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ORIGINAL ARTICLE

The simple low-cost guide to athlete fatigue monitoring

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ABSTRACT

As the demands of training and competition increase so does the potential risk of injury and illness to the athlete whilst seeking to maximize their adaptive processes to promote optimal performance. Therefore, as a strategy to mitigate this risk, strength and conditioning coaches need reliable and valid monitoring tools to track an athlete's status throughout training to ensure progression of adaptation, and that the athlete remains healthy throughout the adaptation process. The purpose of this article is to provide the reader an evidence-driven outline of basic, simple, and cost-effective monitoring tools which are reliable and valid to observe the fitness/fatigue paradigm and track overall athlete physical adaptation and health throughout the training process, suitable for most settings. A weekly example calculating sessional ratings of perceived exertion (sRPE), training load, monotony, and strain is provided along with a basic monitoring system as a guide for the reader.
Keywords: Sport medicine, Injury prevention, Load management, Overtraining.

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INTRODUCTION

To realize athletic performance, the strength and conditioning coach (S&C) has two main goals in training any athlete. First, to improve their athletic capabilities to achieve maximum potential and secondly, develop and use specific training protocols that facilitate appropriate timing of peak performance while reducing the risk of injuries (Dorgo, 2009). By achieving these two goals, the S&C coach supports the technical coach and other medical staff by presenting an athlete with a greater likelihood of being physically healthy and capable to give the desired performance. Thus, the S&C coach should use various assessment tools to monitor and track the effects of a training program, the athlete' readiness to compete, and their overall well-being (McGuigan et al., 2020).

Throughout the training process, the S&C coach will structure different configurations of training loads (TL) (i.e. various training intensities and volume of work) depending on the timeframe and positioning within a season (Plisk & Stone, 2003). Each training type presents a novel stimulus that will promote a specific, associated, adaptation within the context of the specific sporting and athlete needs. This may include one or more of; changes to overall body composition, increasing specific muscle cross sectional area, improving maximal strength, enhancing rate of force development, and/or power production. For example, during the preseason, higher TL may be prescribed to drive specific physiological adaptations such as maximal strength and power or aerobic conditioning (Plisk & Stone, 2003). However, these increases are typically accompanied by higher residual fatigue and thus an increased risk of injury, illness, and underperformance (Drew & Finch, 2016; Stone et al., 2007). If this trend of higher TL is maintained without adequate recovery, then the athlete will eventually reach a state of non-functional overreaching and/or overtraining, which is detrimental to the athletes performance and ultimately their health (Kellmann et al., 2018).

Importantly, the S&C coach is concerned with the athletes' ability to tolerate the prescribed TL and the associated adaptations in either a negative or positive direction (Cunanan et al., 2018). Therefore, quantifying the specific training load of each type of training prescribed is imperative for the S&C coach to utilize in their planning and monitoring, so that subsequent decisions are well informed. Simply put, if we analogize training as medicine, we must start with knowing the dose by type. However, there are varying types of training prescribed and various stimulus-response relationships at play, making it difficult to scale and normalize between training types. How does a coach compare strengths sessions with field sessions, mobility sessions with conditioning sessions? Knowing these loads by type is critical but gaining an understanding of load across all training types and in total allows the coach to make better dose-response decisions.

Within the context of sports, adaptation to training is reflective of the organisms' (in this scenario the athlete as the system) ability to adjust and adapt to the stimuli that disrupts homeostasis throughout the training process and the systems' ability to return to homeostasis (recover for the next stimuli) (Chiu & Barnes, 2003; Cunanan et al., 2018; Plisk & Stone, 2003; Selye, 1956). A negative trend in adaptations may indicate, and result, in an overall residual fatigue state that without sufficient recovery, over a prolonged period, may contribute to injuries, illness, and reduced performance leading to overreaching and in severe cases overtraining (Edwards, 2018; Thorpe et al., 2017). Positive adaptive responses, indicates a greater level of fitness and preparedness for competition (Zatsiorsky et al., 2021). Therefore, the purpose of this review is two-fold, (i) provide the reader with the empirical evidence that supports simple tools utilized by the S&C coach in a real-world setting to monitor fatigue, the adaptative response and overall health of the athlete, and (ii) provide a practical system for how these tools can be implemented throughout the training process.

