Autonomic nervous system indices of player readiness during elite-level rugby union game-week micro-cycles

ABSTRACT

Purpose: Elite-level rugby union (RU) is a high-intensity contact sport that involves large training and match volumes across a season, which can lead to post-match fatigue. Autonomic nervous system (ANS) regulation and perceived fatigue have been suggested to relate to measures of training and match load in RU. However, there have been no studies to assess specific ANS variables in elite RU during in-season micro-cycles. Methods: Player readiness during game-week micro-cycles was measured via heart rate variability (HRV) indices, direct current potential and self-reported well-being among thirteen elite male RU players. To enable comparison, data collection days were categorised in relation to their proximity to match day, ranging from match day minus 3 (MD-3), to match day plus 3 (MD+3). Differences between match days were evaluated using general linear models and Cohen's d effect sizes. Results: There were significant differences between MD and MD+1 for ANS indices (RMSSD p = 0.04, *d* = -0.66, 95%CI 0.11 - 1.20; SDNN p = 0.04, *d* = -0.66, 95%CI 0.12 - 1.20; Total Power p = 0.05, *d* = -0.65, 95%CI 0.11 - 1.20) and wellness measures (Readiness p = 0.18; *d* = -2.33, 95%CI 1.54 - 3.13; Energy p = 0.02; *d* = -2.24, 95%CI 1.44 - 3.03; Soreness p = 0.00; *d* = -2.42, 95%CI 1.63 - 3.23). Conclusions: MD+3 effects were significantly greater than MD+1 in several ANS responses, with wellness recovering at a slower time-course than ANS responses. Measures of HRV are dysregulated post-match, but based on their rapid recovery thereafter, using HRV to assess readiness of elite-level players in RU across a weekly micro-cycle could be limited and requires further investigation.

Keywords

Heart rate variability; wellness; fatigue; recovery; post-match

INTRODUCTION

Elite-level rugby union (RU) involves high-speed collisions and high running volumes [1, 2], which can result in post-match fatigue [3]. Symptoms of post-match fatigue will remain present for multiple days and can accumulate across a competitive season [4]. Elite RU players are required to return to training in the immediate days post-match to prepare for the next [5]. As a result, players often experience sub-optimal 'readiness' throughout subsequent weekly micro-cycles [3]. Within RU, readiness involves players' ability to effectively perform high-intensity rugby-specific actions, and can be characterised using neuromuscular [6, 7], autonomic [8, 9] and perceptual measures [10]. Recent technological developments have enabled objective 'real-time' physiological feedback from training and competition, allowing evaluation of player readiness to perform [11]. However, there is currently limited scientific field-based application of these technologies in elite RU settings.

One such field-based technological development has been the application of heart rate variability (HRV) assessment tools, which characterise fluctuations in autonomic control [12]. Heart rate variability evaluates cardiovascular-autonomic parameters, which are regulated by innervations from the sympathetic and parasympathetic branches of the autonomic nervous system (ANS) [13]. In the time-domain, lower HRV signals are an indicator of insufficient adaptability to stressors, suggesting compromised health or a state of chronic fatigue [12]. Heart rate variability is affected by the balance of sympathetic and parasympathetic tone, which appears to be perturbed following rugby competition [8, 9]. In rugby league [14], daily time domain measures of HRV during a competitive playing season demonstrated a shift in cardiac autonomic balance towards lower HRV on match day, lasting for 1-2 days post-match. Similarly, Noon et al. [15] showed HRV indices were sensitive to rugby training load in non-elite academy players.

Root Mean Square of the Successive Differences (RMSSD) is one of many time-domain HRV measures, which assesses the variability of vagus-mediated differences between neighbouring RR intervals (time between QRS complexes) [16]. Similarly, the standard deviation of successive RR interval differences (namely SDSD and SDNN) can be used to assess autonomic balance [14]. In relation to HRV assessment, SDSD refers to the standard deviation of time elapsed between successive waves of heart signal, with SDNN referring to the intervals between peak electrical output of heart signals. Frequency-domain measures typically show two patterns of oscillation, separated into low frequency (LF; 0.04-0.15 Hz) and high frequency (HF; 0.15-0.4 Hz), which can be used to evaluate parasympathetic and sympathetic regulation [14]. A combination of time- and frequency-domain measures have been used to monitor signs of non-functional overreaching among combat athletes, where distinct changes in HRV were reported alongside increased training load [11]. Whilst single measures of autonomic function might not consistently respond to training stress across individuals [17], a combination of time- and frequency-domain HRV indices (i.e. RMSSD, SDNN, LF, HF) might more appropriately account for physical and psycho-emotional stressors [11, 14].

