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To jog or to stride: A comparison between two standardised running tests to monitor neuromuscular status in team sport athletes

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ABSTRACT

This study investigated: 1) monitoring post-match neuromuscular fatigue (NMF) status in rugby union players using two submaximal running tests (SRT); and 2) the sensitivity of each SRT to locomotor variables obtained during match-play. Twenty-three male rugby players (age: 21.0 ± 1.3 years; height: 185.2 ± 6.1 cm; body mass; 97.3 ± 10.3 kg) were monitored across one season (*n* = 71 player-match and 159 fatigue-players-testing observations). Two different SRTs (SRT-jog [5-minute shuttle run protocol] and SRT-stride [a repeat stride effort protocol]) were used to characterise post-match NMF, with measures taken two days prior to match day (baseline), on MD + 1, and MD + 2. Linear mixed models (±90% CIs) were used to explore differences between measures and match-play locomotor variables. SRT-jog presented a meaningful increase following MD + 1 (ES: 0.63 [0.37 to 0.89]). SRT-Stride showed small increases at MD + 1 (ES: 0.24 [0.02 to 0.49]) and MD + 2 (ES: 0.33 [0.07 to 0.59]) suggesting a potential impairment in running mechanics. SRT-stride was significantly associated with total distance (ES: 0.41 [−0.01 to 0.83]) and collisions (ES: 0.58 [0.18 to 0.99]). While both tests presented small to moderate changes post-match, only the SRT-stride was related to match locomotor variables. Therefore, the SRT-stride may be a more sensitive monitoring tool for monitoring NMF in rugby union players.

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Introduction

The increased occurrence of fixture congestion in professional team sports means athletes are frequently required to train and compete prior to the achievement of total recovery (J. M. Garrett et al., 2019; Leduc, Lacome, et al., 2020). Such a context might lead to potential higher injury risk or under performance. Part of a practitioner's role entails supporting appropriate player readiness for training and match participation. Transient information acquired from subjective, biochemical, metabolic and neuromuscular assessment over the hours and days post-training and/or competition can aid in informing appropriate management (Leduc, Lacome, et al., 2020; K. Taylor et al., 2012).

For the assessment of neuromuscular fatigue (NMF), defined as a response that is less than expected or reduced anticipated contractile response for a given stimulation (MacIntosh & Rassier, 2002), it is common practice for measures to be taken within the first 3 days following match-play (Carling et al., 2018). This timeframe is theoretically consistent with the presence of fatigue and furthermore provides practitioners the opportunity to adapt training content at the individual player level. In turn, such practice can, hypothetically, improve subsequent performance and status of the athlete (K. Taylor et al., 2012). However, due to the ever-increasing professionalisation of sport, multiple constraints exist within high-performance environments. Time pressures on players, competition focus, limited access to players etc., are examples of potential difficulties faced when monitoring fatigue during the daily training and competition environment (Leduc, Tee, et al., 2020).

Currently, the countermovement jump (CMJ) test is recognised as the reference standard test for NMF monitoring in team sport settings (Garrett et al., 2018) owing to its robust reliability and validity (Cormack et al., 2008; K.-L. Taylor et al., 2010). Despite the regular use of CMJ testing within practice and the literature, from both a practical and scientific perspective, several limitations in using this method exist (Buchheit & Simpson, 2017; Cairns et al., 2005; Carling et al., 2018; Leduc, Tee, et al., 2020). In practice, implementing a monitoring system via a jump protocol for a full squad (e.g., 30 rugby players) can be time-consuming and require a dedicated time to be conducted. Scientifically, there is evidence to suggest that the underlying mechanisms of fatigue are task-specific (Cairns et al., 2005). Therefore, team sports, that involve high-intensity repeat sprint efforts, numerous changes of direction, along with accelerations and decelerations, all interspersed with periods of moderate to low-intensity running (Varley

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et al., 2014), may benefit from the analysis of the running profile to provide a greater task-specific method for monitoring NMF (J. M. Garrett et al., 2020).