A brief note on quantification of load

A plethora of research exists in the realm of load quantification and load response (Borresen & Lambert, 2009; Foster, 1998; Fox et al., 2017; Fullagar et al., 2015; Halson, 2014; Thorpe et al., 2017). The reader is therefore directed to the referenced articles to further understand the relationship between load and load response. However, a few salient points need to be addressed. Load can be defined as either external or internal. Internal load refers to the physiological responses to a stimulus and can be perceived (subjective) or measurable (objective), whereas external load refers to the physical work performed (Haddad et al., 2017; Impellizzeri et al., 2004; Impellizzeri et al., 2005). What needs to be considered when examining internal or external load is the variation of responses associated with the stimulus, whether internal or external. For example, a key step in managing the internal load response, requires an understanding of the amount of external load placed on the athlete. For example, Barrett (2017) demonstrated that real time data such as high speed running (HSR) total distance, and maximum velocity can be used in real time to modulate training, thus indirectly influencing internal load. The internal response to the external load applied derives the outcome of the training (Saw et al., 2017). The individual response (i.e., internal load) to the same external load is highly individual and has varying response rates as it is impacted by various factors such as previous training status, genetics, individual characteristics, health, environment, nutrition, and psychological status (Vanrenterghem et al., 2017). The adaptation pathway for various external and internal load with a combination of various methods as highlighted in this article will prove useful. This notion is strengthened by Inoue et al. (2022) in their meta-analyses that there is an agreement between the coaches and athlete as it relates to moderate to hard load prescription, but not easy efforts. It is therefore important to add a looped feedback system between the athletes and the S&C to provide further context as to the readiness of the athletes on the day of physical activity. This is also in line with Bartlett et al. (2017) were 36 out of 41 Australian rules footballers demonstrated that session distance and not HSR was the greatest predictor of RPE. Whereas only 2 players demonstrated that $m \cdot min^{-1}$ was predictive of RPE, and 3 players showed that HSR and % HSR was a better predictor of RPE compared to the other metrics. These described outcomes from Bartlett et al. (2017), strengthens the need for an individualized approach utilizing multiple tools and metrics in conjunction and not in isolation to evaluate the athlete's readiness.

UNDERSTANDING AND APPLYING SUBJECTIVE DATA

Triangulating the most common denominator of athlete monitoring, fatigue management is a topic of interest for the S&C coach (McGuigan et al., 2020; Taylor et al., 2012). For the S&C coach to understand the physiological and psychological load an athlete is experiencing whether acutely or chronically, subjective questionnaires can be used to monitor what is referred to as the internal (athlete perceived) load of any given training session (Foster et al., 2001; Kellmann et al., 2018). Depending on the response, this information can then be used to inform, adjust, and prescribe appropriate future training loads. Furthermore, consistent reporting of high subjective scores after competition by athletes can be used to guide coaching and support staff to a potential increased risk of injury or illness (Hamlin et al., 2019; Rogalski et al., 2013).

Session rating of perceived exertion

Sessional rating of perceived exertion (sRPE) is a simple, short, subjective question-based assessment tool that the athlete answers after either a training session or competition. The response to the short questionnaire provides a S&C coach with an internal (perceived) intensity rating using a scale from 0-10 (Foster et al., 2001; Singh et al., 2007). Each number has a descriptor (0-1 = very easy, 2 = easy, 3 = moderate, 4 = somewhat hard, 5-6 = hard, 7-9 = very hard, and 10 = maximal) to assist the athlete to anchor their internal perception to a valid and reliable response (Foster et al., 2001). The athletes' response can be used to calculate an internal TL reflective of what the athlete experiences during a training session or game. The TL is calculated by multiplying the sRPE score by the duration of the training session or game (Calculation 1) and is expressed as arbitrary units (A.U) (Foster et al., 1996; Foster et al., 2001).