Omegawave® Ltd (Espoo, Finland) technology provides measures of HRV (SDNN, SDSD, RMSSD, LF, HF), alongside measures of direct current potential. Direct current potential is defined as very-slow brainwave activity (0–0.5 Hz) and can be measured through electrodes placed on the scalp or a combination of forehead and thenar eminence [18]. *Omegawave*® is thought to be a universal, integrated indicator of 'stress' and recovery therefrom [19]. However, there have been no studies to assess these specific variables in elite RU during in-season micro-cycles. It would be useful to develop additional understanding of changes in autonomic function and typical indicators of player readiness (i.e. wellness) in the days before and after rugby matches. Therefore, this study aimed to evaluate indices of autonomic function using *Omegawave*® technology for assessing player readiness during micro-cycles of the competition phase of an elite RU season.

METHODS

Experimental approach to the problem

This study was a single-group, observational design that monitored HRV indices, direct current potential and self-reported well-being during a competitive phase of a playing season. All players regularly competed in the English Premiership Rugby competition and played >40 min per match during the study period. Three hundred and forty HRV, brain activity and self-report well-being assessments were collected across a 10-week period. As displayed in Figure 1, data collection days were categorised in relation to their proximity to match day (ranging from match day minus 3, to match day plus 3). All players completed a predetermined training programme advised by the rugby club, which the researchers did not influence.

Subjects

Data was collected from thirteen elite male RU players (age 27 ± 4 years, height 183.2 ± 4.9 cm, body mass 100.5 ± 12.7 kg). These players (n = 7 forwards; n = 6 backs) were classified as elite as they all played regularly in the top tier of the Rugby Football Union (RFU) and were all full-time professional athletes (20). All players were injury-free the month prior to assessment and, therefore, available for match selection, with no players taking medications known to influence autonomic function (such cholinomimetics / cholinesterase antagonists, anticholinergics, adrenoreceptor agonists / sympathomimetics, adrenoreceptor antagonists. Written informed consent was provided by participants and ethical approval was granted by Salford University Institutional Review Board.

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Procedures

Heart rate variability

Omegawave® data was collected between 8 am and 10 am on *Omegawave Coach+* ® software, with no prior exercise completed and post bladder emptying [17]. Raw values were exported and analysed. This technology has been shown to have acceptable sensitivity to training activity (e.g., hard, easy, rest days) [17] and acceptable agreement reported with an ambulatory electrocardiogram system (Coefficient of Variation = *Omegawave* 0.08; electrocardiogram 0.09) [21]. An *Omegawave*® ECG1A device was positioned at the upper thorax, with each individual HRV measurement completed while resting comfortably and motionless in a supine, with arms by the participants' side in a quiet room. Measurements were conducted at room temperature and the players were advised to eat their usual meal every morning, while avoiding caffeinated drinks in the 12 h prior to testing. Players were asked not to consume caffeinated beverages 12 h prior to testing and were questioned immediately prior to testing to ensure compliance. All participants undertook familiarisation procedures using the *Omegawave®* device prior to testing, with SDNN, SDSD, RMSSD, Total Power, LF, HF reported based on the results provided form the *Omegawave®* device. Many of these measures are commonly used and have been defined in prior research [12, 19]. SDNN assesses the standard deviation of the full array of cardio intervals, reflecting the total effect of autonomic regulation (measured in milliseconds). SDSD assesses the standard deviation of differences between adjacent normal to normal cardio intervals. RMSSD is the square root of the sum of differences of a sequential series of cardio intervals, reflecting parasympathetic activity (measured in milliseconds). Total Power is the variance of all normal-to-normal intervals in frequency range of 0 to 0.4 Hz (measured in milliseconds squared). HF reflects parasympathetic frequency in ranges between 0.15 and 0.4 Hz, meanwhile LF reflects mostly sympathetic frequency in ranges between 0.04 and 0.15 Hz.

Direct current potential

An *Omegawave®* device ECG1A (sampling frequency 500 Hz) offers the ability to measure direct current potential as an assessment of the functional state of the central nervous system, using a scale of 1-7, with a score of 7 signifying a better functional state of readiness [19]. Direct current potential is suggested to be sensitive to short- and long-term physiological changes [18, 22].