To overcome some of these constraints that are faced and use a test with greater task specificity, submaximal running tests (SRT) have been developed to monitor NMF in running based high-performance athletes (Buchheit et al., 2018; Fitzpatrick et al., 2021; Garrett et al., 2018; Leduc, Tee, et al., 2020). This has been possible with the development and widespread usage of embedded micro-technology sensors such as Global Positioning System (GPS) with embedded accelerometers. An advantage of a SRT is the time efficient nature, as all athletes can be observed within a short period of time (e.g., 2–5 minutes). Further, the SRT can be included within the normal training environment (i.e., as part of the warm-up). Prior research has also shown SRTs to demonstrate greater sensitivity to NMF in running-based team sport athletes than a CMJ test (J. M. Garrett et al., 2020). When comparing the sensitivity of a CMJ test and SRT for monitoring NMF, J. M. Garrett et al. (2020) found all SRT variables possessed a CV smaller than the SWC. This was compared to only one of the assessed CMJ variables possessing a CV smaller than the SWC. The results would suggest that when implementing a testing program to monitoring changes in NMF status in a predominantly running based sport, a greater task-specific test, like a SRT, will be a more useful (J. M. Garrett et al., 2020).

Following these results, an increase in popularity of SRT procedures by practitioners has been observed, however, the most appropriate protocol for applied use with running-based team sport athletes remains unexplored. To date, four main protocols to measure NMF via a SRT have been proposed. Three utilise a repeat effort protocol and one a shuttle protocol (Buchheit et al., 2018; Fitzpatrick et al., 2021; Garrett et al., 2018; Leduc, Tee, et al., 2020). These protocols vary in terms of effort length, speed, specific athletic population, and variables analysed (Leduc, Lacome, et al., 2020). Overall, the varied SRT protocols have presented promising results in terms of convergent validity and reliability. However, the heterogeneity between protocols makes comparison between tests challenging. Additionally, due to these protocol variations and the potential implications of speed in the running mechanics modifications (Apte et al., 2021; Schubert et al., 2014), it is likely that the various SRT protocols may vary in terms of sensitivity to differing load exposures (e.g., training or match). Consequently, research to understand the potential effects of different locomotor variables on SRT responses would inform practitioners on the scope of such methods to guide appropriate implementation into practice.

Accordingly, the purpose of this study was to determine the practically important changes post-match of two different SRTs; a 5-min shuttle run protocol (SRT-jog) and a repeat stride effort protocol (SRT-stride). The two protocols were chosen due to their previous use in similar populations (i.e., rugby union) and to represent the two types of SRT; repeat effort and shuttle. A secondary purpose was to explore the relationship between prior match load variables on the fluctuations of NMF status. Practically, the findings aim to provide sport science practitioners with insights into the most appropriate SRT for monitoring post-match NMF in predominantly running-based athletes.

Methods

Participants

Twenty-three male rugby union players (age: 21.0 ± 1.3 years; height: 185.2 ± 6.1 cm; body mass; 97.3 ± 10.3 kg) competing at the highest university rugby competition level in the United Kingdom volunteered to participate in this study. The recruitment took part at the beginning of each week where players were asked if they were willing to participate to the study for the following match. This process was repeated throughout the study period and was completely voluntary. To be included, players needed to be selected for the upcoming match and being injury free from the last six months. All participants were accustomed to playing at this level of competition and to the SRT protocols completed within this study. Participants provided informed consent prior to the commencement of the study. Ethics approval was granted by the Leeds Beckett University ethics board (Application Ref: 62496) and the recommendations of the Declaration of Helsinki were respected.

Data collection

As the study was embedded within practice, a longitudinal observational research design was conducted from September 2019 to March 2020. A full representation is displayed in Figure 1. Only a small number of players were involved in the study protocol each week, with 13 matches and a total of 83 player-match observations gathered. Data were excluded if players were not able to complete all data collection points. This resulted in 71 player-match observations, including 159 fatigue-players-testing points (neuromuscular function).

Fatigue monitoring was performed two days before the match (MD-2 [Baseline]), which preceded a period of two days of recovery and was considered the baseline. Each match (MD) took place on the same day (Wednesday) of the week, with kick-off either at a set time of 1400 (home match) or 1800 (away match). Match characteristics were monitored with an embedded GPS device and video analysis to quantify total collision load. Fatigue monitoring was performed on MD + 1 between 1100 and 1200 and MD + 2 at 0730 (dictated by the training schedule, where training commenced at 0800). A similar applied study design has been previously used (see Leduc et al., 2021 for further information).