TL = duration in minutes x sRPE (*Calculation 1*)

Example: 60 x 6 = 360 A.U

The use of session rating of perceived exertion (sRPE) has been reported as reliable and valid for monitoring athletes of different competitive levels and across various sports or team settings and is widely used amongst S&C coaches (Haddad et al., 2017; Taylor et al., 2012). An athletes responses should not be taken immediately after the training session as they may elevate or lower the responses based on the final training modality at the end of the session (Singh et al., 2007). Singh et al. (2007) observed that the sRPE can be recorded 10 minutes after the training session is completed as there were no differences observed in the sRPE scores compared to waiting 30 minutes after completing different modes of resistance training. This change in recording protocol when implemented provides for a more practical implementation of sRPE in sporting environments. Further, sRPE is reliable when compared to objective measures in quantifying TL in resistance and aerobic training, HSR, plyometrics and speed, interval training, regardless of whether it is a male and female athlete population (Haddad et al., 2017). The reader is referred to the excellent review by Haddad et al. (2017) to further understand the relationship between sRPE and populations within different sports.

Validation of sRPE has been examined across sports in different contexts. Impellizzeri et al. (2004) observed moderate to strong correlations (r = 0.71) between sRPE TL and heart rate-based TL across 27 training sessions in young soccer players. Alexiou and Coutts (2008) reported similar results in elite female soccer players with moderate to strong correlations between sRPE TL and heart rate-based TL (r = 0.56-0.97) within individual players. To show its wider validity there has been evidence of strong relationships in male Canadian football players (r = 0.65-0.91) (Clarke et al., 2013), adolescent basketball players (r = 0.80-0.95) (Lupo et al., 2017), Karate (r = 0.65-0.95) Tabben et al. (2015), and resistance training (ICC = 0.88) (Day et al., 2004).

Use of this TL data is a pragmatic approach for S&C coaches to monitor the internal stress of the athlete with different types of training sessions i.e. sport specific practice, gym and field based sessions, or competitive events (Halson, 2014). Using TL data encourages the implementation of appropriate training strategies e.g. adding a recovery session or increasing/decreasing intensity of a particular session/drill (Saw et al., 2016b). Furthermore, the information can aid in tracking the overall training responses of athletes on a week-to-week basis to monitor the overall stress that athletes experience (Foster C et al., 1996; Halson, 2014).

Training monotony and strain

Monotony and strain can provide useful information regarding the broader variability of TL across a microcycle Foster et al. (2001), and these can be calculated using 'external load' quantification (e.g. total load lifted in resistance sessions, total distance run, etc.), but commonly these are used with arbitrary unit measures like sRPE (that are a product of both external load; minutes and internal load; rating of perceived exertion). Training monotony represents the day-to-day variability in training and is calculated by dividing the weekly mean TL by the standard deviation of the daily load calculated over a week (Calculation 2) (Foster, 1998).

Monotony = weekly mean TL / SD (*Calculation 2*)

The resulting metric can be useful to detect if large or small overall TL variations are occurring regardless of whether the types of training being performed are varied. For example, high monotony (little variation) exhibited via continuous high TL, may increase the likelihood of overtraining syndrome (Foster, 1998). This can be evident in equating similar TL's across macrocycles but different measures of strain and monotony may be present (Comyns & Flanagan, 2013). Thus, tracking the variations in TL (high, moderate, and low) and their association to monotony can be useful for the S&C coach to account for adjusting the TL and implementing recovery methods within microcycles (Haddad et al., 2017).

To expand on monotony, training strain, a derived calculation from monotony, can be another useful way to monitor high TL. This is calculated via the weekly TL multiplied by the monotony score (Calculation 3).

Strain = weekly TL * monotony (*Calculation 3*)

High strain can occur when the TL is high with small variations in load (Foster, 1998; Foster et al., 2001). High strain can be considered to represent a higher overall weekly training stress in the athlete and may increase the chance of illness and injury (Foster et al., 2001). Table 1 provides an example of with reference to sRPE, monotony, and strain for a microcycle.

Table 1. Calculations for sRPE, Monotony, and Strain example. Calculations are expressed as arbitrary units.

	Type	RPE	Duration	Unit Load	Daily Load
Mon	Str (UB) Conditioning/Skill	6 7.5	40 60	240 450	690
Tue	Str (LB) Skill/Tactical	6 5	40 45	240 225	465
Wed	Off			0	0
Thurs	Str (WB) Speed/Skill	5 6	40 40	200 240	440
Fri	Skill/Tact + Cond	6 8.5	40 30	240 255	495
Sat/Sun	Off			0	0
Week Total				2090	
Daily mean load				298.5	
Daily SD				283.8	
Monotony				1.05	
Strain				2194.5	

Note. Cond = Conditioning session; Str = Strength; Tact = Tactical training; UB= Upper body; LB= Lower body; WB= Whole Body.

