare (Basel), 10*(4). https://doi.org/10.3390/healthcare10040695

Fernández, D., Moya, D., Cadefau, J. A., & Carmona, G. (2021). Integrating External and Internal Load for Monitoring Fitness and Fatigue Status in Standard Microcycles in Elite Rink Hockey. *Frontiers in Physiology, 12*, 698463. https://doi.org/10.3389/fphys.2021.698463

Fields, J. B., Lameira, D. M., Short, J. L., Merrigan, J. M., Gallo, S., White, J. B., & Jones, M. T. (2021). Relationship Between External Load and Self-Reported Wellness Measures Across a Men's Collegiate Soccer Preseason. *Journal of Strength and Conditioning Research, 35*(5), 1182-1186. https://doi.org/10.1519/jsc.0000000000003997

Fields, J. B., Merigan, J. M., Gallo, S., White, J. B., & Jones, M. T. (2021). External and Internal Load Measures During Preseason Training in Men Collegiate Soccer Athletes. *Journal of Strength and Conditioning Research, 35*(9), 2572-2578. https://doi.org/10.1519/jsc.0000000000004092

Figueiredo, P., Nassis, G. P., & Brito, J. (2019). Within-Subject Correlation Between Salivary IgA and Measures of Training Load in Elite Football Players. *International Journal of*

Sports Physiology and Performance, 14(6), 847–849. https://doi.org/10.1123/ijspp.2018-0455

Flatt, A. A., & Howells, D. (2019). Effects of varying training load on heart rate variability and running performance among an Olympic rugby sevens team. *Journal of Science and Medicine in Sport, 22*(2), 222-226. https://doi.org/10.1016/j.jsams.2018.07.014

Flatt, A. A., Esco, M. R., Allen, J. R., Robinson, J. B., Earley, R. L., Fedewa, M. V., Bragg, A., Keith, C. M., & Wingo, J. E. (2018). Heart Rate Variability and Training Load Among National Collegiate Athletic Association Division 1 College Football Players Throughout Spring Camp. *Journal of Strength and Conditioning Research, 32*(11), 3127-3134. https://doi.org/10.1519/jsc.0000000000002241

Foster, C. (1998). Monitoring training in athletes with reference to overtraining syndrome. *Medicine and Science in Sports and Exercise, 30*(7), 1164–1168. https://doi.org/10.1097/00005768-199807000-00023

Foster, C., Porcari, J. P., Ault, S., Doro, K., Dubiel, J., Engen, M., ... Xiong, S. (2018). Exercise prescription when there is no exercise test: The talk test. *Kinesiology, 50*, 33-48.

Fox, J. L., O'Grady, C. J., & Scanlan, A. T. (2020). The Relationships Between External and Internal Workloads During Basketball Training and Games. *International Journal of Sports Physiology and Performance, 15*(8), 1081-1086. https://doi.org/10.1123/ijspp.2019-0722

Fox, J. L., Scanlan, A. T., Stanton, R., O'Grady, C. J., & Sargent, C. (2020). Losing Sleep Over It: Sleep in Basketball Players Affected by Game But Not Training Workloads. *International Journal of Sports Physiology and Performance, 15*(8), 1117-1124. https://doi.org/10.1123/ijspp.2019-0676

Fox, J. L., Stanton, R., & Scanlan, A. T. (2018). A Comparison of Training and Competition Demands in Semiprofessional Male Basketball Players. *Research Quarterly for Exercise & Sport, 89*(1), 103-111. https://doi.org/10.1080/02701367.2017.1410693

Fox, J. L., Stanton, R., O'Grady, C. J., Teramoto, M., Sargent, C., & Scanlan, A. T. (2022). Are acute player workloads associated with in-game performance in basketball? *Biol Sport, 39*(1), 95-100. https://doi.org/10.5114/biolsport.2021.102805

Friedl, M., Kramer, Shippee. (1995). Acute recovery of physiological and cognitive function in US Army Ranger students in a multistressor field environment. *Presented at: RTO HFM Workshop on "Effect of Prolonged Military Activities in Man. Physiological and Biochemical Changes, Possible Means of Rapid Recuperation"*.

Fuller, D., Colwell, E., Low, J., Agrawal, S., Sutherland, R., Jones, A., & Sultana, K. (2020). Reliability and validity of commercially available wearable devices for measuring steps, energy expenditure, and heart rate: systematic review. *JMIR Health and Health, 8*(10), e18694.

Furlan, R., Barbic, F., Piazza, S., Tinelli, M., Seghizzi, P., & Malliani, A. (2000). Modifications of cardiac autonomic profile associated with a shift schedule of work. *Circulation, 102*(16), 1912–1916. https://doi.org/10.1161/01.CIR.102.16.1912

Furlan, R., Guzzetti, S., Crivellaro, W., Dassi, S., Tinelli, M., Baselli, G., ... Malliani, A. (1990). Continuous 24-hour assessment of the neural regulation of systemic arterial pressure and RR variabilities in ambulant subjects. *Circulation, 81*(2), 537–547. https://doi.org/10.1161/01.CIR.81.2.537

Gabbett, T. J., & Domrow, N. (2007). Relationships between training load, injury, and fitness in sub-elite collision sport athletes. *Journal of Sports Sciences, 25*(13), 1507-1519.

Gabbett, T. J., Nassis, G. P., Oetter, E., Pretorius, J., Johnston, N., Medina, D., . . . Ryan, A. (2017). The athlete monitoring cycle: A practical guide to interpreting and applying training monitoring data. *British Journal of Sports Medicine, 51*(20), 1451–1452.

Gallo-Salazar, C., Del Coso, J., Sanz-Rivas, D., & Fernandez-Fernandez, J. (2019). Game Activity and Physiological Responses of Young Tennis Players in a Competition With Two Consecutive Matches in a Day. *International Journal of Sports Physiology and Performance, 14*(7), 887-893. https://doi.org/10.1123/ijspp.2018-0234

Gamonales, J. M., León, K., Rojas-Valverde, D., Sánchez-Ureña, B., & Muñoz-Jiménez, J. (2021). Data Mining to Select Relevant Variables Influencing External and Internal Workload of Elite Blind 5-a-Side Soccer. *Int J Environ Res Public Health, 18*(6). https://doi.org/10.3390/ijerph18063155

Gantois, P., Piqueras-Sanchiz, F., Cid, M., Pino-Ortega, J., Castillo, D., & Nakamura, F. Y. (2022). The effects of different small-sided games configurations on heart rate, rating of perceived exertion, and running demands in professional soccer players. *European Journal of Sport Science*, 1-9. https://doi.org/10.1080/17461391.2022.2092427

García-Ceberino, J. M., Bravo, A., de la Cruz-Sánchez, E., & Feu, S. (2022). Analysis of Intensities Using Inertial Motion Devices in Female Soccer: Do You Train like You Compete? *Sensors (Basel), 22*(8). https://doi.org/10.3390/s22082870

García-Santos, D., Pino-Ortega, J., García-Rubio, J., Vaquera, A., & Ibáñez, S. J. (2019). Internal and External Demands in Basketball Referees during the U-16 European Women's Championship. *Int J Environ Res Public Health, 16*(18). https://doi.org/10.3390/ijerph16183421

García, F., Fernández, D., & Martín, L. (2022). Relationship Between Game Load and Player's Performance in Professional Basketball. *International Journal of Sports Physiology and Performance*, 1-7. https://doi.org/10.1123/ijspp.2021-0511

Gathercole, R., Sporer, B., & Stellingwerff, T. (2015). Countermovement jump performance with increased training loads in elite female rugby athletes. *International Journal of Sports Medicine, 36*(9), 722–728.

Gelenberg, A. J. (2000). Psychiatric and somatic markers of anxiety: Identification and pharmacologic treatment. Primary Care Companion to the Journal of Clinical Psychiatry, 2(2), 49–54. doi:10.4088/PCC.v02n0204

Gentles, J. A., Coniglio, C. L., Besemer, M. M., Morgan, J. M., & Mahnken, M. T. (2018). The Demands of a Women's College Soccer Season. *Sports (Basel), 6*(1). https://doi.org/10.3390/sports6010016

George, B., Meenakshy. (2015). Assessing the Effect of Long Term Physical Training and Classification of Training Status using HRV and HRR of Female Police Recruits. https://doi.org/DOI 10.5013/IJSSST.a.19.06.15

Ghali, B. M., Owoeye, O. B. A., Stilling, C., Palacios-Derflingher, L., Jordan, M., Pasanen, K., & Emery, C. A. (2020). Internal and External Workload in Youth Basketball Players Who Are Symptomatic and Asymptomatic for Patellar Tendinopathy. *J Orthop Sports Phys Ther, 50*(7), 402-408. https://doi.org/10.2519/jospt.2020.9094

Gielen, J., Mehuys, E., Berckmans, D., Meeusen, R., & Aerts, J.-M. (2022). Monitoring Internal and External Load During Volleyball Competition. *International Journal of Sports Physiology & Performance, 17*(4), 640-645.

Giménez, J. V., Del-Coso, J., Leicht, A. S., & Gomez, M. (2018). Comparison of the movement patterns between small- and large-sided game training and competition in professional soccer players. *J Sports Med Phys Fitness, 58*(10), 1383-1389. https://doi.org/10.23736/s0022-4707.17.07343-1

Giménez, J. V., Leicht, A. S., & Gomez, M. A. (2019). Physical Performance Differences Between Starter and Non-Starter Players During Professional Soccer Friendly Matches. *J Hum Kinet, 69*, 283-291. https://doi.org/10.2478/hukin-2019-0018

Gisselman, A. S., Spontelli, G., Baxter, D. G., Wright, A., Hegedus, E. J., & Tumilty, S. (2016). Musculoskeletal overuse injuries and heart rate variability: Is there a link? Medical hypotheses, 87, 1-7. https://doi.org/10.1016/j.mehy.2015.12.004

Gonçalves, L., Clemente, F. M., Silva, B., Mendes, B., Lima, R., Bezerra, P., & Camões, M. (2020). Variations of season workload and well-being status among professional roller-hockey players: Full season analysis. *Physiol Behav, 215*, 112785. https://doi.org/10.1016/j.physbeh.2019.112785

González-Fimbres, R. A., Hernández-Cruz, G., & Flatt, A. A. (2021). Ultrashort Versus Criterion Heart Rate Variability Among International-Level Girls' Field Hockey Players. *International Journal of Sports Physiology and Performance form, 16*(7), 985-992. https://doi.org/10.1123/ijspp.2020-0362

Goodale, T. L., Gabbett, T. J., Tsai, M. C., Stellingwerff, T., & Sheppard, J. (2017). The Effect of Contextual Factors on Physiological and Activity Profiles in International Women's Rugby Sevens. *International Journal of Sports Physiology and Performance, 12*(3), 370-376. https://doi.org/10.1123/ijspp.2015-0711

Govus, A. D., Coutts, A., Duffield, R., Murray, A., & Fullagar, H. (2018). Relationship Between Pretraining Subjective Wellness Measures, Player Load, and Rating-of-Perceived-Exertion Training Load in American College Football. *International Journal of Sports Physiology and Performance, 13*(1), 95-101. https://doi.org/10.1123/ijspp.2016-0714

Graham, S. R., Cormack, S., Parfitt, G., & Eston, R. (2018). Relationships Between Model Estimates and Actual Match-Performance Indices in Professional Australian Footballers During an In-Season Macrocycle. *International Journal of Sports Physiology and Performance, 13*(3), 339-346. https://doi.org/10.1123/ijspp.2017-0026

Graham, S. R., Cormack, S., Parfitt, G., & Eston, R. (2019). Relationships Between Model-Predicted and Actual Match-Play Exercise-Intensity Performance in Professional Australian Footballers During a Preseason Training Macrocycle. *International Journal of Sports Physiology and Performance, 14*(2), 232-238. https://doi.org/10.1123/ijspp.2017-0752

Graham, T. E., Turcotte, L. P., Kiens, B., & Richter, E. A. (1997). Effect of endurance training on ammonia and amino acid metabolism in humans. *Medicine and Science in Sports and Exercise, 29*(5), 646–653.

Grant, C. C., Mongwe, L., Janse Van Rensburg, D. C., Fletcher, L., Wood, P. S., Terblanche, E., & Du Toit, P. J. (2016). The difference between exercise-induced autonomic and fitness changes measured after 12 and 20 weeks of medium-to-high intensity military training. *Journal of Strength and Conditioning Research, 30*(9), 2453-2459-2459. https://doi.org/10.1519/JSC.0b013e3182a1fe46

Greenham, G., Buckley, J. D., Garrett, J., Eston, R., & Norton, K. (2018). Biomarkers of physiological responses to periods of intensified, non-resistance-based exercise training in well-trained male athletes: A systematic review and meta-analysis. *Sports Medicine, 48*, 2517–2548.

Griffin, A., Kenny, I. C., Comyns, T. M., & Lyons, M. (2021). Training Load Monitoring in Amateur Rugby Union: A Survey of Current Practices. *Journal of Strength and Conditioning Research, 35*(6), 1568-1575. https://doi.org/10.1519/jsc.0000000000003637

Grünbichler, J., Federolf, P., & Gatterer, H. (2020). Workload efficiency as a new tool to describe external and internal competitive match load of a professional soccer team: A descriptive study on the relationship between pre-game training loads and relative match load. *European Journal of Sport Science, 20*(8), 1034-1041. https://doi.org/10.1080/17461391.2019.1697374

Gualtieri, A., Rampinini, E., Sassi, R., & Beato, M. (2020). Workload Monitoring in Top-level Soccer Players During Congested Fixture Periods. *International Journal of Sports Medicine, 41*(10), 677-681. https://doi.org/10.1055/a-1171-1865

Gunnar, M. R., & Quevedo, K. (2007). The neurobiology of stress and development. *Annual Review of Psychology, 58*, 145-173. doi: 10.1146/annurev.psych.58.110405.085605

Guridi Lopategui, I., Castellano Paulis, J., & Echeazarra Escudero, I. (2021). Physical Demands and Internal Response in Football Sessions According to Tactical Periodization. *International Journal of Sports Physiology and Performance, 16*(6), 858-864. https://doi.org/10.1123/ijspp.2019-0829

Haines, B. R., Bourdon, P. C., & Deakin, G. (2016). Reliability of common neuromuscular performance tests in adolescent athletes. *Journal of Australian Strength & Conditioning, 24*(4), 16-22.

Halouani, J., Ghattasi, K., Bouzid, M. A., Rosemann, T., Nikolaidis, P. T., Chtourou, H., & Knechtle, B. (2019). Physical and Physiological Responses during the Stop-Ball Rule

During Small-Sided Games in Soccer Players. *Sports (Basel), 7*(5). https://doi.org/10.3390/sports7050117

Halson SL. Monitoring training load to understand fatigue in athletes. *Sports Medicine*, *44*(Suppl 2):S139–47.

Halson, S. L., & Jeukendrup, A. E. (2004). Does overtraining exist? An analysis of overreaching and overtraining research. *Sports Medicine, 34*, 967-981.

Hammami, A., Randers, M. B., Kasmi, S., Razgallah, M., Tabka, Z., Chamari, K., & Bouhlel, E. (2018). Effects of soccer training on health-related physical fitness measures in male adolescents. *J Sport Health Sci, 7*(2), 169-175. https://doi.org/10.1016/j.jshs.2017.10.009

Harrison, E., Glickman, G. L., Beckerley, S., & Taylor, M. K. (2017). Self-reported sleep during U.S. navy operations and the impact of deployment-related factors. Military Medicine, 182(S1), 189–194. https://doi.org/10.7205/MILMED-D-16-00078

Harrison, Y., & Horne, J. A. (2000). The impact of sleep deprivation on decision making: A review. Journal of Experimental Psychology: Applied, 6(3), 236-249. https://doi.org/10.1037//1076-898x.6.3.236

Harry, K., & Booysen, M. J. (2020). Faster Heart Rate Recovery Correlates With High-Intensity Match Activity in Female Field Hockey Players-Training Implications. *Journal of Strength and Conditioning Research, 34*(4), 1150-1157. https://doi.org/10.1519/jsc.0000000000003073

Hauer, R., Tessitore, A., Knaus, R., & Tschan, H. (2020). Lacrosse Athletes Load and Recovery Monitoring: Comparison between Objective and Subjective Methods. *Int J Environ Res Public Health, 17*(9). https://doi.org/10.3390/ijerph17093329

Head, J., Tenan, M. S., Tweedell, A. J., LaFiandra, M. E., Morelli, F., Wilson, K. M., Ortega, S. V., & Helton, W. S. (2017). Prior mental fatigue impairs marksmanship decision performance. Frontiers in Physiology, 8, Article 680. https://doi.org/10.3389/fphys.2017.00680

Hedelin, R., Wiklund, U., Bjerle, P., & Henriksson-Larsén, K. (2000). Cardiac autonomic imbalance in an overtrained athlete. *Medicine and Science in Sports and Exercise, 32*, 1531-1533.

Heinrich, A., Hansen, D. W., Stoll, O., & Cañal-Bruland, R. (2020). The impact of physiological fatigue and gaze behavior on shooting performance in expert biathletes. *Journal of Science and Medicine in Sport, 23*(9), 883-890. https://doi.org/10.1016/j.jsams.2020.02.010

Heishman, A. D., Daub, B. D., Miller, R. M., Freitas, E. D. S., & Bemben, M. G. (2020). Monitoring External Training Loads and Neuromuscular Performance for Division I Basketball Players over the Preseason. *Journal of Sports Science & Medicine, 19*(1), 204-212.

Heishman, A., Brown, B., Daub, B., Miller, R., Freitas, E. D. S., & Bemben, M. (2019). The influence of countermovement jump protocol on reactive strength index modified and flight time: contraction time in collegiate basketball players. *Sports, 7*(2), 37.

Hellard, P., Guimaraes, F., Avalos, M., Houel, N., Hausswirth, C., & Toussaint, J. F. (2011). Modeling the association between HR variability and illness in elite swimmers. *Medicine and Science in Sports and Exercise, 43*, 1063-1070.