Data analysis

Match load monitoring

During each match, participants wore the same microtechnology unit, including a GPS and a tri-axial accelerometer sampling at 10 hz and 100 hz, respectively (Optimeye S5, Catapult Innovations, Melbourne, Australia). Complete details of the obtainment of match load monitoring are available in prior published material by Leduc et al. (2022). Locomotor variables used to assess the sensitivity of the SRTs were total distance covered (TD; m), high-speed distance (HSD; m), and collision

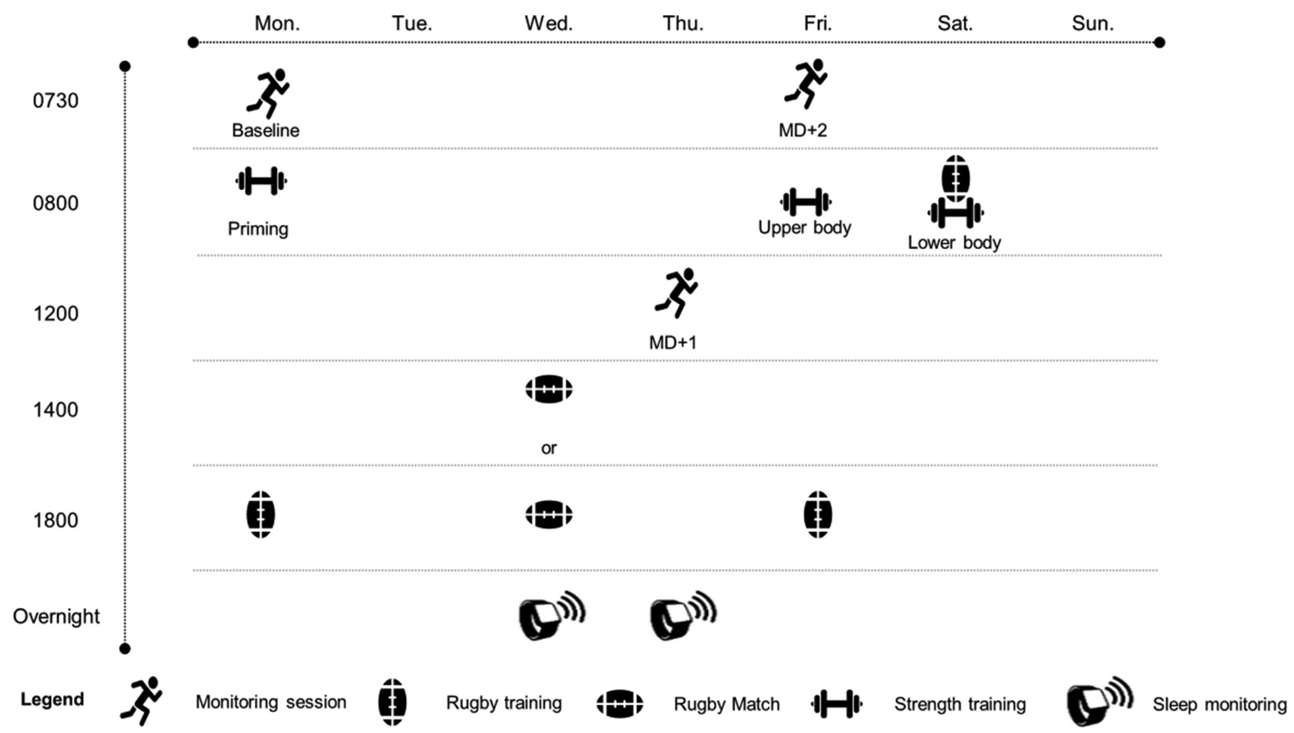

Figure 1. Schematic representation of the study design.

frequency (n). Details surrounding each locomotor variable have been previously detailed (Leduc et al., 2022).

SRT

First, players completed 5 min of running 20 m shuttles at a submaximal running speed fixed at 9 km·h^{-1} (SRT-jog). During this period, the first (min 0 to 1) and last minute (min 4 to 5) of the run were discarded from analysis as per the previous study (Fitzpatrick et al., 2021). During the remaining time period, the sum of the instantaneous rate of change from the vertical component of the accelerometer was calculated for analysis and used as the main outcome variable for SRT-jog (Fitzpatrick et al., 2021). Following 2 min of passive recovery, participants performed four 60 m paced runs in 12 s (mean velocity ≈18 km·h^{-1}) to allow for the calculation of running load index (RLI) as a measure of locomotor efficiency (SRT-stride) (Leduc, Tee, et al., 2020). The RLI was first calculated by the sum of the instantaneous rate of changes from the vertical component of the accelerometer. Each calculated mechanical load was then divided by the average velocity performed by the individual over the period of the obtained running analysis. This method has demonstrated a large relationship ($r = 0.62$) with leg stiffness as well as a small typical error (Leduc, Tee, et al., 2020). Additionally, reliability analysis previously performed with a similar athletic population demonstrated a coefficient of variation of 11.5% and a smallest worthwhile change of 4.8% (Leduc, Tee, et al., 2020). This procedure has been repeated throughout the study period and always performed at similar time of the day (Figure 1) to control any potential measurement bias. Additionally, each running test was performed on the same artificial turf surface to control for the potential effect of ground stiffness on the accelerometer responses.