Wellness questionnaires

Wellness questionnaires can be utilized to provide further context on how the athlete is responding to training and whether adequate recovery is being achieved (Taylor et al., 2012). Typically, these questionnaires gather subjective information regarding most commonly the athlete's sleep quality and length, feelings of overall fatigue, stress, and muscle soreness (Saw et al., 2016b; Taylor et al., 2012). This information provides greater context to the athletes' experience both physically and psychologically outside of their training environment (Saw et al., 2016a). Given, positive adaptations tend to be achieved when the athlete has recovered both physically and psychologically (Barnett, 2006; Halson, 2014), it is pragmatic to include an assessment of the athlete's overall well-being in conjunction with sRPE. However, it is beyond the scope of this article to address all facets of well-being. While overall, the recovery process depends on many factors such as sleep hygiene, nutrition, and psychological stress (Fullagar et al., 2015; Halson, 2008), practitioners with limited resources should primarily focus on the importance of monitoring sleep, which can be considered the most simple and yet sophisticated tool for recovery and athletic performance (Halson, 2008). Secondary to monitoring sleep, tracking muscle soreness can be a useful tool to modulate the training program to help athletes better cope with the physiological stress they may experience (Drew & Finch, 2016). Combining the monitoring of sleep and soreness is a viable and an inexpensive option for the S&C to monitor the overall wellness of the athletes.

The use of wearable technology allows the athlete, technical coach, and S&C coach to understand the sleep, personal well-being patterns that may negatively impact on performance. Athletes performing at the elite and collegiate levels have been reported to lack the necessary sleep for optimal performance (Bolin, 2019; Lastella et al., 2015). Impaired or restricted sleep can lead to reduced mean power production in male footballers Abedelmalek et al. (2013) and male physical education students (Souissi et al., 2008). Furthermore, evidence suggests that lack of sleep also affects lower body strength (Reilly & Piercy, 1994) and cardiovascular performance (Azboy & Kaygisiz, 2009). Creating a questionnaire and education resource that outlines the athlete's sleep patterns is a good starting point (Rogers et al., 1993). However, practitioners are encouraged to utilize validated questionnaires where possible before creating one. Including the other factors previously discussed will also be beneficial to track at the same time to provide further context for decision making purposes (Taylor et al., 2012). The contextual information gathered therefore will aid the S&C, technical, and sports medicine staff to modulate training for the desired physiological adaptations. An example of a soreness and sleep questionnaire can be found in Figure 1.

	1	2	3	4	5	Score
How well did you sleep	I feel rested	Good	Difficulty falling asleep	Tossing and turning	Did not sleep	
Soreness	No soreness	Little soreness	Feeling good	Feeling sore	Extremely sore	

*Larger overall score in wellness may indicate inhibited athlete recoverability

Figure 1. Sample of a simple wellness questionnaire.

The wellness questionnaire (Figure 1) should be collected in the morning prior to training commencing to assess how athletes have coped with the previous day's training or game and identifying any potential problems. Collecting the information prior to the sessions commencing will provide time for practitioners to make necessary adjustments to the training plan, such as TL, intensity, and, volume in conjunction with technical coaches and medical staff (Thorpe et al., 2017). In addition, any interventions such as treatment or increased recovery modalities can be planned to help athletes cope with the session or complete an alternative plan. In some scenarios, the collection of the early morning responses may not be feasible, which would leave room for collecting the information either post-training or at the end of the day (Saw et al., 2015). In this scenario, only acute response to the session can be analysed, and the wellness questionnaire can no longer be used as an evaluation of training readiness and load adjustments. Regardless of the time window used, consistency in approach is fundamental. Lack of consistency may result in potential loss of critical information regarding the athletes' health and critical decisions may be overlooked by the support staff regarding the athletes' overall health.