Self-report well-being questionnaires

Well-being (WB) was assessed using a self-report wellness questionnaire [23], which the players completed upon waking every training day via an online player management tool (*The Sports Office*, UK). This five-part questionnaire assessed subjective responses to questions relating to sleep, muscle soreness, energy levels, mood and appetite; based on prior recommendations [24]. Well-being assessment was scored out of 50 (arbitrary units), with 10 being the highest rating a player could provide for each part of the questionnaire and 1 being the least.

Statistical analyses

To provide a global view of autonomic variability over the training week, dependent variables were viewed from match day minus 3 (MD-3) to match day plus 3 (MD+3) (Figure 1). Analysing the data in this way allowed for both the lead up to and recovery from match play to be evaluated in a manner that has not previously been considered within the literature. A fixed effects only analysis of variance model was used to evaluate the changes in *Omegawave®* and wellness measures between match days. Minimum effects testing was used to evaluate differences between match days [25]. A smallest effect size of interest (SESOI) was established as 0.2 x between-subject standard deviation in line with Cohen's d′ thresholds (d = 0.2 small, d = 0.6 moderate, d = 1.2 large, d = 2.0 very large) [26, 27]. Statistical significance was set at $p < 0.05$, and a significant result indicated that the difference between two match days was greater than d = 0.2. Cohen's d values are reported throughout the results. All analyses were conducted using PROC MIXED via SAS University Edition (SAS Institute, Cary, NC).

The dependent variables considered from *Omegawave®* were; direct current potential, SDNN, SDSD, RMSSD, Total Power, HF nu (the index of parasympathetic modulation of the ANS) and LF nu (the index of sympathetic modulation of the ANS). Wellness measures dependent variables considered were; overall wellness, energy, soreness, motivation, appetite, sleep quality and sleep duration. To account for some of the inter-individual variability in raw *Omegawave®* and wellness measures, all dependent variables were mean centred by individual. *Omegawave®* variables were considered as percentage differences, wellness measures were evaluated as unit differences.

RESULTS

With the exception of MD to MD+1, there were no significant differences between days in either *Omegawave* or WB variables. Significant reductions between MD and MD+1 were observed in RMSSD (p = 0.04, d = -0.66, 95%CI 0.11 - 1.20), SDNN (p = 0.04, d = -0.66, 95%CI 0.12 - 1.20, SDSD (p = 0.04, d = -0.66, 95%CI 0.12 - 1.20), Total Power (p = 0.05, d = -0.65, 95%CI 0.11 - 1.20), Readiness (p = 0.18; d = -2.33, 95%CI 1.54 - 3.13, Energy (p = 0.02; d = -2.24, 95%CI 1.44 - 3.03, Soreness (p = 0.00; d = -2.42, 95%CI 1.63 - 3.23). Only SDNN (MD+3 p = 0.02, d = -0.77, 95%CI 0.20 - 1.33) and Total Power (MD+3 p = 0.04, d' = -0.69, 95%CI 0.13 - 1.26) values were significantly different to MD+1. There was a large amount of uncertainty in the estimate given to all *Omegawave* variables (indicated by the wide confidence intervals), but this uncertainty was much greater on MD+1 compared to any other days.

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DISCUSSION

Reductions in post-match (MD+1) wellness across 10 training weeks was observed in the present study, consistent with other reports of post-match fatigue and reduced readiness in elite RU [3]. We also report, for the first time, large variability in autonomic control across the weekly micro-cycle, with selected indices of HRV most disturbed at MD+1, thus temporally corresponding to some wellness metrics. These findings support prior research in rugby, whereby HRV parameters [14] were reduced following a period of higher training or competition load. In the context of this study, time-domain measures (SDNN, SDSD and RMSSD) appear sensitive to match day load, yet recover during the micro-cycle. Reduction in time-domain HRV measures typically indicate withdrawal of vagal tone (via the parasympathetic nervous system) or increased sympathetic nervous system innervation [13], yet the between-day differences reported here question *Omegawave®* sensitivity to rugby specific match-play load.

As noted by the delayed wellness response, emotional and physiological recovery from the stress of competition was required (Figure 2 and 3). Muscle soreness specifically, took greater than 48 h to recover post-match, which has been reported frequently following collision-based sports [3], yet all HRV indices were recovered by this time. Despite differing time-course of restoration between autonomic control measures and self-reported wellness measures across weekly micro-cycles, the autonomic dysregulation at MD+1 (characterised by a presumed increase in sympathetic and/or decrease in parasympathetic activity) coincided with reductions in self-reported perceptions of recovery. Match demands are likely to drive these effects, with the similar fatigue responses noted across MD+1 measures perhaps not surprising, considering high physical and cognitive match-play loads compared to training day loads during micro-cycles [1, 28].