Statistical analysis

Descriptive statistics (means and standard deviation) were calculated for each variable. Following analysis to ensure normality of residuals of each variable, two sets of linear mixed models were employed. Where a variable was found to be not normally distributed, log transformation was applied. Initial models aimed to assess the pre-post changes in each SRT between MD-2 and MD + 1 and MD + 2. In this model, values derived from SRTs were the main dependent variables, and the day type (MD-2 and MD + 1) included as a fixed effect. Individual players, and match location, were included as random factors. Pairwise comparisons were further assessed with a Tukey post-hoc when a significant difference was observed ($p < 0.05$). The effect of match locomotor variables (TD, HSD and collisions) was calculated by assessing a two-standard deviation (2 SD) of difference in the covariate. These variables were chosen based on initial residual analysis and subject matter expertise. This evaluation approach considered potential differences between extreme values and ensures congruence between Cohen's threshold magnitudes for correlations and standardized differences (Hopkins et al., 2009). Differences in effect size (ES) ± 90% confidence intervals (CI) are classified as trivial (<0.2), small (0.2–0.59), moderate (0.6–1.19), and large (1.2–1.99) (Hopkins, 2004). Where the 90% CI simultaneously overlapped the smallest important ES (0.2) both positively and negatively, the magnitude of the difference was considered "unclear" (Hopkins, 2004).

Table 1. Post-match responses.

	MD-2	MD +1	MD +2	Change from Baseline to MD + 1 d (±90% CI)	Change from Baseline to MD + 2 d (±90% CI)
SRT-jog	4780.9 ± 617.9	5210.7 ± 749.5	4864.0 ± 638.9	0.63 (0.37 to 0.89)	0.13 (−0.12 to 0.39)
SRT-stride	55.5 ± 9.5	58.1 ± 12.4	58.8 ± 10.8	0.24 (0.02 to 0.49)	0.33 (0.07 to 0.59)

Table 2. The effects of match load variables on SRT outcome measures.

Dependent variables	Fixed effects	Estimate (SE)	90% CI	d (±90% CI)
SRT-Stride	Total Distance (m)	3.58 (1.84)	−0.06 to 7.23	0.41 (−0.01 to 0.83)
SRT-Stride	High Speed Running (m)	2.77 (1.96)	−1.12 to 6.66	0.32 (−0.13 to 0.76)
SRT-Stride	Collisions (n)	5.02 (1.76)	1.52 to 8.51	0.58 (0.18 to 0.99)
SRT-Jog	Total Distance (m)	−3.79 (122.23)	−246.24 to 238.66	−0.01 (−0.37 to 0.36)
SRT-Jog	High Speed Running (m)	−9.76 (131.16)	−269.92 to 250.40	−0.01(−0.41 to 0.38)
SRT-Jog	Collisions (n)	−70.69 (134.50)	−337.78 to 196.41	−0.10(−0.50 to 0.29)

Results

Post-match responses

Descriptive values are displayed in Table 1. Regarding the change in SRT-jog between Baseline and MD + 1, an increase in RLI was observed, associated with a moderate ES (0.63 [to 0.37 to 0.89]). The SRT-stride displayed similar results at MD + 1, with a small ES increase observed (0.24 [0.02 to 0.49]) compared to baseline. At MD + 2, a trivial ES increase was found for SRT-jog (0.13 [0.12 to 0.39]), and a small ES increase was observed for SRT-stride (0.33 [0.07 to 0.59]).

Relationship to match variables

No meaningful associations were found for the change in SRT-jog at MD + 1, and any match variables (Table 2). In contrast, meaningful associations were observed regarding the change in SRT-stride. On MD + 1, a meaningful association was observed with total distance (0.41 [−0.01 to 0.83]). A similar association was observed for collisions (0.58 [0.18 to 0.99]).

Discussion

The primary purpose of this study was to compare the sensitivity of different SRTs for monitoring NMF, and analyse their respective relationship with match locomotor variables in male rugby union players. The main findings revealed: 1) both SRT-jog and SRT-stride demonstrate clear variations on MD + 1 when compared to baseline (MD-2), while changes at MD + 2 were only observed in the SRT-stride; 2) Total distance and collisions were the main match load variables associated with changes to SRT-stride on MD + 1. No such association of any match load variables was observed with the SRT-jog.