Objective data

Gathering objective data such as volume, intensity, kinetic and kinematic data can aid the S&C coach to evaluate the athlete's physical readiness for their next training stimuli during a microcycle and the magnitude of training adaptation that has occurred pre- and post-macrocycle. Typically, objective tests involve assessing both the underlying athletic abilities and performance orientated metrics. Tests such as the vertical jump, or countermovement jump (CMJ), lower and upper body strength, linear speed, and change-of-direction speed (Alricsson et al., 2001; Fry & Kraemer, 1991; Hopkins et al., 2001; Reynolds et al., 2006) are used. The application of these tests at multiple intervals during a microcycle and more broadly during a mesocycle can concurrently be utilized to assess athlete readiness and fatigue, or more specifically neuromuscular fatigue (Halson, 2014). Neuromuscular fatigue is defined as a prolonged exercise induced reduction in force or power, regardless of whether the specific task can be sustained or not (Bigland-Ritchie & Woods, 1984). Therefore, it would be pragmatic to assess this component regularly. This review will also cover the monitoring of resistance training with respect to intensity and volume of work done as a means of an inexpensive method to quantify the stimulus placed on the athletes (Scott et al., 2016; Stone et al., 2007; Zatsiorsky et al., 2021).

Neuromuscular fatigue assessment via the stretch shortening cycle (SCC)

The importance in monitoring neuromuscular fatigue may not be as clearly understood, despite it being well-defined term in the literature (Halson, 2014). Fatigue as a construct, in simplistic terms relates to a decrement in performance or force producing capabilities following training is comprised of three factors: 1) metabolic fatigue resulting from a lack of energy availability and is generally short term in impact (less than 90mins) and reversible provided energy availability is provided; 2) neuromuscular fatigue is of a longer duration (possibly up to 36hrs) and is an impairment in force producing capabilities due to restrictions imposed on the signalling pathways distal to the spinal cord through to the muscle fibre neuromuscular junction, is harder to noninvasively measure and predict or influence the time course of recovery; 3) Central Nervous System fatigue or colloquially Cognitive fatigue, which is a force production decrement that results due to a disturbance in central nervous pathway signally and can result from such instances as prolonged sleep deprivation, extensive learning tasks or application of mental faculties (Bigland-Ritchie & Woods, 1984; Halson, 2008, 2014; Kellmann et al., 2018). Considering these three broad facets of fatigue, S&C coaches will commonly prescribe training sessions that consider the need to refuel and thus recover metabolically. However, the difficulty and variation of how neuromuscular fatigue presents, along with the negative impact on an athlete's readiness to perform in their next training session, places a strong emphasis on seeking to quantify and monitor the neuromuscular systems effectively.

The use of the CMJ to assess the stretch shortening cycle (SCC) as a representation of the neuromuscular systems functionality of the lower body via associated kinematic and kinetic data is now common practice amongst practitioners (Claudino et al., 2017; Taylor et al., 2012). The most common metrics reported from CMJ performance are jump height, average or peak power, average or peak velocity, and average or peak force (Rago et al., 2018). Tracking these metrics has been deemed useful across a competitive season (French et al., 2004; McGuigan et al., 2009). The S&C can also be confident with assessing the CMJ jump and jump metrics due to little variation within subjects (<5%) as reported by Markovic et al. (2004). Furthermore, the CMJ can now easily be assessed via many small portable devices, including jump mats, linear position transducers [LPTs], accelerometers, and smartphone apps Rago et al. (2018) which may be a more pragmatic and cost effective. LPT's can be a useful tool in measuring neuromuscular fatigue during training and competitive cycles across different sports when access to force plates is limited (i.e., financially, or logistical). To highlight this notion, Gathercole et al. (2015) investigated acute fatigue in snowboard cross athletes across 19 weeks of training via a LPT. The authors observed large increases in jump duration (longer time to take off) which was identified as eccentric duration (effect size (ES) 1.91) and total duration of the CMJ (ES 1.90) and moderate decrease in concentric measures such as relative absolute mean force (ES 1.23), relative peak force (ES 1.25) 24 hours post training session with the coefficient of variation ranging from 2-16.2% in the chosen displacement data. Moreover, CMJ technique was altered when the athletes were in a fatigued state, which can also allude to a shift in jumping strategy as a means to reduce the likelihood of injury (Kennedy & Drake, 2017). From a practical standpoint, this information could be of use to the S&C to make quick decisions i.e., before planned training sessions to facilitate changes in programming to accommodate the athlete's status. Contact mat systems are also a viable option to monitor fatigue as it relates to measuring the CMJ and squat jump (SJ) Kenny et al. (2012) in combination with smartphone applications (Rago et al., 2018). Rago et al. (2018) reported that moderate to good reliability exists for flight time and jump height (ICC = 0.54-0.97) between contact mat, portable force plates, smart phone application, and accelerometer (Rago et al., 2018). This is in line with Kenny et al. (2012) which also found good test-retest reliability for a jump mat system in comparison to force plates (ICC = 0.99) between the CMJ and the SJ, but not the drop jump (ICC = 0.64). However, Markwick et al. (2015b) reported good reliability for the reactive strength index across various drop heights 20cm (ICC = 0.821-0.982), 30cm (ICC = 0.574-0.951), 40cm (ICC = 0.797-0.979), and 50cm (ICC = 0.991-0.997) utilizing a jump mat system in male professional basketball players. Similar results have been reported via Tenelsen et al. (2019) with different drop heights 24cm (ICC = 0.83), 43cm (ICC = 0.89), and 62cm (ICC = 0.75). Although, good reliability has been shown in the aforementioned studies, it is important for the S&C to understand that different types of jump mat systems have been used across these studies and therefore practitioners must select these devices based on their validity and reliability when monitoring athletes.