Hew-Butler, T. D., Eskin, C., Bickham, J., Rusnak, M., & VanderMeulen, M. (2018). Dehydration is how you define it: Comparison of 318 blood and urine athlete spot checks. *BMJ Open Sport & Exercise Medicine, 4*(1), e000297.

Hopkins, W. G. (1991). Quantification of training in competitive sports: Methods and applications. *Sports Medicine, 12*, 161–183. https://doi.org/10.2165/00007256-199112030-00003

Hormeño-Holgado, A. J., & Clemente-Suárez, V. J. (2019). Effect of different combat jet manoeuvres in the psychophysiological response of professional pilots. *Physiology and Behavior, 208*. https://doi.org/10.1016/j.physbeh.2019.112559

Horner, F., Bilzon, J. L., Rayson, M., Blacker, S., Richmond, V., Carter, J., ... Nevill, A. (2013). Development of an accelerometer-based multivariate model to predict free-living energy expenditure in a large military cohort. *Journal of Sports Sciences, 31*(4), 354–360.

Horta, T. A. G., Bara Filho, M. G., Coimbra, D. R., Miranda, R., & Werneck, F. Z. (2019). Training Load, Physical Performance, Biochemical Markers, and Psychological Stress During a Short Preparatory Period in Brazilian Elite Male Volleyball Players. *Journal of Strength and Conditioning Research, 33*(12), 3392-3399. https://doi.org/10.1519/jsc.0000000000002404

Howle, K., Waterson, A., & Duffield, R. (2020). Injury Incidence and Workloads during congested Schedules in Football. *International Journal of Sports Medicine, 41*(2), 75-81. https://doi.org/10.1055/a-1028-7600

Howley, E. T. (2001). Type of activity: resistance, aerobic and leisure versus occupational physical activity. *Medicine & Science in Sports & Exercise, 33*(5), S364-S369.

Huang, M., Frantz, J., Moralez, G., Sabo, T., Davis, P. F., Davis, S. L., ... & Purkayastha, S. (2019). Reduced resting and increased elevation of heart rate variability with cognitive task performance in concussed athletes. *Journal of Head Trauma Rehabilitation, 34*(1), 45-51. doi: 10.1097/HTR.0000000000000401

Iacono, A. D., Unnithan, V., Shushan, T., King, M., & Beato, M. (2022). Training load responses to football game profile-based training (GPBT) formats: effects of locomotive demands manipulation. *Biol Sport, 39*(1), 145-155. https://doi.org/10.5114/biolsport.2021.102919

Iannaccone, A., Fusco, A., Skarbalius, A., Kniubaite, A., Cortis, C., & Conte, D. (2022). Relationship Between External and Internal Load Measures in Youth Beach Handball.

International Journal of Sports Physiology & Performance, 17(2), 256-262. https://doi.org/10.1123/ijspp.2021-0225

Ihsan, M., Tan, F., Sahrom, S., Choo, H. C., Chia, M., & Aziz, A. R. (2017). Pre-game perceived wellness highly associates with match running performances during an international field hockey tournament. *European Journal of Sport Science, 17*(5), 593-602. https://doi.org/10.1080/17461391.2017.1301559

Impellizzeri, F. M., Marcora, S. M., & Coutts, A. J. (2019). Interna and external training load: 15 years on. *International Journal of Sports Physiology and Performance, 14*(2), 270–273.

Impellizzeri, F. M., Rampinini, E., Coutts, A. J., Sassi, A., & Marcora, S. M. (2004). Use of RPE-based training load in soccer. *Medicine & Science in Sports & Exercise, 36*, 1042–1047. https://doi.org/10.1249/01.MSS.0000135782.99162.5F

Irving, S., Orr, R., & Pope, R. (2019). Profiling the Occupational Tasks and Physical Conditioning of Specialist Police. *International Journal of Exercise Science, 12*(3), 173-186. https://ezproxy.aut.ac.nz/login?url=https://search.ebscohost.com/login.aspx?direct=true&site=eds-live&db=s3h&AN=135047485

Jaarsveld, S., & Lachmann, T. (2017). Intelligence and Creativity in Problem Solving: The Importance of Test Features in Cognition Research. *Frontiers in Psychology*, *8*, Article 2129. https://doi.org/10.3389/fpsyg.2017.02129

James, C., Dhawan, A., Jones, T., & Girard, O. (2021). Quantifying Training Demands of a 2-Week In-Season Squash Microcycle. *International Journal of Sports Physiology and Performance, 16*(6), 779-786. https://doi.org/10.1123/ijspp.2020-0306

James, C., Dhawan, A., Jones, T., Pok, C., Yeo, V., & Girard, O. (2021). Minimal Agreement between Internal and External Training Load Metrics across a 2-wk Training Microcycle in Elite Squash. *Journal of Sport Science and Medicine, 20*(1), 101-109. https://doi.org/10.52082/jssm.2021.101

Jaspers, A., Brink, M. S., Probst, S. G., Frencken, W. G., & Helsen, W. F. (2017). Relationships Between Training Load Indicators and Training Outcomes in Professional Soccer. *Sports Medicine, 47*(3), 533-544. https://doi.org/10.1007/s40279-016-0591-0

Jaspers, A., De Beéck, T. O., Brink, M. S., Frencken, W. G. P., Staes, F., Davis, J. J., & Helsen, W. F. (2018). Relationships Between the External and Internal Training Load in Professional Soccer: What Can We Learn From Machine Learning? *International Journal of Sports Physiology and Performance, 13*(5), 625-630. https://doi.org/10.1123/ijspp.2017-0299

Jaspers, A., Kuyvenhoven, J. P., Staes, F., Frencken, W. G. P., Helsen, W. F., & Brink, M. S. (2018). Examination of the external and internal load indicators' association with overuse injuries in professional soccer players. *J Sci Med Sport, 21*(6), 579-585. https://doi.org/10.1016/j.jsams.2017.10.005

Jin, N., Tian, J., Li, Y., & Mi, J. (2022). A Validation Study of Heart Rate Variability Index in Monitoring Basketball Training Load. *Frontiers in Physiology, 13*, 881927. https://doi.org/10.3389/fphys.2022.881927

Johnson, C. D., Simonson, A. J., Darnell, M. E., DeLany, J. P., Wohleber, M. F., & Connaboy, C. (2018). Energy expenditure and intake during Special Operations Forces field training in a jungle and glacial environment. *Applied Physiology, Nutrition & Metabolism, 43*(4), 381-386. https://ezproxy.aut.ac.nz/login?url=https://search.ebscohost.com/login.aspx?direct=true&site=eds-live&db=s3h&AN=128694622

Jones, P. J., Winthrop, A. L., Schoeller, D. A., Swyer, P. R., Smith, J., Filler, R. M., & Heim, T. (1987). Validation of doubly labeled water for assessing energy expenditure in infants. Pediatric Research, 21(3), 242-246. https://doi.org/10.1203/00006450-198703000-00007

Jorge Santos, F., Caldeira Ferreira, C., Palmira Figueiredo, T., & Espada, M. C. (2021). Influence of different 1v1 small-sided game conditions in internal and external load of U-15 and U-12 soccer players. *Trends in Sport Sciences, 28*(1), 45-53. https://doi.org/10.23829/TSS.2021.28.1-6

Jouanin, J., Dussault, C., Pérès, M., Satabin, P., Piérard, C., Guézennec, C. Y., Jouanin, J.-C., Dussault, C., Pérès, M., Satabin, P., Piérard, C., & Guézennec, C. Y. (2004). Analysis of heart rate variability after a ranger training course. *Military Medicine, 169*(8), 583-587. https://doi.org/10.7205/milmed.169.8.583

Jurvelin, H., Tanskanen-Tervo, M., Kinnunen, H., Santtila, M., & KyrÖLÄInen, H. (2020). Training Load and Energy Expenditure during Military Basic Training Period. *Medicine & Science in Sports & Exercise, 52*(1), 86-93. https://doi.org/10.1249/MSS.0000000000002092

Kajaia, T., Maskhulia, L., Chelidze, K., Akhalkatsi, V., & Kakhabrishvili, Z. (2017). The effects of non-functional overreaching and overtraining on autonomic nervous system function in highly trained athletes. Georgian medical news.

Kamarauskas, P., Lukonaitienė, I., Scanlan, A. T., Ferioli, D., Paulauskas, H., & Conte, D. (2022). Weekly Fluctuations in Salivary Hormone Responses and Their Relationships With Load and Well-Being in Semiprofessional, Male Basketball Players During a Congested In-Season Phase. *International Journal of Sports Physiology and Performance, 17*(2), 263-269. https://doi.org/10.1123/ijspp.2021-0106

Kellmann, M., & Kallus, K. W. (2000). The recovery-stress questionnaire for athletes. Swets & Zeitlinger.

Kellmann, M., & Kallus, K. W. (2001). The Recovery-Stress Questionnaire for Athletes. Human Kinetics.

Kellmann, M., Kölling, S., & Hitzschke, B. (2016). Das Akutmaß und die Kurzskala zur Erfassung von Erholung und Beanspruchung im Sport: Manual [The Acute Measure and Short Scale of Recovery and Stress for Sports: Manual]. Sportverlag Strauß.

Kentta, G., & Hassmen, P. (1998). Overtraining and recovery: A conceptual model. Sports Medicine, 26, 1–16. https://doi.org/10.2165/00007256-199826010-00001

Khoramipour, K., Gaeini, A. A., Shirzad, E., Gilany, K., Chashniam, S., & Sandbakk, Ø. (2021). Metabolic load comparison between the quarters of a game in elite male basketball players using sport metabolomics. *European Journal of Sport Science, 21*(7), 1022-1034. https://doi.org/10.1080/17461391.2020.1805515

King, D. A., Cummins, C., Hume, P. A., & Clark, T. N. (2020). Physical Demands of Amateur Domestic and Representative Netball in One Season in New Zealand Assessed Using Heart Rate and Movement Analysis. *Journal of Strength and Conditioning Research, 34*(7), 2062-2070. https://doi.org/10.1519/jsc.0000000000002605

Kipp, K., Kiely, M. T., & Geiser, C. F. (2016). Reactive strength index modified is a valid measure of explosiveness in collegiate female volleyball players. *Journal of Strength and Conditioning Research, 30*(5), 1341–1347.

Kiviniemi, A. M., Tulppo, M. P., Hautala, A. J., Vanninen, E., & Uusitalo, A. L. T. (2014). Altered relationship between R-R interval and R-R interval variability in endurance athletes with overtraining syndrome. *Scandinavian Journal of Medicine and Science in Sports, 24*, 77-85.

Knapik, J. J., Darakjy, S., Hauret, K. G., Canada, S., Marin, R., & Jones, B. H. (2007). Ambulatory physical activity during United States Army Basic Combat Training. *International Journal of Sports Medicine, 28*(2), 106-115-115. https://doi.org/10.1055/s-2006-924147

Kniubaite, A., Skarbalius, A., Clemente, F. M., & Conte, D. (2019). Quantification of external and internal match loads in elite female team handball. *Biol Sport, 36*(4), 311-316. https://doi.org/10.5114/biolsport.2019.88753

Koenig, J., Jarczok, M. N., Wasner, M., Hillecke, T. K., & Thayer, J. F. (2014). Heart rate variability and swimming. *Sports Medicine, 44*(5), 1377-1391. https://doi.org/10.1007/s40279-014-0196-7

Köklü, Y., Alemdaroğlu, U., Cihan, H., & Wong, D. P. (2017). Effects of Bout Duration on Players' Internal and External Loads During Small-Sided Games in Young Soccer Players. *International Journal of Sports Physiology and Performance, 12*(10), 1370-1377. https://doi.org/10.1123/ijspp.2016-0584

Konarski, J. M., Konarska, A., Strzelczyk, R., Skrzypczak, M., & Malina, R. M. (2021). Internal and External Loads During Hockey 5's Competitions Among U16 Players. *Journal of Strength and Conditioning Research, 35*(11), 3199-3206. https://doi.org/10.1519/jsc.0000000000003251

Kraemer, H. C. (1992). Achieving validity in the measurement of psychological variables. In H. C. Kraemer & D. J. Kupfer (Eds.), How psychotherapy works: Process and technique (pp. 67-92). The Guilford Press.

Krueger, M., Costello, J. T., Stenzel, M., Mester, J., & Wahl, P. (2020). The physiological effects of daily cold-water immersion on 5-day tournament performance in international standard youth field-hockey players. *Eur J Appl Physiol, 120*(1), 295-305. https://doi.org/10.1007/s00421-019-04274-8

Kudielka, B. M., Buske-Kirschbaum, A., Hellhammer, D. H., & Kirschbaum, C. (2004). HPA axis responses to laboratory psychosocial stress in healthy elderly adults, younger adults, and children: Impact of age and gender. *Psychoneuroendocrinology, 29*(1), 83-98. doi: 10.1016/s0306-4530(02)00146-4

Kuipers, H. (1998). Training and overtraining: An introduction. *Medicine and Science in Sports and Exercise, 30,* 1137-1139

Kunz, P., Zinner, C., Holmberg, H. C., & Sperlich, B. (2019). Intra- and Post-match Time-Course of Indicators Related to Perceived and Performance Fatigability and Recovery in Elite Youth Soccer Players. *Frontiers in Physiology, 10*, 1383. https://doi.org/10.3389/fphys.2019.01383

Kupperman et al. 2020. Global Positioning System-Derived Workload Metrics and Injury Risk in Team-Based Field Sports: A Systematic Review. Journal of Athletic Training (Allen Press) Sep2020, Vol. 55 Issue 9, p931 13p.

Lacome, M., Simpson, B. M., Cholley, Y., & Buchheit, M. (2018). Locomotor and Heart Rate Responses of Floaters During Small-Sided Games in Elite Soccer Players: Effect of Pitch Size and Inclusion of Goalkeepers. *International Journal of Sports Physiology and Performance, 13*(5), 668-671. https://doi.org/10.1123/ijspp.2017-0340

Lacome, M., Simpson, B., Broad, N., & Buchheit, M. (2018). Monitoring Players' Readiness Using Predicted Heart-Rate Responses to Soccer Drills. *International Journal of Sports Physiology and Performance, 13*(10), 1273-1280. https://doi.org/10.1123/ijspp.2018-0026

Lastella, M., Roach, G. D., Vincent, G. E., Scanlan, A. T., Halson, S. L., & Sargent, C. (2020). The Impact of Training Load on Sleep During a 14-Day Training Camp in Elite, Adolescent, Female Basketball Players. *International Journal of Sports Physiology and Performance, 15*(5), 724-730. https://doi.org/10.1123/ijspp.2019-0157

Lathlean, T. J. H., Gastin, P. B., Newstead, S. V., & Finch, C. F. (2019). A Prospective Cohort Study of Load and Wellness (Sleep, Fatigue, Soreness, Stress, and Mood) in Elite Junior Australian Football Players. *International Journal of Sports Physiology and Performance, 14*(6), 829–840. https://doi.org/10.1123/ijspp.2018-0372

Le Meur, Y., Pichon, A., Schaal, K., Schmitt, L., Louis, J., Gueneron, J., Vidal, P. P., & Hausswirth, C. (2013). Evidence of parasympathetic hyperactivity in functionally overreached athletes. *Medicine and Science in Sports and Exercise, 45*, 2061-2071.

Leão, C., Mendes, A. P., Custódio, C., Ng, M., Ribeiro, N., Loureiro, N., Araújo, J. P., Afonso, J., Rocha-Rodrigues, S., & Tavares, F. (2022). Nutritional Intake and Training Load of Professional Female Football Players during a Mid-Season Microcycle. *Nutrients, 14*(10). https://doi.org/10.3390/nu14102149

Leduc, C., Jones, B., Robineau, J., Piscione, J., & Lacome, M. (2019). Sleep Quality and Quantity of International Rugby Sevens Players During Pre-season. *Journal of Strength* *and Conditioning Research, 33*(7), 1878-1886. https://doi.org/10.1519/jsc.0000000000002839

Lee, E. C., Fragala, M. S., Kavouras, S. A., Queen, R. M., Pryor, J. L., & Casa, D. J. (2017). Biomarkers in sports and exercise: Tracking health, performance, and recovery in athletes. *Journal of Strength and Conditioning Research, 31*(10), 2920–2937.