Players typically returned to a state of readiness between matches, denoted by both the HRV (SDNN, SDSD and RMSSD) and well-being findings reported. Not only might this demonstrate appropriate programming from the coaching staff involved, it might also indicate that *Omegawave®* assessment may not be sensitive enough to assess chronic readiness in rugby, where training and match load can disrupt homeostasis of different biological systems to varying degrees. The transient reduction in HRV measures recovering more quickly than muscle soreness, could be explained by specific physiological measures being influenced by different root causes [29]. For example, fatigue induced by blunt force trauma from match-play, differs to fatigue arising from running-based exercise. Recent research from American Football [30] supports the notion of high-intensity training stimuli influencing HRV response in a different time-course to other physiological stimuli, which when considered alongside the unique demands of RU match-play (intermittent running, blunt force contact) perhaps further explain the uncertainty and variability noted within the *Omegawave®* results.

Notably, the increased physical and cognitive load on match days, coupled with the concurrent reductions in sleep quality and time domain HRV measures at MD+1, highlighted the potential relationships between autonomic and wellness measures. In an assessment of sleep in collision sport athletes [31], it was reported that collision sport athletes experienced reduced sleep quality during intense training phases. Additionally, within rugby specifically, twenty eight male rugby union players had their sleep patterns assessed over a four game period via an *ACTi watch*, with results demonstrating that sleep was deprived post-match and that this may have had a detrimental effect upon the recovery process [32]. Further research to understand the inter-relationships between sleep quantity or quality and autonomic measures, and how to monitor these among athletes would be useful, given the importance of sleep in the recovery cycle. When considering that travel demands, unfamiliar sleep environments and pre-competition stress can often add to an athlete's sleep disruption [32], the use of non-invasive ANS responses could provide an early practical indication of delayed recovery or the likelihood of poor sleep during periods of high load or competition stress.

A key limitation of this study is the use of Cohen's *d* as a measure of the SESOI. Although Cohen's *d* is regularly used throughout the sport science literature, the raw values equivalent to a *small* change in this study were much smaller than the smallest detectible change in the wellness questionnaire used (all raw SESOI's were less than one unit), and smaller than the typical error values recently reported by Coyne et al. [17] for the individual measures. The authors originally chose a *small* Cohen's *d* as the SESOI so that all measures could be compared against each other in terms of the differences present across the week. Further research now needs to evaluate whether it is the highly variable measurement methods used for these variables that results with reduced practical usefulness or whether the variables themselves are less responsive to match play exposure than is necessary to be detectible in practice. It is also worth noting that heart rate derived measures and the appropriate magnitude of the SWC are less straightforward than other performance tests, due to the individual nature of HR derived data and the associated training load, which has perhaps initiated the HR change [33]. This change in HR indices could be from isolated training sessions or, perhaps, in response to a whole training phase further emphasising the individualized nature of HR data. Lastly, it is worth noting that this study did not measure confounding variables such as concussion or positional groups that may influence self-report measures while also interfering with objective measures. Confounding variable analysis is therefore recommended for future research.

PRACTICAL APPLICATIONS

Despite reductions in post-match wellness and disturbed indices of HRV at MD+1, effects in wellness gradually recovered at a slower time-course than ANS responses. Measures of ANS responses among elite RU players using the *Omegawave®* device, therefore might be useful in determining acute 24 h post-match recovery; however, these measures are either recovered rapidly or not sufficiently sensitive for assessing player readiness across the weekly micro-cycle. Using HRV, and specifically an *Omegawave®* device, to assess readiness of elite players in RU across a weekly micro-cycle could be limited and requires further investigation in comparison to other HRV detection devices.

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Figure 1. Schematic diagram of the measurement across a micro-cycle. The match day (MD: grey box) represents the centre timepoint for which the three timepoints on the left (represented by the 'minus' symbol) are the days before match day (MD-1, MD-2 and MD-3) and the right (represented by the 'plus' symbol) are the days after match day (MD+1, MD+2 and MD+3). Data was collected on each of the six timepoints.

Figure 2. Between day differences in all Omegawave® variables; (A) HF nu (B) LF nu (C) Total power (D) RMSSD (E) SDSD (F) SNNN (G) direct current potential.

Figure 3. Between day differences in all wellness measure variables (A) Readiness (B) Soreness (C) Energy (D) Motivation (E) Appetite (F) Sleep quality (G) Sleep quantity.