A pragmatic approach in using jump mats to assess NMF is to track decrements in CMJ height throughout short term training/competitive cycles (Delextrat et al., 2012; Loturco et al., 2017; McGahan et al., 2019; Oliver et al., 2015). Though, jump height alone may be a crude estimate of NMF due to variations in jumping strategy during a fatigued state (Gathercole et al., 2015; Jalilvand et al., 2019; Kennedy & Drake, 2017), it is still a viable and cost-effective way to monitor athletes. Furthermore, it is also suggested that subjective measures should be used in combination with CMJ height due to potential minimal changes in this metric post competitive activity (Alba-Jiménez et al., 2022; Lombard et al., 2021).

Drop Jump (DJ)

Additional to the CMJ, the DJ may be useful to detect neuromuscular fatigue (Hamilton, 2009). The DJ is done by stepping off a box of predetermined height and upon landing immediately rebounding explosively for maximal height (Pedley et al., 2017). The derived calculation from the DJ is called the reactive strength index (RSI) and can serve as a method of measuring explosiveness (Barker et al., 2018) (Calculation 4a). The explosive nature of the jump mimics many athletic tasks and may be a more reliable way to assess fatigue in the SSC (Flanagan et al., 2008). The RSI can be recorded via the use of contact mats. To interpret the outcome metrics within a neuromuscular fatigue framework, a lower ratio from a baseline established via assessing change in relation to the typical error (TE) established as coefficient of variation (CV) of the test is associated with a reduction in explosive capabilities, and thus a reduction in performance (Twist & Highton, 2013). A true change in the score in either positive or negative direction, has to be greater than the CV of the test (Hopkins, 2004; Hopkins et al., 2001). The reliability of the RSI has been confirmed by Markwick et al. (2015a) who tested the DJ across 20-, 40-, and 50 cm in elite male basketball players with the CV ranging from 2.1-3.1 % across all heights. The use of multiple drop heights is recommended due to the variation of athlete capabilities. This is highlighted by Byrne et al. (2017) during the exploration of optimal drop height and drop heights from 30-60cm, they observed CV ranging from 2.98% in optimal conditions and 4.2% across all heights. Although deemed reliable across day-to-day testing, Beattie et al. Beattie and Flanagan (2015) stressed in their study that RSI may not be sensitive to detect changes across the whole squad and recommended that each athlete should have an established threshold to detect individual changes in RSI. An additional way to assess RSI is to utilize a modified version where a CMJ take-off time is compared to contact time (Suchomel et al., 2015). This method may be more suitable for athletes that have not been familiarized with the DJ. The calculation is similar to the DJ replaced with the CMJ and the contact time with time to take-off to adjust the formula (Calculation 4b).