Lee, M., & Mukherjee, S. (2019). Relationship of Training Load with High-intensity Running in Professional Soccer Players. *International Journal of Sports Medicine, 40*(5), 336-343. https://doi.org/10.1055/a-0855-3843

Leicht, A. S., Connor, J., Conduit, N., Vaquera, A., & Gómez, M. A. (2021). Impact of Match Type on Exercise Volume and Intensity of Semi-Professional Basketball Referees During a Competitive Season. *Research Quarterly for Exercise & Sport, 92*(4), 843-850. https://doi.org/10.1080/02701367.2020.1788207

Li, F., Knjaz, D., & Rupčić, T. (2021). Influence of Fatigue on Some Kinematic Parameters of Basketball Passing. *Int J Environ Res Public Health, 18*(2). https://doi.org/10.3390/ijerph18020700

Liao, Y., Shonkoff, E. T., & Dunton, G. F. (2015). The acute relationships between affect, physical feeling states, and physical activity in daily life: A review of current evidence. *Frontiers in Psychology, 6*, 1975. doi: 10.3389/fpsyg.2015.01975

Lim, J., & Dinges, D. F. (2010). A meta-analysis of the impact of short-term sleep deprivation on cognitive variables. Psychological Bulletin, 136(3), 375-389. https://doi.org/10.1037/a0018883

Lima, R. F., González Férnandez, F. T., Silva, A. F., Laporta, L., de Oliveira Castro, H., Matos, S., Badicu, G., Pereira, G. A., De Conti Teixeira Costa, G., & Clemente, F. M. (2022). Within-Week Variations and Relationships between Internal and External Intensities Occurring in Male Professional Volleyball Training Sessions. *Int J Environ Res Public Health, 19*(14). https://doi.org/10.3390/ijerph19148691

Lima, R. F., Lima, R. F., Silva, A., Clemente, F. M., Silva, A., Silva, A., Afonso, J., Castro, H., Clemente, F. M., & Lima, R. F. (2020). External and internal Load and their Effects on Professional Volleyball Training. *International Journal of Sports Medicine, 41*(7), 468-474. https://doi.org/10.1055/a-1087-2183

Lima, R. F., Silva, A., Afonso, J., Castro, H., & Clemente, F. M. (2020). External and internal Load and their Effects on Professional Volleyball Training. *International Journal of Sports Medicine, 41*(7), 468-474. https://doi.org/10.1055/a-1087-2183

Lo, M., Aughey, R. J., Hopkins, W. G., Gill, N., & Stewart, A. M. (2022). The impact of matches and travel on rugby players' sleep, wellness and training. *PLoS One, 17*(2), e0261517. https://doi.org/10.1371/journal.pone.0261517

Lockie, R. G., Bloodgood, A., Moreno, M., McGuire, M., Balfany, K., & Dawes, J. (2020). Training load demands measured by surface electromyography wearable technology when performing law enforcement-specific body drags / trenažna optrećenja merena nosivom površinskom elektromiografijom prilikom izvođenja specifičnog povlačenja tela od strane pripadnika policije. *Facta Universitatis: Series Physical Education & Sport, 18*(1), 1-12. https://ezproxy.aut.ac.nz/login?url=https://search.ebscohost.com/login.aspx?direct=true&site=eds-live&db=s3h&AN=144210254

Lorenzo Calvo, J., Granado-Peinado, M., de la Rubia, A., Muriarte, D., Lorenzo, A., & Mon-López, D. (2021). Psychological States and Training Habits during the COVID-19 Pandemic Lockdown in Spanish Basketball Athletes. *Int J Environ Res Public Health, 18*(17). https://doi.org/10.3390/ijerph18179025

Louder, T., Thompson, B. J., Banks, N., & Bressel, E. (2019). A mixed-methods approach to evaluating the internal validity of the Reactive Strength Index. *Sports, 7*(7), 157. doi: 10.3390/sports7070157

Lovell, R., Halley, S., Siegler, J., Wignell, T., Coutts, A. J., & Massard, T. (2020). Use of Numerically Blinded Ratings of Perceived Exertion in Soccer: Assessing Concurrent and Construct Validity. *International Journal of Sports Physiology and Performance, 15*(10), 1430-1436. https://doi.org/10.1123/ijspp.2019-0740

Lu, Y. X., Clemente, F. M., Bezerra, P., Crowley-McHattan, Z. J., Cheng, S. C., Chien, C. H., Kuo, C. D., & Chen, Y. S. (2021). Quantification of Respiratory and Muscular Perceived Exertions as Perceived Measures of Internal Loads During Domestic and Overseas Training Camps in Elite Futsal Players. *Frontiers in Psychology, 12*, 751030. https://doi.org/10.3389/fpsyg.2021.751030

Luine, V. N. (2014). Estradiol and cognitive function: past, present and future. *Hormones and Behavior, 66(*4), 602-618.

Lukonaitienė, I., Conte, D., Paulauskas, H., Pliauga, V., Kreivytė, R., Stanislovaitienė, J., & Kamandulis, S. (2021, Sep). Investigation of readiness and perceived workload in junior female basketball players during a congested match schedule. *Biol Sport, 38*(3), 341-349. https://doi.org/10.5114/biolsport.2021.99702

Lukonaitienė, I., Kamandulis, S., Paulauskas, H., Domeika, A., Pliauga, V., Kreivytė, R., Stanislovaitienė, J., & Conte, D. (2020). Investigating the workload, readiness and physical performance changes during intensified 3-week preparation periods in female national Under18 and Under20 basketball teams. *Journal of Sports Sciences, 38*(9), 1018-1025. https://doi.org/10.1080/02640414.2020.1738702

Lupo, C., Ungureanu, A. N., Boccia, G., Licciardi, A., Rainoldi, A., & Brustio, P. R. (2021). Internal-Training-Load Monitoring, Notational and Time-Motion Analyses, Psychometric Status, and Neuromuscular Responses in Elite Rugby Union. *International Journal of Sports Physiology and Performance, 16*(3), 421-428. https://doi.org/10.1123/ijspp.2020-0260

Lupo, C., Ungureanu, A. N., Frati, R., Panichi, M., Grillo, S., & Brustio, P. R. (2019). Player Session Rating of Perceived Exertion: A More Valid Tool Than Coaches' Ratings to Monitor Internal Training Load in Elite Youth Female Basketball. *International Journal of Sports Physiology and Performance*, 1-6. https://doi.org/10.1123/ijspp.2019-0248

Luteberget, L. S., Houtmeyers, K. C., Vanrenterghem, J., Jaspers, A., Brink, M. S., & Helsen, W. F. (2021). Load Monitoring Practice in Elite Women Association Football. *Front Sports Act Living, 3*, 715122. https://doi.org/10.3389/fspor.2021.715122

Mala, J., Szivak, T. K., & Kraemer, W. J. (2015). Improving performance of heavy load carriage during high-intensity combat-related tasks. *Strength and Conditioning Journal, 37*(4), 43-52. doi:10.1519/ssc.0000000000000136

Malone, J. J., Jaspers, A., Helsen, W., Merks, B., Frencken, W. G. P., & Brink, M. S. (2018). Seasonal Training Load and Wellness Monitoring in a Professional Soccer Goalkeeper. *International Journal of Sports Physiology and Performance, 13*(5), 672-675. https://doi.org/10.1123/ijspp.2017-0472

Malone, S., Hughes, B., & Collins, K. (2019a). Effect of Training Load Distribution on Aerobic Fitness Measures in Hurling Players. *Journal of Strength and Conditioning Research, 33*(3), 825-830. https://doi.org/10.1519/jsc.0000000000002004

Malone, S., Hughes, B., & Collins, K. (2019b). The Influence of Exercise-to-Rest Ratios on Physical and Physiological Performance During Hurling-Specific Small-Sided Games. *Journal of Strength and Conditioning Research, 33*(1), 180-187. https://doi.org/10.1519/jsc.0000000000001887

Malone, S., Hughes, B., Roe, M., Mangan, S., & Collins, K. (2020). Factors that Influence Session-Rating of Perceived Exertion in Elite Gaelic Football. *Journal of Strength and Conditioning Research, 34*(4), 1176-1183. https://doi.org/10.1519/jsc.0000000000002192

Malone, S., Owen, A., Mendes, B., Hughes, B., Collins, K., & Gabbett, T. J. (2018, Mar). High-speed running and sprinting as an injury risk factor in soccer: Can well-developed physical qualities reduce the risk? *J Sci Med Sport, 21*(3), 257-262. https://doi.org/10.1016/j.jsams.2017.05.016

Malone, S., Owen, A., Newton, M., Mendes, B., Tiernan, L., Hughes, B., & Collins, K. (2018). Wellbeing perception and the impact on external training output among elite soccer players. *Journal of Science and Medicine in Sport, 21*(1), 29-34. https://doi.org/10.1016/j.jsams.2017.03.019

Malone, S., Roe, M., Doran, D. A., Gabbett, T. J., & Collins, K. (2017a). High chronic training loads and exposure to bouts of maximal velocity running reduce injury risk in elite Gaelic football. *Journal of Science and Medicine in Sport, 20*(3), 250-254. https://doi.org/10.1016/j.jsams.2016.08.005

Malone, S., Roe, M., Doran, D. A., Gabbett, T. J., & Collins, K. D. (2017b). Protection Against Spikes in Workload With Aerobic Fitness and Playing Experience: The Role of the Acute:Chronic Workload Ratio on Injury Risk in Elite Gaelic Football. *International Journal of Sports Physiology and Performance, 12*(3), 393-401. https://doi.org/10.1123/ijspp.2016-0090

Mancha-Triguero, D., García-Rubio, J., Antúnez, A., & Ibáñez, S. J. (2020). Physical and Physiological Profiles of Aerobic and Anaerobic Capacities in Young Basketball Players. *Int J Environ Res Public Health, 17*(4). https://doi.org/10.3390/ijerph17041409

Manuel, B., Billy, S., Christoph, Z., & Silvia, A. (2020). Intra-Individual and Seasonal Variation of Selected Biomarkers for Internal Load Monitoring in U-19 Soccer Players. *Frontiers in Physiology, 11*. https://doi.org/10.3389/fphys.2020.00838

Margolis, L. M., Murphy, N. E., Martini, S., Spitz, M. G., Thrane, I., McGraw, S. M., Blatny, J. M., Castellani, J. W., Rood, J. C., Young, A. J., Montain, S. J., Gundersen, Y., & Pasiakos, S. M. (2014). Effects of winter military training on energy balance, whole-body protein balance, muscle damage, soreness, and physical performance. Applied Physiology, Nutrition, and Metabolism, 39(12), 1395-1401. https://doi.org/10.1139/apnm-2014-0212

Martens, R., Vealey, R. S., & Burton, D. (1990). Competitive anxiety in sport (pp. 6 et seq). ISBN 9780873229357

Martin, M., Rampinini, E., Bosio, A., Azzalin, A., McCall, A., & Ward, P. (2022). Relationships Between Internal and External Load Measures and Fitness Level Changes in Professional Soccer Players. *Research Quarterly for Exercise & Sport*, 1-13. https://doi.org/10.1080/02701367.2022.2053646

Martínez-Serrano, A., Freitas, T. T., Franquesa, X., Enrich, E., Mallol, M., & Alcaraz, P. E. (2022). Does External Load Reflect Acute Neuromuscular Fatigue and Rating of Perceived Exertion in Elite Young Soccer Players? *Journal of Strength and Conditioning Research*. https://doi.org/10.1519/jsc.0000000000004296

Marynowicz, J., Kikut, K., Lango, M., Horna, D., & Andrzejewski, M. (2020). Relationship Between the Session-RPE and External Measures of Training Load in Youth Soccer Training. *Journal of Strength and Conditioning Research, 34*(10), 2800-2804. https://doi.org/10.1519/jsc.0000000000003785

Mateus, N., Gonçalves, B., Felipe, J. L., Sánchez-Sánchez, J., Garcia-Unanue, J., Weldon, A., & Sampaio, J. (2021). In-season training responses and perceived wellbeing and recovery status in professional soccer players. *PLoS One, 16*(7), e0254655. https://doi.org/10.1371/journal.pone.0254655

Maughan, P. C., MacFarlane, N. G., & Swinton, P. A. (2021). Relationship Between Subjective and External Training Load Variables in Youth Soccer Players. *International Journal of Sports Physiology and Performance, 16*(8), 1127–1133. https://doi.org/10.1123/ijspp.2019-0956

Maughan, P. C., MacFarlane, N. G., & Swinton, P. A. (2022). The influence of season phase on multivariate load relationships in professional youth soccer. *Journal of Sports Sciences, 40*(3), 345-350. https://doi.org/10.1080/02640414.2021.1993642

Maughan, P., Swinton, P., & MacFarlane, N. (2021). Relationships Between Training Load Variables in Professional Youth Football Players. *International Journal of Sports Medicine, 42*(7), 624-629. https://doi.org/10.1055/a-1300-2959

Mavor, M. P., Ross, G. B., Clouthier, A. L., Karakolis, T., & Graham, R. B. (2020). Validation of an IMU suit for military-based tasks. Sensors, 20(15), 4280. doi:10.3390/s20154280

McCaskie, C. J., Young, W. B., Fahrner, B. B., & Sim, M. (2018). Association Between Pre-season Training and Performance in Elite Australian Football. *International Journal of Sports Physiology and Performance*, 1-25. https://doi.org/10.1123/ijspp.2018-0086

McFadden, B. A., Walker, A. J., Arent, M. A., Bozzini, B. N., Sanders, D. J., Cintineo, H. P., Bello, M. L., & Arent, S. M. (2020). Biomarkers Correlate With Body Composition and Performance Changes Throughout the Season in Women's Division I Collegiate Soccer Players. *Front Sports Act Living, 2*, 74. https://doi.org/10.3389/fspor.2020.00074

McFadden, B. A., Walker, A. J., Bozzini, B. N., Hofacker, M., Russell, M., & Arent, S. M. (2022). Psychological and Physiological Changes in Response to the Cumulative Demands of a Women's Division I Collegiate Soccer Season. *Journal of Strength and Conditioning Research, 36*(5), 1373-1382. https://doi.org/10.1519/jsc.0000000000004062

McFadden, B. A., Walker, A. J., Bozzini, B. N., Sanders, D. J., & Arent, S. M. (2020). Comparison of Internal and External Training Loads in Male and Female Collegiate Soccer Players During Practices vs. Games. *Journal of Strength and Conditioning Research, 34*(4), 969-974. https://doi.org/10.1519/jsc.0000000000003485

McGuigan, H., Hassmén, P., Rosic, N., & Stevens, C. J. (2020). Training monitoring methods used in the field by coaches and practitioners: A systematic review. *International Journal of Sports Science & Coaching, 0*(0), 1-13. https://doi.org/10.1177/1747954120913172

McGuigan, M. (2017). Monitoring training and performance in athletes. Champaign, IL: Human Kinetics.

McGuinness, A., Malone, S., Hughes, B., Collins, K., & Passmore, D. (2019). Physical Activity and Physiological Profiles of Elite International Female Field Hockey Players Across the Quarters of Competitive Match Play. *Journal of Strength and Conditioning Research, 33*(9), 2513-2522. https://doi.org/10.1519/jsc.0000000000002483

McGuinness, A., Malone, S., Petrakos, G., & Collins, K. (2019). Physical and Physiological Demands of Elite International Female Field Hockey Players During Competitive Match Play. *Journal of Strength and Conditioning Research, 33*(11), 3105-3113. https://doi.org/10.1519/jsc.0000000000002158

McGuinness, A., McMahon, G., Malone, S., Kenna, D., Passmore, D., & Collins, K. (2020). Monitoring Wellness, Training Load, and Running Performance During a Major International Female Field Hockey Tournament. *Journal of Strength and Conditioning Research, 34*(8), 2312-2320. https://doi.org/10.1519/jsc.0000000000002835

McGuinness, A., Passmore, D., Malone, S., & Collins, K. (2022). Peak Running Intensity of Elite Female Field Hockey Players During Competitive Match Play. *Journal of Strength and Conditioning Research, 36*(4), 1064-1070. https://doi.org/10.1519/jsc.0000000000003582

McLaren, S. J., Smith, A., Bartlett, J. D., Spears, I. R., & Weston, M. (2018). Differential training loads and individual fitness responses to pre-season in professional rugby union players. *Journal of Sports Sciences, 36*(21), 2438-2446. https://doi.org/10.1080/02640414.2018.1461449

McNair, D. M., Lorr, M., & Droppleman, L. F. (1992). Profile of Mood States manual. Education and Industrial Testing Service.

Meeusen, R., Duclos, M., Foster, C., et al. (2013). Prevention, diagnosis and treatment of the overtraining syndrome: Joint consensus statement of the European College of Sport Science (ECSS) and the American College of Sports Medicine (ACSM). *European Journal of Sport Science, 13*(1), 1–24. https://doi.org/10.1080/17461391.2012.730061

Mendes, B., Palao, J. M., Silvério, A., Owen, A., Carriço, S., Calvete, F., & Clemente, F. M. (2018). Daily and weekly training load and wellness status in preparatory, regular and congested weeks: a season-long study in elite volleyball players. *Research in Sports Medicine, 26*(4), 462-473. https://doi.org/10.1080/15438627.2018.1492393

Mhenni, T., Michalsik, L. B., Mejri, M. A., Yousfi, N., Chaouachi, A., Souissi, N., & Chamari, K. (2017). Morning-evening difference of team-handball-related short-term maximal physical performances in female team handball players. *Journal of Sports Sciences, 35*(9), 912-920. https://doi.org/10.1080/02640414.2016.1201212

Michael, Siddall, O'Leary, Groeller, Sampson, Blacker & Drain (2022) Monitoring work and training load in military settings – what's in the toolbox? *European Journal of Sport Science, 22*(1), 58-71, DOI: 10.1080/17461391.2021.1971774

Mietus, J., Peng, C., Henry, I., Goldsmith, R., & Goldberger, A. (2002). The pNNx files: Re-examining a widely used heart rate variability measure. *Heart, 88*, 378–380. https://doi.org/10.1136/heart.88.4.378

Migueles, J. H., Cadenas-Sanchez, C., Ekelund, U., Delisle Nyström, C., Mora-Gonzalez, J., Löf, M., ... Ortega, F. B. (2017). Accelerometer data collection and processing criteria to assess physical activity and other outcomes: A systematic review and practical considerations. *Sports Medicine, 47*(9), 1821–1845.

Milanović, Z., Rađa, A., Erceg, M., Trajković, N., Stojanović, E., Lešnik, B., Krustrup, P., & Randers, M. B. (2020). Reproducibility of Internal and External Training Load During Recreational Small-Sided Football Games. *Research Quarterly for Exercise & Sport, 91*(4), 676-681. https://doi.org/10.1080/02701367.2019.1697794

Miller, G. E., Chen, E., & Zhou, E. S. (2007). If it goes up, must it come down? Chronic stress and the hypothalamic-pituitary-adrenocortical axis in humans. *Psychological Bulletin, 133*(1), 25-45. doi: 10.1037/0033-2909.133.1.25

Moffat, S. D., Zonderman, A. B., Metter, E. J., Blackman, M. R., Harman, S. M., Resnick, S. M. (2002). Longitudinal assessment of serum free testosterone concentration predicts memory performance and cognitive status in elderly men. *Journal of Clinical Endocrinology & Metabolism, 87*(11), 5001-5007.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & PRISMA Group (2010). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *International journal of surgery (London, England), 8*(5), 336–341. https://doi.org/10.1016/j.ijsu.2010.02.007

Montgomery, P. G., & Maloney, B. D. (2018). Three-by-Three Basketball: Inertial Movement and Physiological Demands During Elite Games. *International Journal of Sports Physiology and Performance, 13*(9), 1169-1174. https://doi.org/10.1123/ijspp.2018-0031

Montini, M., & Rocchi, J. E. (2020). Monitoring Training Load in Soccer: The ROMEI Model. *Journal of Strength and Conditioning Research*. https://doi.org/10.1519/jsc.0000000000003875

Móra, Á., Komka, Z., Végh, J., Farkas, I., Kocsisné, G. S., Bosnyák, E., Szmodis, M., Ligetvári, R., Csöndör, É., Almási, G., Oláh, A., Kemper, H. C. G., Tóth, M., & Ács, P. (2022). Comparison of the Cardiovascular Effects of Extreme Psychological and Physical Stress Tests in Male Soccer Players. *Int J Environ Res Public Health, 19*(2). https://doi.org/10.3390/ijerph19020715

Morales, J., Álamo, J. M., García-Massó, X., Buscà, B., López, J. L., Serra-Anó, P., & González, L. M. (2014). Use of heart rate variability in monitoring stress and recovery in judo athletes. *Journal of Strength and Conditioning Research, 28*, 1896-1905.