Though, previous research has established a 30cm box height is reliable in assessing RSI Flanagan et al. (2008), there is scope for the box height to be normalized to the start of a macro cycle's pretest result. Thus, regularly assessing the optimal DJ height allows for a better understanding of the athlete's current capability and adjusting the height of the box used for assessment can lead to a more realistic and current training status understanding. Hamilton (2009) reported that the RSI is a sensitive measure to track acute neuromuscular fatigue in elite young soccer players during a condensed tournament play, highlighting the importance of tracking for understanding training status. Furthermore, Fitzpatrick et al. (2019) extended this observation, reporting that RSI was sensitive to performance changes after 24 hours of strenuous exercise in youth soccer players. Interestingly, CMJ, squat jump and subjective wellness measures were included in this study and did not show any sensitivity to changes in fatigue. This highlights the need to include multiple assessments as each athlete my respond differently depending on the task and measurement.

RSI = Jump height / Contact time (*Calculation* 4a)

Example: 0.38m / 0.230s = 1.65

Modified RSI = Jump height / Take-off (*Calculation* 4b)

Example: 0.38m / 0.310= 1.22

Resistance training volume and intensity as a means of managing stimulus

This section will primarily underline resistance training as a training modality due to its commonality and use. However, other training modalities (i.e., maximal speed, aerobic speed) can be used and adapted to regulate the training session stimulus. It is important that data which characterizes the resistance training, both planned and completed (actual), such as volume load (VL) and training intensity (TI) is highly useful to track throughout an athletes career (Stone et al., 2007). This information provides adaptive situational context when combined with wellness, and sRPE data (Day et al., 2004; Singh et al., 2007) to better understand when, why, and how an athlete responded either positively or negatively to any given training stimuli. VL is defined as an estimate of workload for a session and accounts for the total weight lifted for an exercise session and is expressed as metric ton Haff (2010), this should be captured both as what is/was planned for a training session and what was actually completed during the training session by the athlete. TI is defined as the average weight lifted for an individual exercise or the entire a training session (Haff, 2010). Both components can be useful to track as it relates to fatigue within the realm of resistance training (Scott et al., 2016). VL has been shown to be a good measure of physiological stress and external load (Genner & Weston, 2014) and can be useful when comparing to sRPE scores. TI is also useful to track as it relates to the average weight lifted across a training session (Haff, 2010). Monitoring the TI can aid the strength and conditioning coach's understanding of the contribution of VL and TI based on the type of exercise and category of exercises within the given training season (Haff, 2010; Scott et al., 2016; Stone et al., 2007). As an extension to this process which provides further contextual insight into an athlete's adaptation, and the strength and conditioning coach's planning process at no financial cost, the VL and TI can be further categorized based on the type of lifts performed such as, single or multi joint lifts, dynamic/explosive power lifts, closed or open chain etc. Over time the strength and conditioning coach may then see trends associated to better training readiness or greater levels of fatigue when different VL and TI are completed across the different lift categories.

A few caveats to consider when monitoring VL is that this is a direct measure of the absolute weight lifted and may not reflect the relative intensity or the relative load of a gym-based exercise (Brzycki, 1993). This is especially important when comparing between athletes in terms of the stimulus induced adaptation or the individual stimulus applied based on the same exercise. An example is provided with two athletes performing the same exercise with the same prescribed intensity (% RM) but with different loads (Table 2 and 3). The absolute tonnage lifted for each athlete, relative VL, and relative TI is described. Due to the difference in absolute tonnage lifted between athletes it would be difficult to compare the individuals. Therefore, an easy solution is to normalize the tonnage relative to the athlete using Calculation 5b, which provides a clearer understanding of the volume load stimulus applied. However, the relative intensity should be considered for each lift Carroll et al. (2019) as highlighted in Table 3. Though, each athlete is working at a 77% RM, the relative intensity differs for each. Athlete A and B are both instructed to squat 4 sets of 8 at 77% of 1RM, resulting in athlete A squatting at 115Kg and athlete B at 85kg. However, even though both athletes are performing the exercises below their 8RM, the relative intensity remains high. Since their 8RM loads (athlete A 120kg vs. athlete B 88kg) is established, athlete A and B are lifting 115kg and 85 of their 8RM. This results in a higher relative intensity than prescribed and may cause athletes to fail in subsequent sets and therefore the targeted stimuli may not be met. The opposite holds true as well. Considering our first example of athlete A. This athlete now must complete 8 sets of 4 repetitions at 77% of 1RM. Athlete A would have a 4RM load of 135kg, this results in a relative intensity of 85% (115/135). It is therefore important to consider the loading schemes and targeted stimuli when considering gym-based exercises to ensure that the athlete is targeting the desired stimuli.
Calculation 5a,5b, and 5c provides an example of how to calculate the VL, Relative VL, and Relative TI.

Table 2. Descriptive characteristics of sample athletes.

Athlete A back squat	**Athlete B back squat**
1RM = 150kg	1RM = 110kg
8RM = 120Kg	8RM = 88Kg

Table 3. Calculations.

Measurement	**Athlete A**	**Athlete B**
Absolute volume (VL in KG)	4x8x115 = 3680	4x8x85 = 2720
Relative Volume (A.U)	4x8x 77% RM = 2464	4x8x 77% RM = 2464
Relative intensity %	115kg/120Kg = 95.8%	85kg/88kg = 96.5 %

VL = sets x repetitions x weight lifted (kg/lb) (*Calculation* 5a)
TI = VL/Total repetitions

Relative VL = sets x repetitions x % RM (*Calculation* 5b)
TI = VL/Total repetitions

Relative intensity = % RM prescribed / Absolute RM (*Calculation* 5c)

IMPLEMENTATION

The S&C coach should aim to implement a consistent system of assessment within their sporting context, and available resources. The assessments described above are cost effective and time efficient for most settings. The following section highlights how to implement the sRPE, Wellness questionnaires, and CMJ to inform the training process and has been based on the authors practical experiences. We will not detail the statistical analysis as this is beyond the manuscript scope, however for details on how to analyse and interpret the described tests and associated trends see descriptions by Hopkins and Stone et al. (Hopkins, 2004; Stone et al., 2007). The reader should seek to implement a monitoring system that fits within their sporting context and constraints. The general recommendation for weekly monitoring (Table 4) described uses minimal equipment and efficiently expands on the planning processes that S&C coaches should already be applying.

Table 4. General monitoring system for a microcycle example adapted from McGuigan et al., 2020; Taylor et al., 2012.

Assessment	Frequency	Rationale and purpose
CMJ	Ideally every day pre and post sessions	To measure neuromuscular fatigue: Pmax, Pmean, Vmax, Vmean, CMJ dip, and JH
RSI (drop jump)	Daily pre-session	To measure neuromuscular fatigue: contact time/ contact time. Lower ratio than 1 may indicate fatigue
sRPE	Daily post-session	Compare the level of exertion of the athlete to the intended exertion of the planned session
TL	Weekly	Measure of intensity across a microcycle
Monotony	Weekly	Measure of variation in training across a microcycle
Strain	Weekly	Measure of the product of TL and monotony
Wellness	Ideally every day	Overall health of the athlete: include hours of sleep, sleep quality, soreness, fatigue, and stress
VL	Daily-post session	Measure the contribution of VL based on the type of exercise and category of exercises within the given training season
TI	Daily-post session	Measure the contribution of TI based on the type of exercise and category of exercises within the given training season

Note. CMJ = countermovement jump, RSI = reactive strength index, sRPE = session rated of perceived exertion, TL = training load, VL = volume load, TI = training intensity, Vmax = Maximum velocity, Pmax = Maximum Power, Pmean = Mean power, and JH = Jump Height.

Practical application

This article sought to provide the S&C coach with guidance on how to create a simple and inexpensive monitoring system for fatigue management in athletes. Ideally, the S&C coach should examine the data before (24-48 hours) and after each session, which provides the opportunity to discuss any concerns that may present in the data collected with the athlete for context. Wellness can be completed 2-3 times per week via a simple checklist prior to a session, providing athlete context for how they are feeling and whether any training adjustments are required based on these perceptions. Monitoring with performance tests such as the CMJ and RSI can be completed easily at the beginning of the session at the end of a warm-up to provide insight into their readiness to train. We recommend that the strength and conditioning coach should establish thresholds from baseline specific to their athletes and training location for each assessment monitored, throughout the training day and week to better understand the demands placed on the athlete. It is important to use multiple assessments to monitor athletes as one measurement alone will not provide a holistic picture regarding the athlete's status. Finally, the interpretation of any monitoring should be individualized and not based on the entire team for context.

AUTHOR CONTRIBUTIONS

FJ conceptually designed the paper and structurally outlined the review and allocated the sections to the authorship team to provide support for each section. All authors contributed equally to this work and support its publication.

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