Moran, D. S., Evans, R., Arbel, Y., Luria, O., Hadid, A., Yanovich, R., ... Finestone, A. S. (2013). Physical and psychological stressors linked with stress fractures in recruit training. *Scandinavian Journal of Medicine & Science in Sports, 23*(4), 443–450.

Morandi, R. F., Pimenta, E. M., Andrade, A. G. P., Serpa, T. K. F., Penna, E. M., Costa, C. O., Júnior, M., & Garcia, E. S. (2020). Preliminary Validation of Mirrored Scales for Monitoring Professional Soccer Training Sessions. *J Hum Kinet, 72*, 265-278. https://doi.org/10.2478/hukin-2019-0112

Morgan, W. P., Brown, D. R., Raglin, J. S., et al. (1987). Psychological monitoring of overtraining and staleness. *British Journal of Sports Medicine, 21*, 107–114. https://doi.org/10.1136/bjsm.21.3.107

Mourot, L., Bouhaddi, M., Perrey, S., Cappelle, S., Henriet, M. T., Wolf, J. P., Rouillon, J. D., & Regnard, J. (2004). Decrease in heart rate variability with overtraining: Assessment by the Poincaré plot analysis. *Clin Physiol Funct Imaging, 24*, 10-18.

Mullen, T., Twist, C., & Highton, J. (2021). The Physiological and Perceptual Effects of Stochastic Simulated Rugby League Match Play. *International Journal of Sports Physiology and Performance, 16*(1), 73-79. https://doi.org/10.1123/ijspp.2018-0834

Mullen, T., Twist, C., Daniels, M., Dobbin, N., & Highton, J. (2021). Influence of Contextual Factors, Technical Performance, and Movement Demands on the Subjective Task Load Associated With Professional Rugby League Match-Play. *International Journal of Sports Physiology and Performance, 16*(6), 763-771. https://doi.org/10.1123/ijspp.2019-0998

Myers, N. L., Aguilar, K. V., Mexicano, G., Farnsworth, J. L., 2nd, Knudson, D., & Kibler, W. B. (2020). The Acute: Chronic Workload Ratio Is Associated with Injury in Junior Tennis Players. *Medicine and Science in Sports and Exercise, 52*(5), 1196-1200. https://doi.org/10.1249/mss.0000000000002215

Myllymäki, T., Rusko, H., Syväoja, H., Juuti, T., Kinnunen, M. L., & Krolainen, H. (2012). Effects of exercise intensity and duration on nocturnal heart rate variability and sleep. *European Journal of Applied Physiology, 112*(2), 801-809. https://doi.org/10.1007/s00421-011-2018-9

Nakamura, F. Y., Antunes, P., Nunes, C., Costa, J. A., Esco, M. R., & Travassos, B. (2020). Heart Rate Variability Changes From Traditional vs. Ultra-Short-Term Recordings in Relation to Preseason Training Load and Performance in Futsal Players. *Journal of Strength and Conditioning Research, 34*(10), 2974-2981. https://doi.org/10.1519/jsc.0000000000002910

Nakamura, F. Y., Pereira, L. A., Moraes, J. E., Kobal, R., Kitamura, K., Cal Abad, C. C., Teixeira Vaz, L. M., & Loturco, I. (2017). Physical and physiological differences of backs and forwards from the Brazilian National rugby union team. *J Sports Med Phys Fitness, 57*(12), 1549-1556. https://doi.org/10.23736/s0022-4707.16.06751-7

Neiss, R. (1988). Reconceptualizing arousal: Psychobiological states in motor performance. *Psychological Bulletin, 103*(3), 345. https://doi.org/10.1037/0033-2909.103.3.345

Nicolò, A., Montini, M., Girardi, M., Felici, F., Bazzucchi, I., & Sacchetti, M. (2019). Respiratory Frequency as a Marker of Physical Effort During High-Intensity Interval Training in Soccer Players. *International Journal of Sports Physiology and Performance*, 1-8. https://doi.org/10.1123/ijspp.2019-0028

Nikolova, R., Aleksiev, L., Vukov, M., Nikolova, R., Aleksiev, L., & Vukov, M. (2007). Psychophysiological assessment of stress and screening of health risk in peacekeeping operations. *Military Medicine, 172*(1), 44-48. https://doi.org/10.7205/milmed.172.1.44

Nindl, B. C., Barnes, B. R., Alemany, J. A., Frykman, P. N., Shippee, R. L., & Friedl, K. E. (2007). Physiological consequences of U.S. Army Ranger training. *Medicine and Science in Sports and Exercise, 39*(8), 1380-1387. https://doi.org/10.1249/MSS.0b013e318067e2f7

Nindl, B. C., Leone, C. D., Tharion, W. J., Johnson, R. F., Castellani, J. W., Patton, J. F., & Montain, S. J. (2002). Physical performance responses during 72 h of military operational stress. *Medicine and Science in Sports and Exercise, 34*(11), 1814–1822. https://doi.org/10.1249/01.MSS.0000037095.34542.44

Nindl, B. C., Scofield, D. E., Strohbach, C. A., Centi, A. J., Evans, R. K., Yanovich, R., & Moran, D. S. (2012). IGF-I, IGFBPs, and inflammatory cytokine responses during gender-integrated Israeli Army basic combat training. *Journal of Strength and Conditioning Research, 26*(Suppl2), S73–S81.

Nisbett, R. E., & Wilson, T. D. (1977). Telling more than we can know: Verbal reports on mental processes. *Psychological Review, 84*(3), 231-259. https://doi.org/10.1037/0033-295X.84.3.231

Nobari, H., Aquino, R., Clemente, F. M., Khalafi, M., Adsuar, J. C., & Pérez-Gómez, J. (2020). Description of acute and chronic load, training monotony and strain over a season and its relationships with well-being status: A study in elite under-16 soccer players. *Physiol Behav, 225*, 113117. https://doi.org/10.1016/j.physbeh.2020.113117

Nobari, H., Arslan, E., Martins, A. D., & Oliveira, R. (2022). Are acute:chronic workload ratios of perceived exertion and running based variables sensible to detect variations between player positions over the season? A soccer team study. *BMC Sports Sci Med Rehabil, 14*(1), 51. https://doi.org/10.1186/s13102-022-00445-x

Nobari, H., Barjaste, A., Haghighi, H., Clemente, F. M., Carlos-Vivas, J., & Pérez-Gómez, J. (2022). Quantification of training and match load in elite youth soccer players: a full-season study. *J Sports Med Phys Fitness, 62*(4), 448-456. https://doi.org/10.23736/s0022-4707.21.12236-4

Nobari, H., Gholizadeh, R., Martins, A. D., Badicu, G., & Oliveira, R. (2022). In-Season Quantification and Relationship of External and Internal Intensity, Sleep Quality, and Psychological or Physical Stressors of Semi-Professional Soccer Players. *Biology (Basel), 11*(3). https://doi.org/10.3390/biology11030467

Nobari, H., Martins, A. D., Oliveira, R., & Paolo Ardigò, L. (2022). Seasonal variations of the relationships between measures of training monotony and strain in professional soccer players. *Sci Rep, 12*(1), 10930. https://doi.org/10.1038/s41598-022-15278-4

Noor, D., McCall, A., Jones, M., Duncan, C., Ehrmann, F., Meyer, T., & Duffield, R. (2021). Perceived load, fatigue and recovery responses during congested and non-congested micro-cycles in international football tournaments. *Journal of Science and Medicine in Sport, 24*(12), 1278-1283. https://doi.org/10.1016/j.jsams.2021.07.001

North Atlantic Treaty Organisation. (2009). Optimizing operational physical fitness (TR-HFM-080). Neuilly-sur-Seine Cedex: Research and Technology Organisation.

Nunes, N. A., Gonçalves, B., Coutinho, D., & Travassos, B. (2020). How Numerical Unbalance Constraints Physical and Tactical Individual Demands of Ball Possession Small-Sided Soccer Games. *Frontiers in Psychology, 11*, 1464. https://doi.org/10.3389/fpsyg.2020.01464

O'Connor, D. B., Archer, J., Hair, W. M., & Wu, F. C. (2001). Activational effects of testosterone on cognitive function in men. *Neuropsychologia, 39*(13), 1385-1394.

O'Driscoll, R., Turicchi, J., Beaulieu, K., Scott, S., Matu, J., Deighton, K., ... & Stubbs, R. J. (2020). How well do activity monitors estimate energy expenditure? A systematic review and meta-analysis of the validity of current technologies. *British Journal of Sports Medicine, 54*, 332-340.

O'Keeffe, S., O'Connor, S., & N, N. C. (2020). Are internal load measures associated with injuries in male adolescent Gaelic football players? *European Journal of Sport Science, 20*(2), 249-260. https://doi.org/10.1080/17461391.2019.1621950

O'Leary, T. J., Saunders, S. C., McGuire, S. J., Venables, M. C., & Izard, R. M. (2018). Sex Differences in Training Loads during British Army Basic Training. *Medicine & Science in Sports & Exercise, 50*(12), 2565-2574.

https://ezproxy.aut.ac.nz/login?url=https://search.ebscohost.com/login.aspx?direct=true&site=eds-live&db=edb&AN=132994291

Ojanen, T., Häkkinen, K., Vasankari, T., & Kyröläinen, H. (2018). Changes in Physical Performance During 21 d of Military Field Training in Warfighters. *Military Medicine, 183*(5/6), e174-e181. https://doi.org/10.1093/milmed/usx049

Oliva-Lozano, J. M., Muyor, J. M., Fortes, V., & McLaren, S. J. (2021). Decomposing the variability of match physical performance in professional soccer: Implications for monitoring individuals. *European Journal of Sport Science, 21*(11), 1588-1596. https://doi.org/10.1080/17461391.2020.1842513

Oliva-Lozano, J. M., Muyor, J. M., Puche Ortuño, D., Rico-González, M., & Pino-Ortega, J. (2021). Analysis of key external and internal load variables in professional female futsal players: a longitudinal study. *Research in Sports Medicine*, 1-10. https://doi.org/10.1080/15438627.2021.1963728

Oliveira, R., Brito, J. P., Loureiro, N., Padinha, V., Ferreira, B., & Mendes, B. (2020). Does the distribution of the weekly training load account for the match results of elite professional soccer players? *Physiol Behav, 225*, 113118. https://doi.org/10.1016/j.physbeh.2020.113118

Oliveira, R., Brito, J. P., Martins, A., Mendes, B., Marinho, D. A., Ferraz, R., & Marques, M. C. (2019). In-season internal and external training load quantification of an elite European soccer team. *PLoS One, 14*(4), e0209393. https://doi.org/10.1371/journal.pone.0209393

Oliveira, R., Brito, J., Martins, A., Mendes, B., Calvete, F., Carriço, S., Ferraz, R., & Marques, M. C. (2019). In-season training load quantification of one-, two- and three-game week schedules in a top European professional soccer team. *Physiol Behav, 201*, 146-156. https://doi.org/10.1016/j.physbeh.2018.11.036

Oliveira, R., Martins, A., Nobari, H., Nalha, M., Mendes, B., Clemente, F. M., & Brito, J. P. (2021). In-season monotony, strain and acute/chronic workload of perceived exertion, global positioning system running based variables between player positions of a top elite soccer team. *BMC Sports Sci Med Rehabil, 13*(1), 126. https://doi.org/10.1186/s13102-021-00356-3

Oliveira, R., Palucci Vieira, L. H., Martins, A., Brito, J. P., Nalha, M., Mendes, B., & Clemente, F. M. (2021,). In-Season Internal and External Workload Variations between Starters and Non-Starters-A Case Study of a Top Elite European Soccer Team. *Medicina (Kaunas), 57*(7). https://doi.org/10.3390/medicina57070645

Op De Beéck, T., Jaspers, A., Brink, M. S., Frencken, W. G. P., Staes, F., Davis, J. J., & Helsen, W. F. (2019). Predicting Future Perceived Wellness in Professional Soccer: The Role of Preceding Load and Wellness. *International Journal of Sports Physiology and Performance, 14*(8), 1074-1080. https://doi.org/10.1123/ijspp.2017-0864

Orr RM, Pope R, Schram B, Lyons K, Correa D, Tomes C, Hing W. Individual light armour vest (ILAV) report. gold coast: AUST: Tactical Research Unit, Bond University. Available from: Tactical Research Unit, Bond University; 2015.

Ortigosa-Márquez, J.M., Reigal, R.E., Portell, M., Morales-Sánchez, V., & Hernández-Mendo, A. (2017). Observación AutomatizadA: La Variabilidad de la Frecuencia Cardíaca y Su Relación Con Las Variables Psicológicas Determinantes Del Rendimiento en Nadadores Jóvenes. *Anales de Psicología, 33*, 436-441. doi: 10.6018/analesps.33.3.274361

Otaegi, A., & Los Arcos, A. (2020). Quantification of the Perceived Training Load in Young Female Basketball Players. *Journal of Strength and Conditioning Research, 34*(2), 559-565. https://doi.org/10.1519/jsc.0000000000002370

Ozaeta, E., Fernández-Lasa, U., Martínez-Aldama, I., Cayero, R., & Castillo, D. (2022). Match Physical and Physiological Response of Amateur Soccer Referees: A Comparison between Halves and Match Periods. *Int J Environ Res Public Health, 19*(3). https://doi.org/10.3390/ijerph19031306

Panduro, J., Ermidis, G., Røddik, L., Vigh-Larsen, J. F., Madsen, E. E., Larsen, M. N., Pettersen, S. A., Krustrup, P., & Randers, M. B. (2022). Physical performance and loading for six playing positions in elite female football: full-game, end-game, and peak periods. *Scand J Med Sci Sports, 32 Suppl 1*, 115-126. https://doi.org/10.1111/sms.13877

Pandorf, C., Harman, E. A., Frykman, P. N., Patton, J. F., Mello, R. P., & Nindl, B. C. (2002). Correlates of load carriage performance among women. *Work 18*(2): 179-89

Papadakis, L., Tymvios, C., & Patras, K. (2020). The relationship between training load and fitness indices over a pre-season in professional soccer players. *J Sports Med Phys Fitness, 60*(3), 329-337. https://doi.org/10.23736/s0022-4707.20.10109-9

Parker, L. J. F., Elliott-Sale, K. J., Hannon, M., Morton, J. P., & Close, G. L. (2022). Where do you go when your periods go?: A case-study examining secondary amenorrhea in a professional internationally-capped female soccer player through the lens of the sport nutritionist. *Science & Medicine in Football, 6*(5), 643-649.

Parrado, E., Cervantes, J., Pintanel, M., Rodas, G., & Capdevila-Ortís, L. (2010). Perceived tiredness and heart rate variability in relation to overload during a field hockey world cup. *Perceptual and Motor Skills*, 110, 699-713. doi: 10.2466/pms.110.3.699-713

Paulsen, K. M., Butts, C. L., & McDermott, B. P. (2018). Observation of Women Soccer Players' Physiology During a Single Season. *Journal of Strength and Conditioning Research, 32*(6), 1702-1707. https://doi.org/10.1519/jsc.0000000000002025

Pereira, L. A., Abad, C. C. C., Leiva, D. F., Oliveira, G., Carmo, E. C., Kobal, R., & Loturco, I. (2019). Relationship Between Resting Heart Rate Variability and Intermittent Endurance Performance in Novice Soccer Players. *Research Quarterly for Exercise & Sport, 90*(3), 355-361. https://doi.org/10.1080/02701367.2019.1601666

Pereira, L. A., Freitas, T. T., Zanetti, V., & Loturco, I. (2022). Variations in Internal and External Training Load Measures and Neuromuscular Performance of Professional Soccer Players During a Preseason Training Period. *J Hum Kinet, 81*, 149-162. https://doi.org/10.2478/hukin-2022-0012

Perroni, F., Tessitore, A., Cortis, C., Lupo, C., D'Artibale, E., Cignitti, L., & Capranica, L. (2010). Energy cost and energy sources during a simulated firefighting activity. *Journal of*

Strength and Conditioning Research, 24(12), 3457-3463. doi:10.1519/jsc.0b013e3181b2c7ff

Peterson, M. D., Dodd, D. J., Alvar, B. A., Rhea, M. R., & Favre, M. (2008). Undulation training for development of hierarchical fitness and improved firefighter job performance. *Journal of Strength and Conditioning Research, 22*(5), 1683-1695. doi:10.1519/jsc.0b013e31818215f4

Phibbs, P. J., Jones, B., Roe, G., Read, D. B., Darrall-Jones, J., Weakley, J., Rock, A., & Till, K. (2018). Organized Chaos in Late Specialization Team Sports: Weekly Training Loads of Elite Adolescent Rugby Union Players. *Journal of Strength and Conditioning Research, 32*(5), 1316-1323. https://doi.org/10.1519/jsc.0000000000001965

Plavina, L., Kolesova, O., Eglite, J., Cakstins, A., Cakstina, S., & Kolesovs, A. (2021). Antioxidative system capacity after a 10-day-long intensive training course and one-month-long recovery in military cadets. *Physical Activity Review, 9*(1), 62-69. https://ezproxy.aut.ac.nz/login?url=https://search.ebscohost.com/login.aspx?direct=true&site=eds-live&db=s3h&AN=148816650

Plews, D. J., Laursen, P. B., Kilding, A. E., et al. (2012). Heart rate variability in elite triathletes, is variation in variability the key to effective training? A case comparison. *European Journal of Applied Physiology, 112*, 3729–3741.

Plews, D. J., Laursen, P. B., Le Meur, Y., Hausswirth, C., Kilding, A. E., & Buchheit, M. (2014). Monitoring training with heart rate-variability: How much compliance is needed for valid assessment? *International Journal of Sports Physiology and Performance, 9*(5), 783-790. https://doi.org/10.1123/ijspp.2013-0482

Plews, D. J., Laursen, P. B., Stanley, J., Kilding, A. E., Buchheit, M., and Allen, J. (2013). Training adaptation and heart rate variability in elite endurance athletes: opening the door to effective monitoring. *Sports Medicine, 43*, 773–81.

Plisky, P., Schwartkopf-Phifer, K., Huebner, B., Garner, M. B., & Bullock, G. (2021). Systematic Review and Meta-Analysis of the Y-Balance Test Lower Quarter: Reliability, Discriminant Validity, and Predictive Validity. *International Journal of Sports Physical Therapy, 16*(5), 1190-1209.

Portes, R., Manuel Navarro, R., Ribas, C., Alonso, E., & Jiménez, S. L. (2022). The Relationship between External and Internal Load during Elite Pre-season Friendly Basketball Games. *La relación entre la carga externa y la carga interna durante partidos amistosos en baloncesto de élite., 18*(67), 43-53. https://doi.org/10.5232/ricyde2022.0674

Poureghbali, S., Arede, J., Rehfeld, K., Schöllhorn, W., & Leite, N. (2020). Want to Impact Physical, Technical, and Tactical Performance during Basketball Small-Sided Games in Youth Athletes? Try Differential Learning Beforehand. *Int J Environ Res Public Health, 17*(24). https://doi.org/10.3390/ijerph17249279

Póvoas, S. C. A., Castagna, C., Resende, C., Coelho, E. F., Silva, P., Santos, R., Seabra, A., Tamames, J., Lopes, M., Randers, M. B., & Krustrup, P. (2017). *Physical and*

Physiological Demands of Recreational Team Handball for Adult Untrained Men. *Biomed Res Int*, 6204603. https://doi.org/10.1155/2017/6204603

Puente, C., Abián-Vicén, J., Areces, F., López, R., & Del Coso, J. (2017). Physical and Physiological Demands of Experienced Male Basketball Players During a Competitive Game. *Journal of Strength and Conditioning Research, 31*(4), 956-962. https://doi.org/10.1519/jsc.0000000000001577

Pueo, B., Jimenez-Olmedo, J. M., Penichet-Tomas, A., Ortega Becerra, M., & Espina Agullo, J. J. (2017). Analysis of Time-Motion and Heart Rate in Elite Male and Female Beach Handball. *Journal of Sport Science and Medicine, 16*(4), 450-458.

Querido, S. M., & Clemente, F. M. (2020). Analyzing the effects of combined small-sided games and strength and power training on the fitness status of under-19 elite football players. *J Sports Med Phys Fitness, 60*(1), 1-10. https://doi.org/10.23736/s0022-4707.19.09818-9

Quintas, G., Reche, X., Daniel Sanjuan-Herraez, J., Martinez, H., Herrero, M., Valle, X., Masa, M., & Rodas, G. (2020). Urine metabolomic analysis for monitoring internal load in professional football players. *Metabolomics, 16*(4), 45. https://doi.org/10.1007/s11306-020-01668-0

Rabbani, A., Kargarfard, M., Castagna, C., Clemente, F. M., & Twist, C. (2019). Associations Between Selected Training-Stress Measures and Fitness Changes in Male Soccer Players. *International Journal of Sports Physiology and Performance, 14*(8), 1050-1057. https://doi.org/10.1123/ijspp.2018-0462

Rago et al. (2020). Methods to collect and interpret external training load using microtechnology incorporating GPS in professional football: a systematic review. *Research in Sports Medicine, 28*, 3, 437–458 https://doi.org/10.1080/15438627.2019.1686703

Rago, V., Brito, J., Figueiredo, P., Krustrup, P., & Rebelo, A. (2019). Relationship between External Load and Perceptual Responses to Training in Professional Football: Effects of Quantification Method. *Sports (Basel), 7*(3). https://doi.org/10.3390/sports7030068

Rago, V., Krustrup, P., Martín-Acero, R., Rebelo, A., & Mohr, M. (2020). Training load and submaximal heart rate testing throughout a competitive period in a top-level male football team. *Journal of Sports Sciences, 38*(11-12), 1408-1415. https://doi.org/10.1080/02640414.2019.1618534

Rago, V., Vigh-Larsen, J. F., Deylami, K., Muschinsky, A., & Mohr, M. (2020). Use of Rating of Perceived Exertion-Based Training Load in Elite Ice Hockey Training and Match-Play. *Journal of Strength and Conditioning Research, Publish Ahead of Print*. https://doi.org/10.1519/jsc.0000000000003915

Ramos-Campo, D. J., Rubio-Arias, J. A., Ávila-Gandía, V., Marín-Pagán, C., Luque, A., & Alcaraz, P. E. (2017). Heart rate variability to assess ventilatory thresholds in professional basketball players. *J Sport Health Sci, 6*(4), 468-473. https://doi.org/10.1016/j.jshs.2016.01.002

Raya-González, J., Nakamura, F. Y., Castillo, D., Yanci, J., & Fanchini, M. (2019). Determining the Relationship Between Internal Load Markers and Noncontact Injuries in Young Elite Soccer Players. *International Journal of Sports Physiology and Performance, 14*(4), 421-425. https://doi.org/10.1123/ijspp.2018-0466

Redmond, J. E., Cohen, B. S., Simpson, K., Spiering, B. A., & Sharp, M. A. (2013). Measuring physical activity during US Army Basic Combat Training: A comparison of 3 methods. U S. *Army Medical Department Journal, 48–54*. https:// pubmed.ncbi.nlm.nih.gov/24146242/

Reina Roman, M., Garcia-Rubio, J., Feu, S., & Jose Ibanez, S. (2019). Training and Competition Load Monitoring and Analysis of Women's Amateur Basketball by Playing Position: Approach Study. *Frontiers in Pychology, 9*. https://doi.org/10.3389/fpsyg.2018.02689

Reinhardt, L., Schulze, S., Kurz, E., & Schwesig, R. (2020). An Investigation into the Relationship Between Heart Rate Recovery in Small-Sided Games and Endurance Performance in Male, Semi-professional Soccer Players. *Sports Medicine, 6*(1), 43. https://doi.org/10.1186/s40798-020-00273-8

Reinhardt, L., Schulze, S., Schwesig, R., & Kurz, E. (2020). Physical Match Performance in Sub-elite Soccer Players - Introduction of a new Index. *International Journal of Sports Medicine, 41*(12), 858-866. https://doi.org/10.1055/a-1165-1950

Rentz, L. E., Hornsby, W. G., Gawel, W. J., Rawls, B. G., Ramadan, J., & Galster, S. M. (2021). Contextual Variation in External and Internal Workloads across the Competitive Season of a Collegiate Women's Soccer Team. *Sports (Basel), 9*(12). https://doi.org/10.3390/sports9120165

Ribeiro, J. N., Monteiro, D., Gonçalves, B., Brito, J., Sampaio, J., & Travassos, B. (2022). Variation in Physical Performance of Futsal Players During Congested Fixtures. *International Journal of Sports Physiology and Performance, 17*(3), 367-373. https://doi.org/10.1123/ijspp.2020-0922

Richmond, V. L., Carter, J. M., Wilkinson, D. M., Homer, F. E., Rayson, M. P., Wright, A., Bilzon, J. L., Richmond, V. L., Carter, J. M., Wilkinson, D. M., Homer, F. E., Rayson, M. P., Wright, A., & Bilzon, J. L. J. (2012). Comparison of the physical demands of single-sex training for male and female recruits in the British Army. *Military Medicine, 177*(6), 709-715. https://doi.org/10.7205/milmed-d-11-00416

Richmond, V. L., Horner, F. E., Wilkinson, D. M., Rayson, M. P., Wright, A., & Izard, R. (2014). Energy balance and physical demands during an 8-week arduous military training course. *Military Medicine, 179*(4), 421-427. https://doi.org/10.7205/MILMED-D-13-00313

Ritchie, D., Hopkins, W. G., Buchheit, M., Cordy, J., & Bartlett, J. D. (2017). Quantification of Training Load During Return to Play After Upper- and Lower-Body Injury in Australian Rules Football. *International Journal of Sports Physiology and Performance, 12*(5), 634-641. https://doi.org/10.1123/ijspp.2016-0300

Roberts, M. A., O'Dea, J., Boyce, A., & Mannix, E. T. (2002). Fitness levels of firefighter recruits before and after a supervised exercise training program. *Journal of Strength and*

Conditioning Research, 16(2), 271. doi:10.1519/1533-4287(2002)016<0271:flofrb>2.0.co;2

Robineau, J., Marrier, B., Le Meur, Y., Piscione, J., Peeters, A., & Lacome, M. (2019). "Road to Rio": A Case Study of Workload Periodization Strategy in Rugby-7s During an Olympic Season. *Front Sports Act Living, 1*, 72. https://doi.org/10.3389/fspor.2019.00072

Roe, G., Darrall-Jones, J., Till, K., Phibbs, P., Read, D., Weakley, J., Rock, A., & Jones, B. (2017). The effect of physical contact on changes in fatigue markers following rugby union field-based training. *European Journal of Sport Science, 17*(6), 647-655. https://doi.org/10.1080/17461391.2017.1287960

Romero-Moraleda, B., Nedergaard, N. J., Morencos, E., Casamichana, D., Ramirez-Campillo, R., & Vanrenterghem, J. (2021). External and internal loads during the competitive season in professional female soccer players according to their playing position: differences between training and competition. *Research in Sports Medicine, 29*(5), 449-461. https://doi.org/10.1080/15438627.2021.1895781

Rossi, A., Perri, E., Pappalardo, L., Cintia, P., Alberti, G., Norman, D., & Iaia, F. M. (2022). Wellness Forecasting by External and Internal Workloads in Elite Soccer Players: A Machine Learning Approach. *Frontiers in Physiology, 13*, 896928. https://doi.org/10.3389/fphys.2022.896928

Rowell, A. E., Aughey, R. J., Hopkins, W. G., Stewart, A. M., & Cormack, S. J. (2017). Identification of sensitive measures of recovery after external load from football match play. *International Journal of Sports Physiology and Performance, 12*(7), 969–976.

Ruben, P., Rafael Manuel, N., Carlos, R., Enrique, A., & Sergio, L. J. (2022). The Relationship between External and Internal Load during Elite Pre-season Friendly Basketball Games. [La relación entre la carga externa y la carga interna durante partidos amistosos en baloncesto de élite]. *Revista Internacional de Ciencias del Deporte, 18*(67), 43-53. https://doi.org/10.5232/ricyde2022.06704

Rushall, B. S. (1990). A tool for measuring stress tolerance in elite athletes. *Journal of Applied Sport Psychology, 2*, 51–66. https://doi.org/10.1080/10413209008406432

Russell, S., Simpson, M. J., Evans, A. G., Coulter, T. J., & Kelly, V. G. (2021). Physiological and Perceptual Recovery-Stress Responses to an Elite Netball Tournament. *International Journal of Sports Physiology and Performance, 16*(10), 1462-1471. https://doi.org/10.1123/ijspp.2020-0317

Saidi, K., Zouhal, H., Boullosa, D., Dupont, G., Hackney, A. C., Bideau, B., Granacher, U., & Ben Abderrahman, A. (2022). Biochemical Markers and Wellness Status During a Congested Match Play Period in Elite Soccer Players. *International Journal of Sports Physiology and Performance, 17*(4), 605-620. https://doi.org/10.1123/ijspp.2020-0914

Saidi, K., Zouhal, H., Rhibi, F., Tijani, J. M., Boullosa, D., Chebbi, A., Hackney, A. C., Granacher, U., Bideau, B., & Ben Abderrahman, A. (2019). Effects of a six-week period of congested match play on plasma volume variations, hematological parameters, training workload and physical fitness in elite soccer players. *PLoS One, 14*(7), e0219692. https://doi.org/10.1371/journal.pone.0219692

Salonen, M., Huovinen, J., Kyröläinen, H., Piirainen, J. M., & Vaara, J. P. (2019). Neuromuscular Performance and Hormonal Profile During Military Training and Subsequent Recovery Period. *Military Medicine, 184*(3/4), e113-e119. https://doi.org/10.1093/milmed/usy176

Sánchez-Molina, J., Clemente-Suárez, V. J., & Robles-Pérez, J. J. (2018). Assessment of Psychophysiological Response and Specific Fine Motor Skills in Combat Units. *Journal of Medical Systems, 42*(4). https://doi.org/10.1007/s10916-018-0922-9

Sánchez-Sáez, J. A., Sánchez-Sánchez, J., Martínez-Rodríguez, A., Felipe, J. L., García-Unanue, J., & Lara-Cobos, D. (2021). Global Positioning System Analysis of Physical Demands in Elite Women's Beach Handball Players in an Official Spanish Championship. *Sensors (Basel), 21*(3). https://doi.org/10.3390/s21030850

Sánchez-Sánchez, J., Botella, J., Felipe Hernández, J. L., León, M., Paredes-Hernández, V., Colino, E., Gallardo, L., & García-Unanue, J. (2021). Heart Rate Variability and Physical Demands of In-Season Youth Elite Soccer Players. *Int J Environ Res Public Health, 18*(4). https://doi.org/10.3390/ijerph18041391

Sanders, D., & Heijboer, M. (2019). Physical demands and power profile of different stage types within a cycling grand tour. *European Journal of Sport Science, 19*(6), 736-744. https://doi.org/10.1080/17461391.2018.1554706

Sansone, P., Ceravolo, A., & Tessitore, A. (2022). External, Internal, Perceived Training Loads and Their Relationships in Youth Basketball Players Across Different Positions. *International Journal of Sports Physiology and Performance, 17*(2), 249-255. https://doi.org/10.1123/ijspp.2020-0962

Sansone, P., Gasperi, L., Tessitore, A., & Gomez, M. A. (2021). Training load, recovery and game performance in semiprofessional male basketball: influence of individual characteristics and contextual factors. *Biol Sport, 38*(2), 207-217. https://doi.org/10.5114/biolsport.2020.98451

Sansone, P., Tessitore, A., Paulauskas, H., Lukonaitiene, I., Tschan, H., Pliauga, V., & Conte, D. (2019). Physical and physiological demands and hormonal responses in basketball small-sided games with different tactical tasks and training regimes. *Journal of Science and Medicine in Sport, 22*(5), 602-606. https://doi.org/10.1016/j.jsams.2018.11.017

Sansone, P., Tschan, H., Foster, C., & Tessitore, A. (2020). Monitoring Training Load and Perceived Recovery in Female Basketball: Implications for Training Design. *Journal of Strength and Conditioning Research, 34*(10), 2929-2936. https://doi.org/10.1519/jsc.0000000000002971

Saw, A. E., Kellmann, M., Main, L. C., & Gastin, P. B. (2017). Athlete self-report measures in research and practice: Considerations for the discerning reader and fastidious practitioner. *International Journal of Sports Physiology and Performance, 12*(Suppl 2), S2-127–S2-135. https://doi.org/10.1123/ijspp.2016-0395

Scanlan, A. T., Fox, J. L., Borges, N. R., Dascombe, B. J., & Dalbo, V. J. (2017). Cumulative Training Dose's Effects on Interrelationships Between Common Training-Load Models During Basketball Activity. *International Journal of Sports Physiology and Performance, 12*(2), 168-174. https://doi.org/10.1123/ijspp.2015-0708

Scanlan, A. T., Fox, J. L., Borges, N. R., Tucker, P. S., & Dalbo, V. J. (2018). Temporal changes in physiological and performance responses across game-specific simulated basketball activity. *J Sport Health Sci, 7*(2), 176-182. https://doi.org/10.1016/j.jshs.2016.05.002

Scanlan, A. T., Stanton, R., Sargent, C., O'Grady, C., Lastella, M., & Fox, J. L. (2019). Working Overtime: The Effects of Overtime Periods on Game Demands in Basketball Players. *International Journal of Sports Physiology and Performance, 14*(10), 1331-1337. https://doi.org/10.1123/ijspp.2018-0906

Schoeller, D. A., & van Santen, E. (1982). Measurement of energy expenditure in humans by doubly labeled water method. *Journal of Applied Physiology*, *53*(4), 955–959. https://doi.org/10.1152/jappl.1982.53.4.955

Schuh-Renner, A., Grier, T. L., Canham-Chervak, M., Hauschild, V. D., Roy, T. C., Fletcher, J., & Jones, B. H. (2017). Risk factors for injury associated with low, moderate, and high mileage road marching in a U.S. Army infantry brigade. *Journal of Science and Medicine in Sport, 20*(Suppl 4), S28– S33.

Scott, D., & Lovell, R. (2018). Individualisation of speed thresholds does not enhance the dose-response determination in football training. *Journal of Sports Sciences, 36*(13), 1523-1532. https://doi.org/10.1080/02640414.2017.1398894

Scott, M. T. U., Scott, T. J., & Kelly, V. G. (2016). The validity and reliability of global positioning systems in team sport: A brief review. *Journal of Strength and Conditioning Research, 30*(5), 1470-1490.

Sekiguchi, Y., Curtis, R. M., Huggins, R. A., Benjamin, C. L., Walker, A. J., Arent, S. M., Adams, W. M., Anderson, T., & Casa, D. J. (2021). The Relationships Between Perceived Wellness, Sleep, and Acute: Chronic Training Load in National Collegiate Athletics Association Division I Male Soccer Players. *Journal of Strength and Conditioning Research, 35*(5), 1326-1330. https://doi.org/10.1519/jsc.0000000000004003

Shaffer, F., & Ginsberg, J. P. (2017). An overview of heart rate variability metrics and norms. *Frontiers in Public Health, 5*, 258. https://doi.org/10.3389/fpubh.2017.00258

Shattuck, N. L., Matsangas, P., & Dahlman, A. S. (2018). Sleep and fatigue issues in military operations. In Sleep and combat-related post-traumatic stress disorder (pp. 69-76). Springer.

Silva, D., Fernandes, D., Verri, S. M., Nakamura, F. Y., & Machado, F. A. (2013). Longitudinal changes in cardiac autonomic function and aerobic fitness indices in endurance runners: A case study with a high-level team. *European Journal of Sport Science, 14*(5), 443-451. https://doi.org/10.1080/17461391.2013.844729

Silva, P., Santos, E. D., Grishin, M., & Rocha, J. M. (2018). Validity of Heart Rate-Based Indices to Measure Training Load and Intensity in Elite Football Players. *Journal of Strength* *and Conditioning Research, 32*(8), 2340-2347. https://doi.org/10.1519/jsc.0000000000002057

Simim, M. A. M., da Mota, G. R., Marocolo, M., da Silva, B. V. C., de Mello, M. T., & Bradley, P. S. (2018). The Demands of Amputee Soccer Impair Muscular Endurance and Power Indices But Not Match Physical Performance. *Adapt Phys Activ Q, 35*(1), 76-92. https://doi.org/10.1123/apaq.2016-0147

Simpson, K., Redmond, J. E., Cohen, B. S., Hendrickson, N. R., Spiering, B. A., Steelman, R., ... Sharp, M. A. (2013). Quantification of physical activity performed during US Army Basic Combat training. *U S. Army Medical Department Journal, 55–65*. https://pubmed.ncbi.nlm.nih.gov/24146243/

Simpson, M. J., Jenkins, D. G., & Kelly, V. G. (2020). Workload Differences Between Training Drills and Competition in Elite Netball. *International Journal of Sports Physiology and Performance, 15*(10), 1385-1392. https://doi.org/10.1123/ijspp.2019-0971

Simpson, M. J., Jenkins, D. G., Scanlan, A. T., & Kelly, V. G. (2020). Relationships Between External- and Internal-Workload Variables in an Elite Female Netball Team and Between Playing Positions. *International Journal of Sports Physiology and Performance, 15*(6), 841-846. https://doi.org/10.1123/ijspp.2019-0619

Sly, L. (2018). U.S. soldiers are revealing sensitive and dangerous information by jogging. The Washington Post. https://www.washingtonpost.com/world/a-map-showing-the-users-of-fitness-devices-lets-the-world-see-where-us-soldiers-are-and-what-they-are-doing/2018/01/28/86915662-0441-11e8-aa61-f3391373867e_story.html

Smith, C. D., Cooper, A. D., Merullo, D. J., Cohen, B. S., Heaton, K. J., Claro, P. J., & Smith, T. (2019). Sleep restriction and cognitive load affect performance on a simulated marksmanship task. *Journal of Sleep Research, 28*(3), e12637. https://doi.org/10.1111/jsr.12637

Sobolewski, E. J. (2020). The Relationships between Internal and External Load Measures for Division I College Football Practice. *Sports (Basel), 8*(12). https://doi.org/10.3390/sports8120165

Soligard T, Schwellnus M, Alonso JM, Bahr R, Clarsen B, Dijkstra HP, Gabbett T, Gleeson M, Hägglund M, Hutchinson MR, Janse van Rensburg C, Khan KM, Meeusen R, Orchard JW, Pluim BM, Raftery M, Budgett R, and Engebretsen L. How much is too much? (Part 1) International Olympic Committee consensus statement on load in sport and risk of injury. *Br J Sports Med 50*: 1030–1041, 2016.

Spencer, K., Paget, N., Farley, O. R. L., & Kilding, A. E. (2020). Activity Profile of Elite Netball Umpires During Match Play. *Journal of Strength and Conditioning Research, 34*(10), 2832-2839. https://doi.org/10.1519/jsc.0000000000003248

Spencer, K., Paget, N., Kilding, A., & McErlain-Naylor, S. A. (2020). Physical, physiological, and technical demands of national netball umpires at different competition levels. *Journal of Sports Sciences, 38*(14), 1660-1665. https://doi.org/10.1080/02640414.2020.1754718

Springham, M., Williams, S., Waldron, M., McLellan, C., & Newton, R. U. (2022). Summated training and match load predictors of salivary immunoglobulin-A, alpha-amylase, testosterone, cortisol and T:C profile changes in elite-level professional football players: A longitudinal analysis. *European Journal of Sport Science, 22*(8), 1156-1166. https://doi.org/10.1080/17461391.2021.1949638

Stewart, A., Ferriero, D., Josephson, S., Lowenstein, D., Messing, R., Oksenberg, J., Johnston, S., & Hauser, S. (2012). Fighting decision fatigue. *Annals of Neurology, 71*(5), 614–615. https://doi.org/10.1002/ana.23508

Stochi de Oliveira, R., & Borin, J. P. (2021). Monitoring and Behavior of Biomotor Skills in Futsal Athletes During a Season. *Frontiers in Psychology, 12*, 661262. https://doi.org/10.3389/fpsyg.2021.661262

Stojiljković, N., Scanlan, A., Dalbo, V., Stankovic, R., Milanović, Z., & Stojanović, E. (2020). Physiological responses and activity demands remain consistent irrespective of team size in recreational handball. *Biol Sport, 37*(1), 69-78. https://doi.org/10.5114/biolsport.2020.92516

Strath, S. J., Swartz, A. M., Bassett, D. R., O'Brien, W. L., King, G. A., & Ainsworth, B. E. (2000). Evaluation of heart rate as a method for assessing moderate intensity physical activity. *Medicine & Science in Sports & Exercise, 32*(9 Suppl), S465. https://doi.org/10.1097/00005768-200009001-00008

Suárez-Iglesias, D., Dehesa, R., Scanlan, A. T., Rodríguez-Marroyo, J. A., & Vaquera, A. (2021). Defensive Strategy and Player Sex Impact Heart-Rate Responses During Games-Based Drills in Professional Basketball. *International Journal of Sports Physiology and Performance, 16*(3), 360-366. https://doi.org/10.1123/ijspp.2019-0736

Sudman, S., & Bradburn, N. M. (1982). Asking questions: A practical guide to questionnaire design. Jossey-Bass.

Sulaiman, N., Mohamad Nasir, M. A., Adnan, R., Misdan, M., Mastura, M., & Ahmad, H. (2011). Criterion validity of yoyo intermittent endurance test in estimating maximal oxygen consumption among malaysian elite football players. 2011 IEEE Colloquium on Humanities, Science and Engineering Humanities, Science and Engineering (CHUSER), 281-284.

Svilar, L., Castellano, J., Jukic, I., & Casamichana, D. (2018). Positional Differences in Elite Basketball: Selecting Appropriate Training-Load Measures. *International Journal of Sports Physiology and Performance, 13*(7), 947-952. https://doi.org/10.1123/ijspp.2017-0534

Swann, C., Keegan, R. J., Piggott, D., & Crust, L. (2012). A systematic review of the experience, occurrence, and controllability of flow states in elite sport. *Psychology of Sport and Exercise, 13*(6), 807-819.

Tai, C. C., Chen, Y. L., Kalfirt, L., Masodsai, K., Su, C. T., & Yang, A. L. (2022). Differences between Elite Male and Female Badminton Athletes Regarding Heart Rate Variability, Arterial Stiffness, and Aerobic Capacity. *Int J Environ Res Public Health, 19*(6). https://doi.org/10.3390/ijerph19063206

Tait, J. L., Aisbett, B., Corrigan, S. L., Drain, J. R., & Main, L. C. (2022). Recovery of Cognitive Performance Following Multi-Stressor Military Training. *Human Factors*, 1-1. https://doi.org/10.1177/00187208221086686

Tanskanen, M. M., Uusitalo, A. L., Kinnunen, H., HÄKkjnen, K., KyrÖLÄInen, H., & Atalay, M. (2011). Association of Military Training with Oxidative Stress and Overreaching. *Medicine & Science in Sports & Exercise, 43*(8), 1552-1560.

Tanskanen, M., Kyröläinen, H., Uusitalo, A., Huovinen, J., Nissilä, J., Kinnunen, H.,, & Atalay, M., & Häkkinen, K. (2011). Serum sex-hormone binding globulin and cortisol. *Medicine & Science in Sports & Exercise, 43*(8), 1552-1560.

Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. (1996). Heart rate variability. *Circulation, 93*(5), 1043–1065. https://doi.org/10.1161/01.CIR.93.5.1043

Taylor, R. J., Sanders, D., Myers, T., Abt, G., Taylor, C. A., & Akubat, I. (2018). The Dose-Response Relationship Between Training Load and Aerobic Fitness in Academy Rugby Union Players. *International Journal of Sports Physiology and Performance, 13*(2), 163-169. https://doi.org/10.1123/ijspp.2017-0121

Teixeira, A. S., Nunes, R. F. H., Yanci, J., Izzicupo, P., Forner Flores, L. J., Romano, J. C., Guglielmo, L. G. A., & Nakamura, F. Y. (2018). Different Pathways Leading up to the Same Futsal Competition: Individual and Inter-Team Variability in Loading Patterns and Preseason Training Adaptations. *Sports (Basel), 7*(1). https://doi.org/10.3390/sports7010007

Teixeira, J. E., Alves, A. R., Ferraz, R., Forte, P., Leal, M., Ribeiro, J., Silva, A. J., Barbosa, T. M., & Monteiro, A. M. (2022). Effects of Chronological Age, Relative Age, and Maturation Status on Accumulated Training Load and Perceived Exertion in Young Sub-Elite Football Players. *Frontiers in Physiology, 13*, 832202. https://doi.org/10.3389/fphys.2022.832202

Thayer, J. F., Ahs, F., Fredrikson, M., Sollers, J. J., & Wager, T. D. (2012). A Meta-analysis of heart rate variability and neuroimaging studies: Implications for heart rate variability as a marker of stress and health. *Neuroscience & Biobehavioral Reviews, 36*(2), 747-756. https://doi.org/10.1016/j.neubiorev.2011.11.009

Thomas, M. L., & Russo, M. B. (2007). Neurocognitive monitors: Toward the prevention of cognitive performance decrements and catastrophic failures in the operational environment. *Aviation, Space, and Environmental Medicine, 78*(5), B144–B152.

Thorpe, R. T., Strudwick, A. J., Buchheit, M., Atkinson, G., Drust, B., & Gregson, W. (2017). The Influence of Changes in Acute Training Load on Daily Sensitivity of Morning-Measured Fatigue Variables in Elite Soccer Players. *International Journal of Sports Physiology and Performance, 12*(Suppl 2), S2107-s2113. https://doi.org/10.1123/ijspp.2016-0433

Tian, Y., He, Z. H., Zhao, J. X., Tao, D. L., Xu, K. Y., Earnest, C. P., & McNaughton, L. R. (2013). Heart rate variability threshold values for early-warning nonfunctional overreaching in elite female wrestlers. *Journal of Strength and Conditioning Research, 27*, 1511-1519.

Tomes, C., Schram, B., & Orr, R. (2021). Field Monitoring the Effects of Overnight Shift Work on Specialist Tactical Police Training with Heart Rate Variability Analysis. *Sustainability (2071-1050), 13*(14), 7895-7895. https://doi.org/10.3390/su13147895

Tometz, M. J., Jevas, S. A., Esposito, P. M., & Annaccone, A. R. (2022). Validation of Internal and External Load Metrics in NCAA D1 Women's Beach Volleyball. *Journal of Strength and Conditioning Research, 36*(8), 2223-2229. https://doi.org/10.1519/jsc.0000000000003963

Tornero-Aguilera, J. F., Robles-Pérez, J. J., & Clemente-Suárez, V. J. (2018). Use of Psychophysiological Portable Devices to Analyse Stress Response in Different Experienced Soldiers. *Journal of Medical Systems, 42*(4). https://doi.org/10.1007/s10916-018-0929-2

Tornero-Aguilera, J., Robles-Pérez, J., & Clemente-Suárez, V. (2017). Effect of Combat Stress in the Psychophysiological Response of Elite and Non-Elite Soldiers. *Journal of Medical Systems, 41*(6), 1-6. https://doi.org/10.1007/s10916-017-0748-x

Trank, T. V., Ryman, D. H., Minagawa, R. Y., Trone, D. W., & Shaffer, R. A. (2001). Running mileage, movement mileage, and fitness in male U.S. Navy recruits. *Medicine & Science in Sports & Exercise, 33*(6), 1033–1038.

Troester, J. C., & Duffield, R. (2022). Postural Control Responses to Different Acute and Chronic Training Load Profiles in Professional Rugby Union. *Journal of Strength and Conditioning Research, 36*(1), 220-225. https://doi.org/10.1519/jsc.0000000000003385

Truppa, L., Nuti, L., Mazzoleni, S., Garofalo, P., & Mannini, A. (2021). Quantitative Analysis of Performance Recovery in Semi-Professional Football Players after the COVID-19 Forced Rest Period. *Sensors (Basel), 22*(1). https://doi.org/10.3390/s22010242

Twist, C., & Highton, J. (2013). Monitoring fatigue and recovery in rugby league players. *International Journal of Sports Physiology and Performance, 8*, 467–474.

Uthoff, A., Bustos, A., Metral, G., Cronin, J., Dolcetti, J., & Rumpf, M. C. (2022). Does Warming Up With Wearable Resistance Influence Internal and External Training Load in National Level Soccer Players? *Sports Health, 14*(1), 92-98. https://doi.org/10.1177/19417381211055696

Vahia, D., Kelly, A., Knapman, H., & Williams, C. A. (2019). Variation in the Correlation Between Heart Rate and Session Rating of Perceived Exertion-Based Estimations of Internal Training Load in Youth Soccer Players. *Pediatr Exerc Sci, 31*(1), 91-98. https://doi.org/10.1123/pes.2018-0033

Van Dongen, H. P., Maislin, G., Mullington, J. M., & Dinges, D. F. (2003). The cumulative cost of additional wakefulness: Dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation*. Sleep, 26*(2), 117-126. https://doi.org/10.1093/sleep/26.2.117

Vesterinen, V., Nummela, A.T., Heikura, I., Laine, T., Hynynen, E., Botella, J., & Häkkinen, K. (2016). Individual endurance training prescription with heart rate variability. *Medicine* *and Science in Sports and Exercise, 48*, 1347-1354. doi: 10.1249/MSS.0000000000000901

Vickers, J. N., & Williams, A. M. (2007). Performing under pressure: The effects of physiological arousal, cognitive anxiety, and gaze control in biathlon. *Journal of Motor Behavior, 39*(5), 381–394. https://doi.org/10.3200/JMBR.39.5.381-394

Vickery, W., & Harkness, A. (2017). Physical, Physiological and Perceptual Match Demands of Amateur Mixed Gender Touch Players. *Journal of Sport Science and Medicine, 16*(4), 589-594.

Vigh-Larsen, J. F., Beck, J. H., Daasbjerg, A., Knudsen, C. B., Kvorning, T., Overgaard, K., Andersen, T. B., & Mohr, M. (2019). Fitness Characteristics of Elite and Subelite Male Ice Hockey Players: A Cross-Sectional Study. *Journal of Strength and Conditioning Research, 33*(9), 2352-2360. https://doi.org/10.1519/jsc.0000000000003285

Vigh-Larsen, J. F., Ermidis, G., Rago, V., Randers, M. B., Fransson, D., Nielsen, J. L., Gliemann, L., Piil, J. F., Morris, N. B., FV, D. E. P., Overgaard, K., Andersen, T. B., Nybo, L., Krustrup, P., & Mohr, M. (2020). Muscle Metabolism and Fatigue during Simulated Ice Hockey Match-Play in Elite Players. *Medicine and Science in Sports and Exercise, 52*(10), 2162-2171. https://doi.org/10.1249/mss.0000000000002370

Vikmoen, O., Teien, H. K., Raustøl, M., Aandstad, A., Tansø, R., Gulliksrud, K., Skare, M., & Raastad, T. (2020). Sex differences in the physiological response to a demanding military field exercise. *Scandinavian Journal of Medicine & Science in Sports, 30*(8), 1348-1359. https://ezproxy.aut.ac.nz/login?url=https://search.ebscohost.com/login.aspx?direct=true&site=eds-live&db=s3h&AN=145340066

Weaving, D., Dalton-Barron, N., McLaren, S., Scantlebury, S., Cummins, C., Roe, G., Jones, B., Beggs, C., & Abt, G. (2020). The relative contribution of training intensity and duration to daily measures of training load in professional rugby league and union. *Journal of Sports Sciences, 38*(14), 1674-1681. https://doi.org/10.1080/02640414.2020.1754725

Weaving, D., Dalton, N. E., Black, C., Darrall-Jones, J., Phibbs, P. J., Gray, M., Jones, B., & Roe, G. A. B. (2018). The Same Story or a Unique Novel? Within-Participant Principal-Component Analysis of Measures of Training Load in Professional Rugby Union Skills Training. *International Journal of Sports Physiology and Performance, 13*(9), 1175-1181. https://doi.org/10.1123/ijspp.2017-0565

Weaving, D., Jones, B., Marshall, P., Till, K., & Abt, G. (2017). Multiple Measures are Needed to Quantify Training Loads in Professional Rugby League. *International Journal of Sports Medicine, 38*(10), 735-740. https://doi.org/10.1055/s-0043-114007

Weaving, D., Jones, B., Till, K., Marshall, P., Earle, K., & Abt, G. (2020). Quantifying the External and Internal Loads of Professional Rugby League Training Modes: Consideration for Concurrent Field-Based Training Prescription. *Journal of Strength and Conditioning Research, 34*(12), 3514-3522. https://doi.org/10.1519/jsc.0000000000002242

Weiss, K. J., Allen, S. V., McGuigan, M. R., & Whatman, C. S. (2017). The Relationship Between Training Load and Injury in Men's Professional Basketball. *International Journal of Sports Physiology and Performance, 12*(9), 1238-1242. https://doi.org/10.1123/ijspp.2016-0726

Westerterp, K.R., 2001. Limits to sustainable human metabolic rate. Journal of Experimental Biology, 204, 3183–3187.

Whitworth-Turner, C. M., Di Michele, R., Muir, I., Gregson, W., & Drust, B. (2019). Training load and schedule are important determinants of sleep behaviours in youth-soccer players. *European Journal of Sport Science, 19*(5), 576-584. https://doi.org/10.1080/17461391.2018.1536171

Wiig, H., Andersen, T. E., Luteberget, L. S., & Spencer, M. (2020). Individual Response to External Training Load in Elite Football Players. *International Journal of Sports Physiology and Performance, 15*(5), 696-704. https://doi.org/10.1123/ijspp.2019-0453

Wilkinson, D. M., Rayson, M. P., & Bilzon, J. L. (2008). A physical demands analysis of the 24-week British Army Parachute Regiment recruit training syllabus. *Ergonomics, 51*(5), 649–662.

Wilkinson, D. M., Rayson, M. P., & Bilzon, J. L. J. (2008). A physical demands analysis of the 24-week British Army Parachute Regiment recruit training syllabus. *Ergonomics, 51*(5), 649-662-662. https://doi.org/10.1080/00140130701757367

Willberg, C., Wieland, B., Rettenmaier, L., Behringer, M., & Zentgraf, K. (2022). The relationship between external and internal load parameters in 3 × 3 basketball tournaments. *BMC Sports Sci Med Rehabil, 14*(1), 152. https://doi.org/10.1186/s13102-022-00530-1

Williams, M. N. C., Dalbo, V. J., Fox, J. L., O'Grady, C. J., & Scanlan, A. T. (2021). Comparing Weekly Training and Game Demands According to Playing Position in a Semiprofessional Basketball Team. *International Journal of Sports Physiology and Performance, 16*(6), 772-778. https://doi.org/10.1123/ijspp.2020-0457

Williams, S., Booton, T., Watson, M., Rowland, D., & Altini, M. (2017). Heart rate variability is a moderating factor in the workload-injury relationship of competitive Crossfit™ athletes. *Journal of Sport Science and Medicine, 16*, 443-449.

Williams, S., West, S., Howells, D., Kemp, S. P. T., Flatt, A. A., & Stokes, K. (2018). Modelling the HRV Response to Training Loads in Elite Rugby Sevens Players. *Journal of Sport Science and Medicine, 17*(3), 402-408.

Williamson, D., McCarthy, E., & Ditroilo, M. (2020). Acute Physiological Responses to Ultra Short Race-Pace Training in Competitive Swimmers. *J Hum Kinet, 75*, 95-102. https://doi.org/10.2478/hukin-2020-0040

Windt, J., MacDonald, K., Taylor, D., Zumbo, B. D., Sporer, B. C., & Martin, D. T. (2020). "To tech or not to tech?" A critical decision-making framework for implementing technology in sport. *Journal of Athletic Training, 55*(9), 902-910.

Winters, J. D., Heebner, N. R., Johnson, A. K., Poploski, K. M., Royer, S. D., Takashi, N., Randall, C. A., Abt, J. P., & Lephart, S. M. (2021). Altered Physical Performance Following Advanced Special Operations Tactical Training. *Journal of Strength and Conditioning Research, 35*(7), 1809-1816.

Wood, T. G., Scanlan, A. T., Minett, G. M., & Kelly, V. G. (2022). A Comparison of the External and Internal Demands Imposed during Conditioning Training and Match-Play in Semi-Professional and Development Female Netball Players. *Sports (Basel), 10*(1). https://doi.org/10.3390/sports10010012

Wundersitz, D. W., Staunton, C. A., Gordon, B. A., & Kingsley, M. I. (2021). The influence of playing surface on external demands and physiological responses during a soccer match simulation. *Journal of Sports Sciences, 39*(24), 2869-2877. https://doi.org/10.1080/02640414.2021.1976472

Wyss, T., Scheffler, J., & Mäder, U. (2012). Ambulatory physical activity in Swiss Army recruits. *International Journal of Sports Medicine, 33*(9), 716-722-722. https://doi.org/10.1055/s-0031-1295445

Younesi, S., Rabbani, A., Clemente, F. M., Silva, R., Sarmento, H., & Figueiredo, A. J. (2021a). Dose-Response Relationships between Training Load Measures and Physical Fitness in Professional Soccer Players. *Int J Environ Res Public Health, 18*(8). https://doi.org/10.3390/ijerph18084321

Younesi, S., Rabbani, A., Clemente, F. M., Silva, R., Sarmento, H., & Figueiredo, A. J. (2021b). Relationships Between Aerobic Performance, Hemoglobin Levels, and Training Load During Small-Sided Games: A Study in Professional Soccer Players. *Frontiers in Physiology, 12*, 649870. https://doi.org/10.3389/fphys.2021.649870

Zurutuza, U., Castellano, J., Echeazarra, I., & Casamichana, D. (2017). Absolute and Relative Training Load and Its Relation to Fatigue in Football. *Frontiers in Psychology, 8*, 878. https://doi.org/10.3389/fpsyg.2017.00878

Zurutuza, U., Castellano, J., Echeazarra, I., Guridi, I., & Casamichana, D. (2019). Selecting Training-Load Measures to Explain Variability in Football Training Games. *Frontiers in Psychology, 10*, 2897. https://doi.org/10.3389/fpsyg.2019.02897

Appendices

Appendix A.

Internal Monitoring Methods in Traditional Sports Environments.

Study	Sport	HR	HR Recovery	HRV	TRIMP	Hydration	Hormone Markers	Lactate	Glucose	RPE	Cognition/ Reaction
Abbott et al. (2018)	Soccer									x	
Abdullahi et al. (2019)	Badminton	x									
Akiyama et al. (2019)	Lacrosse	x									
Akubat et al. (2018)	Soccer	x			x			x			
Alder et al. (2019)	Badminton	x									x
Altmann et al. (2021)	Soccer	x						x			
Anderson et al. (2021)	Soccer	x									
Anguis et al. (2022)	Football	x									x
Aoki et al. (2017)	Basketball	x	x		x					x	
Askow et al. (2021)	Soccer	x			x					x	
Azcárate et al. (2020)	Soccer									x	
Barnes et al. (2020)	Rugby	x								x	
Beato et al. (2017)	Futsal	x								x	
Beato et al. (2021)	Soccer	x								x	
Bělka et al. (2017)	Handball	x								x	
Benjamin et al. (2021)	Soccer	x									x
Bigg et al. (2021)	Hockey				x						
Birdsey et al. (2019)	Netball	x					x			x	
Birdsey et al. (2022)	Netball	x					x			x	
Bjørndal et al. (2021)	Handball									x	
Blair et al. (2018)	Rugby	x									
Bozzini et al. (2021)	Volleyball	x									
Brandes et al. (2021)	Soccer	x						x		x	
Branquinho et al. (2020)	Soccer	x									

Branquinho et al. (2021)	Soccer	x					
Bredt et al. (2020)	Basketball	x					
Brisola et al. (2020)	Water polo					x	x
Bruno et al. (2021)	Other	x					x
Buchheit et al. (2021)	Soccer	x					
Bunn et al. (2021)	Lacrosse	x					
Campbell et al. (2018)	Rugby	x					x
Campbell et al. (2021)	Football	x					x
Campos-Vazquez et al. (2021)	Soccer	x					x
Castillo et al. (2017)	Soccer	x		x			x
Castillo-Rodríguez et al. (2020)	Soccer	x					
Cirer-Sastre et al. (2019)	Soccer	x			x		x
Clemente et al. (2018)	Soccer	x					x
Clemente et al. (2019)	Soccer						
Clemente et al. (2019)	Soccer	x					x
Coelho et al. (2019)	Other	x	x				x
Coker et al. (2021)	Soccer	x					
Colby et al. (2018)	Football						
Colosio et al. (2021)	Soccer	x					
Comyns et al. (2021)	Rugby						x
Conlan et al. (2021)	Rugby						
Conte et al. (2021)	Rugby						x
Conte et al. (2021)	Basketball	x					x
Conte et al. (2021)	Basketball						x
Coppalle et al. (2021)	Soccer						x
Coppus et al. (2021)	Soccer	x					x
Costa et al. (2019)	Soccer	x	x	x			
Costa et al. (2022)	Soccer	x	x				x
Costa et al. (2019)	Soccer	x	x	x			
Costa et al. (2021)	Soccer	x	x	x			x
Costa et al. (2022)	Soccer						x
Coyne et al. (2021)	Basketball						x

Crang et al. (2020)	Rugby						x
Crouch et al. (2021)	Lacrosse	x					
Cruz et al. (2018)	Basketball						x
Cullen et al. (2021)	Football	x					
Curtis et al. (2021)	Soccer	x					
da Silva et al. (2021)	Soccer						
Dalen et al. (2019)	Soccer			x			
Daniel et al. (2021)	Hockey						x
de Dios-Álvarez et al. (2021)	Soccer						x
de Dios-Álvarez et al. (2021)	Soccer						x
Delecroix et al. (2019)	Football						x
Dello Iacono et al. (2017)	Soccer	x				x	
Dobbin et al. (2021)	Touch Rugby	x					
Doeven et al. (2021)	Basketball						x
Douchet et al. (2021)	Soccer	x					x
Dubois et al. (2021)	Rugby	x					
Duthie et al. (2018)	Soccer						
Enes et al. (2021)	Soccer						x
Enes et al. (2021)	Soccer						x
Ferioli et al. (2018)	Basketball						x
Ferioli et al. (2021)	Basketball						x
Fernandes et al. (2021)	Soccer						x
Fernandes et al. (2022)	Soccer						x
Fernández et al. (2021)	Hockey						x
Fields et al. (2021)	Soccer	x	x		x		x
Fields et al. (2021)	Soccer	x	x		x		x
Figueiredo et al. (2019)	Football						x
Flatt et al. (2018)	Football	x	x				
Flatt et al. (2019)	Rugby	x	x				
Fox et al. (2020)	Basketball	x					x

Fox et al. (2020)	Basketball	x			x
Fox et al. (2022)	Basketball	x			x
Fox et al. (2018)	Basketball	x			x
Gallo-Salazar et al. (2019)	Tennis	x			x
Gamonales et al. (2021)	Soccer	x			
Gantois et al. (2022)	Soccer	x			x
García et al. (2022)	Basketball	x			
García-Ceberino et al. (2022)	Soccer	x			
García-Santos et al. (2019)	Basketball	x			
Gentles et al. (2018)	Soccer				x
Ghali et al. (2020)	Basketball				
Gielen et al. (2021)	Volleyball	x			
Giménez et al. (2021)	Soccer				
Giménez et al. (2019)	Soccer				
Gonçalves et al. (2020)	Hockey				x
González-Fimbres et al. (2021)	Hockey	x			
Goodale et al. (2017)	Rugby	x			
Govus et al. (2021)	Football				x
Graham et al. (2021)	Football			x	x
Graham et al. (2021)	Football			x	x
Griffin et al. (2021)	Rugby				x
Grünbichler et al. (2021)	Soccer	x			
Gualtieri et al. (2020)	Soccer				x
Guridi Lopategui et al. (2021)	Football				
Halouani et al. (2019)	Soccer	x			
Hammami et al. (2018)	Soccer	x			
Harry et al. (2020)	Hockey	x	x		
Hauer et al. (2020)	Lacrosse	x			

Heinrich et al. (2020)	Other	x					x		
Horta et al. (2021)	Volleyball					x			
Howle et al. (2020)	Football	x							
Iacono et al. (2022)	Football	x							x
Iannaccone et al. (2022)	Handball	x							
Ihsan et al. (2017)	Hockey								x
James et al. (2021)	Squash	x			x				x
James et al. (2021)	Squash	x			x				x
Jaspers et al. (2021)	Soccer								x
Jaspers et al. (2018)	Soccer								x
Jaspers et al. (2018)	Soccer	x							x
Jin et al. (2022)	Basketball	x		x	x				x
Jorge Santos et al. (2021)	Soccer								
Kamarauskas et al. (2021)	Basketball	x				x			
Khoramipour et al. (2021)	Basketball						x	x	
King et al. (2021)	Netball	x							
Kniubaite et al. (2019)	Handball	x							x
Köklü et al. (2017)	Soccer	x					x		x
Konarski et al. (2021)	Hockey	x							
Krueger et al. (2021)	Hockey	x	x				x		x
Kunz et al. (2021)	Soccer	x					x		x
Lacome et al. (2018)	Soccer	x							
Lacome et al. (2021)	Soccer	x							
Lastella et al. (2021)	Basketball								
Lathlean et al. (2021)	Football								x
Leão et al. (2022)	Football								

Leduc et al. (2019)	Rugby					x
Lee et al. (2019)	Soccer			x		
Leicht et al. (2021)	Basketball	x				
Li et al. (2021)	Basketball	x			x	
Lima et al. (2022)	Volleyball					x
Lima et al. (2021)	Volleyball					x
Lima et al. (2020)	Volleyball					x
Lo et al. (2022)	Rugby					
Lorenzo Calvo et al. (2021)	Basketball					x
Lovell et al. (2021)	Soccer	x				x
Lu et al. (2021)	Futsal	x		x		x
Lukonaitienė et al. (2021)	Basketball	x	x	x		x
Lukonaitienė et al. (2020)	Basketball	x	x	x		x
Lupo et al. (2021)	Rugby	x				x
Lupo et al. (2021)	Basketball	x				x
Luteberget et al. (2021)	Football					
Malone et al. (2018)	Soccer					x
Malone et al. (2019)	Other	x				
Malone et al. (2019)	Other	x			x	
Malone et al. (2020)	Football					x
Malone et al. (2018)	Soccer					x
Malone et al. (2018)	Soccer					x
Malone et al. (2017)	Football					x
Malone et al. (2017)	Football					x
Mancha-Triguero et al. (2021)	Basketball					
Manuel et al. (2020)	Soccer					x
Martin et al. (2021)	Soccer					x
Martínez-Serrano et al. (2021)	Soccer					x
Marynowicz et al. (2020)	Soccer					x

Mateus et al. (2021)	Soccer	x					
Maughan et al. (2021)	Football					x	
Maughan et al. (2021)	Soccer					x	
Maughan et al. (2022)	Soccer					x	
McCaskie et al. (2018)	Football					x	
McFadden et al. (2020)	Soccer	x		x			
McFadden et al. (2022)	Soccer	x		x			
McFadden et al. (2020)	Soccer	x		x			
McGuinness et al. (2019)	Hockey	x				x	
McGuinness et al. (2019)	Hockey	x				x	
McGuinness et al. (2020)	Hockey					x	
McGuinness et al. (2022)	Hockey	x				x	
McLaren et al. (2021)	Rugby	x				x	
Mendes et al. (2018)	Volleyball					x	
Mhenni et al. (2017)	Handball					x	
Milanović et al. (2020)	Football	x					
Montgomery et al. (2021)	Basketball	x			x		
Montini et al. (2020)	Soccer					x	
Móra et al. (2021)	Soccer	x	x				
Morandi et al. (2021)	Soccer					x	
Mullen et al. (2021)	Rugby	x					x
Mullen et al. (2021)	Rugby						x
Myers et al. (2020)	Tennis					x	
Nakamura et al. (2021)	Futsal	x	x				
Nakamura et al. (2021)	Rugby	x	x				
Nicolò et al. (2021)	Soccer	x					
Nobari et al. (2021)	Soccer					x	
Nobari et al. (2021)	Soccer					x	
Nobari et al. (2021)	Soccer					x	
Nobari et al. (2022)	Soccer	x				x	
Nobari et al. (2021)	Soccer					x	
Noor et al. (2021)	Football					x	
Nunes et al. (2020)	Soccer					x	

O'Keeffe et al. (2020)	Football						x
Oliva-Lozano et al. (2021a)	Soccer						
Oliva-Lozano et al. (2021b)	Futsal						
Oliveira et al. (2019)	Soccer						x
Oliveira et al. (2020)	Soccer						x
Oliveira et al. (2019)	Soccer						x
Oliveira et al. (2021)	Soccer						x
Oliveira et al. (2021)	Soccer						x
Op De Beéck et al. (2019)	Soccer						
Otaegi et al. (2020)	Basketball						
Ozaeta et al. (2022)	Soccer	x					
Panduro et al. (2022)	Football	x					
Papadakis et al. (2020)	Soccer			x			
Paulsen et al. (2018)	Soccer	x					
Pereira et al. (2019)	Soccer	x	x				
Pereira et al. (2021)	Soccer						
Phibbs et al. (2018)	Rugby						x
Portes et al. (2021)	Basketball	x		x			
Poureghbali et al. (2021)	Basketball	x					
Póvoas et al. (2021)	Handball	x				x	
Puente et al. (2017)	Basketball	x					
Pueo et al. (2021)	Handball	x					
Querido et al. (2021)	Football						x
Quintas et al. (2020)	Football				x		
Rabbani et al. (2019)	Soccer	x		x			
Rago et al. (2019)	Football						x
Rago et al. (2020)	Football	x					x
Rago et al. (2021)	Hockey						x
Ramos-Campo et al. (2021)	Basketball	x	x				

Raya-González et al. (2019)	Soccer								
Reina Roman et al. (2019)	Basketball								
Reinhardt et al. (2021)	Soccer		x				x		
Reinhardt et al. (2020)	Soccer	x							
Rentz et al. (2021)	Soccer	x							
Ribeiro et al. (2022)	Futsal								x
Ritchie et al. (2017)	Football								x
Robineau et al. (2019)	Rugby								x
Roe et al. (2017)	Rugby	x				x			x
Romero-Moraleda et al. (2021)	Soccer								x
Rossi et al. (2021)	Soccer								x
Ruben et al. (2021)	Basketball	x			x				
Russell et al. (2021)	Netball	x				x			
Saidi et al. (2022)	Soccer						x		x
Saidi, et al. (2019)	Soccer						x		
Sánchez-Sáez et al. (2021)	Handball	x							
Sánchez-Sánchez et al. (2021)	Soccer	x		x					
Sanders et al. (2019)	Other	x							
Sansone et al. (2022)	Basketball	x							x
Sansone et al. (2021)	Basketball								x
Sansone et al. (2021)	Basketball								x
Sansone et al. (2020)	Basketball	x				x			x
Scanlan et al. (2017)	Basketball	x					x	x	x
Scanlan et al. (2021)	Basketball						x	x	x
Scanlan et al. (2019)	Basketball	x			x		x	x	x
Scott et al. (2018)	Football	x							x
Sekiguchi et al. (2021)	Soccer	x							
Silva et al. (2018)	Football	x			x				
Simim et al. (2021)	Soccer	x					x		

Simpson et al. (2020a)	Netball	x						x
Simpson et al. (2020b)	Netball	x						x
Sobolewski et al. (2020)	Football	x						x
Spencer et al. (2020)	Netball	x						x
Spencer et al. (2020)	Netball	x						x
Springham et al. (2021)	Football					x		x
Stochi de Oliveira et al. (2021)	Futsal							x
Stojiljković et al. (2020)	Handball	x					x	x
Suárez-Iglesias et al. (2021)	Basketball	x						
Svilar et al. (2018)	Basketball							x
Tai et al. (2022)	Badminton	x		x				
Taylor et al. (2018)	Rugby	x			x		x	x
Teixeira et al. (2021)	Futsal	x						x
Teixeira et al. (2021)	Football							x
Thorpe et al. (2021)	Soccer	x	x	x				
Tometz et al. (2022)	Volleyball	x			x			x
Troester et al. (2022)	Rugby							
Truppa et al. (2021)	Football	x						
Uthoff et al. (2022)	Soccer							x
Vahia et al. (2021)	Soccer	x						x
Vickery et al. (2021)	Touch Rugby	x						
Vigh-Larsen et al. (2021)	Hockey						x	
Vigh-Larsen et al. (2020)	Hockey	x					x	
Weaving et al. (2021)	Rugby							x
Weaving et al. (2020)	Rugby							x
Weaving et al. (2017)	Rugby	x						
Weaving et al. (2021)	Rugby							x
Weiss et al. (2021)	Basketball							
Whitworth-Turner et al. (2019)	Soccer							
Wiig et al. (2020)	Football							x

Willberg et al. (2022)	Basketball										
Williams et al. (2021)	Basketball	x								x	
Williams et al. (2018)	Rugby	x		x						x	
Williamson et al. (2020)	Swimming	x						x		x	
Wood et al. (2022)	Netball									x	
Wundersitz et al. (2021)	Soccer	x								x	
Younesi et al. (2021)	Soccer	x			x					x	
Younesi et al. (2021)	Soccer									x	
Zurutuza et al. (2017)	Football									x	
Zurutuza et al. (2019)	Football	x								x	
n =		165	5	21	27	1	14	26	4	172	5
% =		55.0%	1.7%	7.0%	9.0%	0.3%	4.7%	8.7%	1.3%	57.3%	1.7%

Appendix B.

External Monitoring Methods in Traditional Sports Environments.

Study	Sport	GPS	Performance/ Neuromuscular Tests	Accelerometers/ Pedometers	Training Load Calculations	Questionnaires	Sleep
Abbott et al. (2018)	Soccer	x		x			
Abdullahi et al. (2019)	Badminton	x					
Akiyama et al. (2019)	Lacrosse	x					
Akubat et al. (2018)	Soccer	x			x		
Alder et al. (2019)	Badminton						
Altmann et al. (2021)	Soccer						
Anderson et al. (2021)	Soccer	x					
Anguis et al. (2022)	Football						
Aoki et al. (2017)	Basketball		x				
Askow et al. (2021)	Soccer	x				x	
Azcárate et al. (2020)	Soccer						
Barnes et al. (2020)	Rugby				x		
Beato et al. (2017)	Futsal	x					
Beato et al. (2021)	Soccer	x					
Bělka et al. (2017)	Handball						
Benjamin et al. (2021)	Soccer		x				
Bigg et al. (2021)	Hockey						
Birdsey et al. (2019)	Netball		x	x			
Birdsey et al. (2022)	Netball		x	x			
Bjørndal et al. (2021)	Handball					x	
Blair et al. (2018)	Rugby						
Bozzini et al. (2021)	Volleyball	x					
Brandes et al. (2021)	Soccer						
Branquinho et al. (2020)	Soccer				x		
Branquinho et al. (2021)	Soccer						
Bredt et al. (2020)	Basketball			x			
Brisola et al. (2020)	Water polo				x		

Bruno et al. (2021)	Other	x	x				
Buchheit et al. (2021)	Soccer	x	x	x			
Bunn et al. (2021)	Lacrosse						
Campbell et al. (2018)	Rugby		x			x	x
Campbell et al. (2021)	Football		x			x	x
Campos-Vazquez et al. (2021)	Soccer						
Castillo et al. (2017)	Soccer						
Castillo-Rodríguez et al. (2020)	Soccer						
Cirer-Sastre et al. (2019)	Soccer	x		x			
Clemente et al. (2018)	Soccer	x		x		x	x
Clemente et al. (2019)	Soccer	x					
Clemente et al. (2019)	Soccer	x			x		
Coelho et al. (2019)	Other					x	
Coker et al. (2021)	Soccer						
Colby et al. (2018)	Football	x					
Colosio et al. (2021)	Soccer						
Comyns et al. (2021)	Rugby					x	
Conlan et al. (2021)	Rugby						x
Conte et al. (2021)	Rugby					x	x
Conte et al. (2021)	Basketball					x	x
Conte et al. (2021)	Basketball					x	x
Coppalle et al. (2021)	Soccer	x					
Coppus et al. (2021)	Soccer						
Costa et al. (2019)	Soccer	x					x
Costa et al. (2022)	Soccer		x				
Costa et al. (2019)	Soccer				x	x	x
Costa et al. (2021)	Soccer			x	x	x	x
Costa et al. (2022)	Soccer	x			x	x	x
Coyne et al. (2021)	Basketball				x		
Crang et al. (2020)	Rugby	x					
Crouch et al. (2021)	Lacrosse					x	x
Cruz et al. (2018)	Basketball		x				

Cullen et al. (2021)	Football	x					
Curtis et al. (2021)	Soccer						
da Silva et al. (2021)	Soccer	x		x			
Dalen et al. (2019)	Soccer						
Daniel et al. (2021)	Hockey	x			x		
de Dios-Álvarez et al. (2021)	Soccer	x				x	
de Dios-Álvarez et al. (2021)	Soccer	x				x	
Delecroix et al. (2019)	Football				x		
Dello Iacono et al. (2017)	Soccer		x				
Dobbin et al. (2021)	Touch Rugby		x				x
Doeven et al. (2021)	Basketball		x			x	x
Douchet et al. (2021)	Soccer	x	x			x	x
Dubois et al. (2021)	Rugby						
Duthie et al. (2018)	Soccer	x					
Enes et al. (2021)	Soccer	x		x			
Enes et al. (2021)	Soccer	x		x			
Ferioli et al. (2018)	Basketball		x				
Ferioli et al. (2021)	Basketball		x				
Fernandes et al. (2021)	Soccer					x	x
Fernandes et al. (2022)	Soccer					x	x
Fernández et al. (2021)	Hockey						
Fields et al. (2021)	Soccer	x					x
Fields et al. (2021)	Soccer	x				x	x
Figueiredo et al. (2019)	Football	x					
Flatt et al. (2018)	Football					x	
Flatt et al. (2019)	Rugby					x	
Fox et al. (2020)	Basketball			x			x
Fox et al. (2020)	Basketball			x			x
Fox et al. (2022)	Basketball			x			x
Fox et al. (2018)	Basketball			x			x
Gallo-Salazar et al. (2019)	Tennis	x					

Gamonales et al. (2021)	Soccer						
Gantois et al. (2022)	Soccer						
García et al. (2022)	Basketball						
García-Ceberino et al. (2022)	Soccer						
García-Santos et al. (2019)	Basketball		x				
Gentles et al. (2018)	Soccer	x		x			
Ghali et al. (2020)	Basketball					x	
Gielen et al. (2021)	Volleyball			x			
Giménez et al. (2021)	Soccer	x					
Giménez et al. (2019)	Soccer	x					
Gonçalves et al. (2020)	Hockey						x
González-Fimbres et al. (2021)	Hockey			x			
Goodale et al. (2017)	Rugby						
Govus et al. (2021)	Football	x		x		x	x
Graham et al. (2021)	Football			x			
Graham et al. (2021)	Football			x			
Griffin et al. (2021)	Rugby					x	
Grünbichler et al. (2021)	Soccer	x		x			
Gualtieri et al. (2020)	Soccer	x					
Guridi Lopategui et al. (2021)	Football	x			x		
Halouani et al. (2019)	Soccer						
Hammami et al. (2018)	Soccer						
Harry et al. (2020)	Hockey		x				
Hauer et al. (2020)	Lacrosse					x	
Heinrich et al. (2020)	Other		x				
Horta et al. (2021)	Volleyball		x			x	
Howle et al. (2020)	Football						
Iacono et al. (2022)	Football	x					
Iannaccone et al. (2022)	Handball						
Ihsan et al. (2017)	Hockey	x				x	x
James et al. (2021)	Squash			x			

James et al. (2021)	Squash			x			
Jaspers et al. (2021)	Soccer			x			
Jaspers et al. (2018)	Soccer			x			
Jaspers et al. (2018)	Soccer			x			
Jin et al. (2022)	Basketball						
Jorge Santos et al. (2021)	Soccer	x					
Kamarauskas et al. (2021)	Basketball					x	x
Khoramipour et al. (2021)	Basketball						
King et al. (2021)	Netball			x			
Kniubaite et al. (2019)	Handball						
Köklü et al. (2017)	Soccer						
Konarski et al. (2021)	Hockey	x					
Krueger et al. (2021)	Hockey	x		x			x
Kunz et al. (2021)	Soccer						
Lacome et al. (2018)	Soccer	x					
Lacome et al. (2021)	Soccer	x					
Lastella et al. (2021)	Basketball						x
Lathlean et al. (2021)	Football					x	x
Leão et al. (2022)	Football	x					
Leduc et al. (2019)	Rugby						x
Lee et al. (2019)	Soccer						
Leicht et al. (2021)	Basketball				x		
Li et al. (2021)	Basketball						
Lima et al. (2022)	Volleyball						
Lima et al. (2021)	Volleyball						
Lima et al. (2020)	Volleyball						
Lo et al. (2022)	Rugby	x		x		x	x
Lorenzo Calvo et al. (2021)	Basketball					x	x
Lovell et al. (2021)	Soccer						
Lu et al. (2021)	Futsal						
Lukonaitienė et al. (2021)	Basketball						
Lukonaitienė et al. (2020)	Basketball		x				
Lupo et al. (2021)	Rugby		x				
Lupo et al. (2021)	Basketball		x				

Luteberget et al. (2021)	Football					x	
Malone et al. (2018)	Soccer	x			x	x	
Malone et al. (2019)	Other	x					
Malone et al. (2019)	Other		x				
Malone et al. (2020)	Football	x			x	x	
Malone et al. (2018)	Soccer	x			x	x	
Malone et al. (2018)	Soccer	x			x	x	
Malone et al. (2017)	Football	x			x		
Malone et al. (2017)	Football				x		
Mancha-Triguero et al. (2021)	Basketball		x	x			
Manuel et al. (2020)	Soccer						
Martin et al. (2021)	Soccer						
Martínez-Serrano et al. (2021)	Soccer		x				
Marynowicz et al. (2020)	Soccer						
Mateus et al. (2021)	Soccer	x				x	x
Maughan et al. (2021)	Football	x					
Maughan et al. (2021)	Soccer	x					
Maughan et al. (2022)	Soccer	x					
McCaskie et al. (2018)	Football						
McFadden et al. (2020)	Soccer		x			x	x
McFadden et al. (2022)	Soccer		x			x	x
McFadden et al. (2020)	Soccer		x			x	x
McGuinness et al. (2019)	Hockey					x	x
McGuinness et al. (2019)	Hockey					x	x
McGuinness et al. (2020)	Hockey					x	x
McGuinness et al. (2022)	Hockey					x	x
McLaren et al. (2021)	Rugby		x				
Mendes et al. (2018)	Volleyball					x	x
Mhenni et al. (2017)	Handball						
Milanović et al. (2020)	Football						
Montgomery et al. (2021)	Basketball						
Montini et al. (2020)	Soccer						

Móra et al. (2021)	Soccer						
Morandi et al. (2021)	Soccer						
Mullen et al. (2021)	Rugby	x					
Mullen et al. (2021)	Rugby	x					
Myers et al. (2020)	Tennis						
Nakamura et al. (2021)	Futsal		x				
Nakamura et al. (2021)	Rugby		x				
Nicolò et al. (2021)	Soccer						
Nobari et al. (2021)	Soccer	x				x	x
Nobari et al. (2021)	Soccer	x				x	x
Nobari et al. (2021)	Soccer	x				x	x
Nobari et al. (2022)	Soccer	x				x	x
Nobari et al. (2021)	Soccer	x				x	x
Noor et al. (2021)	Football						x
Nunes et al. (2020)	Soccer	x					
O'Keeffe et al. (2020)	Football				x	x	
Oliva-Lozano et al. (2021a)	Soccer	x					
Oliva-Lozano et al. (2021b)	Futsal						
Oliveira et al. (2019)	Soccer	x					
Oliveira et al. (2020)	Soccer	x					
Oliveira et al. (2019)	Soccer	x					
Oliveira et al. (2021)	Soccer	x					
Oliveira et al. (2021)	Soccer	x					
Op De Beéck et al. (2019)	Soccer			x		x	x
Otaegi et al. (2020)	Basketball		x				
Ozaeta et al. (2022)	Soccer		x				
Panduro et al. (2022)	Football	x					
Papadakis et al. (2020)	Soccer		x				
Paulsen et al. (2018)	Soccer						
Pereira et al. (2019)	Soccer	x	x				
Pereira et al. (2021)	Soccer	x	x				
Phibbs et al. (2018)	Rugby			x			
Portes et al. (2021)	Basketball						
Poureghbali et al. (2021)	Basketball						

Póvoas et al. (2021)	Handball						
Puente et al. (2017)	Basketball			x			
Pueo et al. (2021)	Handball	x					
Querido et al. (2021)	Football						
Quintas et al. (2020)	Football						
Rabbani et al. (2019)	Soccer			x			
Rago et al. (2019)	Football	x		x		x	
Rago et al. (2020)	Football	x		x		x	
Rago et al. (2021)	Hockey	x		x		x	
Ramos-Campo et al. (2021)	Basketball						
Raya-González et al. (2019)	Soccer				x		
Reina Roman et al. (2019)	Basketball						
Reinhardt et al. (2021)	Soccer	x					
Reinhardt et al. (2020)	Soccer	x					
Rentz et al. (2021)	Soccer	x					
Ribeiro et al. (2022)	Futsal	x					
Ritchie et al. (2017)	Football	x					
Robineau et al. (2019)	Rugby	x					
Roe et al. (2017)	Rugby		x				
Romero-Moraleda et al. (2021)	Soccer	x		x			
Rossi et al. (2021)	Soccer	x				x	x
Ruben et al. (2021)	Basketball						
Russell et al. (2021)	Netball						
Saidi et al. (2022)	Soccer		x			x	x
Saidi, et al. (2019)	Soccer		x			x	x
Sánchez-Sáez et al. (2021)	Handball	x		x			
Sánchez-Sánchez et al. (2021)	Soccer	x		x			
Sanders et al. (2019)	Other						
Sansone et al. (2022)	Basketball						
Sansone et al. (2021)	Basketball						

Sansone et al. (2021)	Basketball						
Sansone et al. (2020)	Basketball						
Scanlan et al. (2017)	Basketball						
Scanlan et al. (2021)	Basketball						
Scanlan et al. (2019)	Basketball				x		
Scott et al. (2018)	Football	x				x	
Sekiguchi et al. (2021)	Soccer					x	
Silva et al. (2018)	Football						
Simim et al. (2021)	Soccer		x				
Simpson et al. (2020a)	Netball				x		
Simpson et al. (2020b)	Netball				x		
Sobolewski et al. (2020)	Football						
Spencer et al. (2020)	Netball			x			
Spencer et al. (2020)	Netball			x			
Springham et al. (2021)	Football						
Stochi de Oliveira et al. (2021)	Futsal		x				
Stojiljković et al. (2020)	Handball						
Suárez-Iglesias et al. (2021)	Basketball						
Svilar et al. (2018)	Basketball						
Tai et al. (2022)	Badminton						
Taylor et al. (2018)	Rugby						
Teixeira et al. (2021)	Futsal	x	x				
Teixeira et al. (2021)	Football	x					
Thorpe et al. (2021)	Soccer					x	x
Tometz et al. (2022)	Volleyball					x	
Troester et al. (2022)	Rugby		x				
Truppa et al. (2021)	Football					x	
Uthoff et al. (2022)	Soccer						
Vahia et al. (2021)	Soccer						
Vickery et al. (2021)	Touch Rugby						
Vigh-Larsen et al. (2021)	Hockey		x				

Vigh-Larsen et al. (2020)	Hockey		x				
Weaving et al. (2021)	Rugby						
Weaving et al. (2020)	Rugby						
Weaving et al. (2017)	Rugby						
Weaving et al. (2021)	Rugby						
Weiss et al. (2021)	Basketball					x	
Whitworth-Turner et al. (2019)	Soccer						x
Wiig et al. (2020)	Football						
Willberg et al. (2022)	Basketball	x	x		x		
Williams et al. (2021)	Basketball		x				
Williams et al. (2018)	Rugby		x				
Williamson et al. (2020)	Swimming						
Wood et al. (2022)	Netball				x		
Wundersitz et al. (2021)	Soccer			x			
Younesi et al. (2021)	Soccer						
Younesi et al. (2021)	Soccer		x				
Zurutuza et al. (2017)	Football	x	x			x	
Zurutuza et al. (2019)	Football	x	x			x	
n =		96	52	44	26	68	54
% =		32.0%	17.3%	14.7%	8.7%	22.7%	18.0%