SRT-Jog

Overall, a change in movement strategy, evidenced by changes in the accelerometer variables, was again shown as a sensitive method of measuring NMF in male rugby union players, which is in-line with previous work (Buchheit et al., 2018; Fitzpatrick et al., 2021; Garrett et al., 2018; Leduc, Tee, et al., 2020). The SRT-jog showed a moderate increase at MD + 1. Comparable results have been observed by Fitzpatrick et al. (2019) using this method where they saw similar changes the following day after a training session. Fitzpatrick et al. (2019) observed decreases in vertical acceleration, which is speculated to be the result of decreased vertical stiffness. However, several methodological differences limited the suitability of direct comparison to the present findings. For example, methodological differences exist with respect to the fatiguing protocol (match-play rather than training), participants (University rugby union players rather than academy football players), the Player Load derived metrics observed (vertical only vs total, vertical and mediolateral) and the speed used (9 vs. 12 km.h^{-1}). The large differences in speed utilised during the SRT-jog assessment postulates that potential changes in gait mechanics (induced by the increased speed) may involve different mechanisms, and therefore, may explain the discrepancy between the two studies. The speed was lower in the present study to reflect a pace suitable for the player characteristics included (e.g., rugby union backs and forward) whereby using a faster speed of a 12 km.h^{-1} for example, would result in excessive speed prescription post-match compared to their respective physical characteristics. This further supports the need for standardisation of running test methods in the future to ensure reproducibility and continuity in the field of interest (McLaren et al., 2019). One possibility would be to integrate individual speed thresholds, which would account for individual players' characteristics (McLaren et al., 2019). Such an approach would enable a more tailored sub-maximal test protocol for each athlete. However, increased practical feasibility challenges such as increased set-up and test execution should be considered.

When looking at the potential effects of specific locomotor or collision variables, mixed dose-response effects were observed. To the authors' knowledge, this is the first study exploring the potential association between prior match load variables and SRT-Jog. Consequently, the ability to compare and discuss the present results against prior literature is limited, and the postulated assumptions remain hypothetical in nature. Regardless, the lack of effect of match load variables remain somewhat surprising considering the increase in SRT-jog observed at MD + 1. Consequently, this lack of effect potentially reflects a lack of sensitivity of the SRT-jog protocol to NMF induced by rugby union play, and therefore, presents challenges supporting the integration into practice. Accordingly, these results need to be reproduced and causal links between changes in accelerometer load during any SRT and NMF aetiology (i.e., central and peripheral) investigated (Leduc, Tee, et al., 2020). However, it is reasonable to postulate that a combination of methodological factors may explain the lack of association found. Indeed, the speed used ($9\,km.h^{-1}$) in the study was substantially lower than (Fitzpatrick et al., 2021). Therefore, as previously mentioned, this may have led to players selecting a different running strategy during either the constant jogging phase or the change of direction. If so, the selected running strategy resulting from the different speed, may not be sensitive to detect associations with the load sustained during the prior match. Such findings would inform that a minimal speed or exposure may be required to assess the construct of interest (i.e., NMF). Indeed, inappropriate test protocols (in this case speed) may have led to either under-stressing or overstressing the athlete (Noonan & Dean, 2000). The case of under-stressing or overstressing the person could lead to invalid conclusions (which may be partially highlighted by the present results) due to ceiling or floor effects (Noonan & Dean, 2000). Future studies should investigate the minimum level of speed required and the potential effects on running or change of direction strategy during a shuttle test protocol, to properly assess and report parameters by which the SRT-jog protocol may be used to indicate player NMF status.

SRT-Stride

The SRT-stride findings demonstrated an increase at MD + 1 and MD + 2. This again suggests the increase observed results in an impairment of running efficiency, which is in-line with prior research using similar SRT-stride protocols (Garrett et al., 2023; Garrett et al., 2018; Leduc, Tee, et al., 2020). The exact mechanism is yet to be known and requires further work. However, a concomitant decreased stride length and increased stride frequency results in an increase in the quantity of movement required to perform the test, and is thought to explain the increase in RLI observed (J. M. Garrett et al., 2018, 2023; Leduc, Tee, et al., 2020). The additional inclusion of match location as random factor accounted for more variation in SRT-stride measures, compared to prior work, indicating the potential impact of travel. However, globally the findings using the SRT-stride protocol remained consistent with previous studies (Garrett et al., 2023; Garrett et al., 2018; Leduc, Tee, et al., 2020).

Collisions and total distance were the main predictors explaining the change in SRT-stride following match participation. Previous research has reported similar effects between collisions in a rugby league match play and changes in NMF status when using countermovement jumps (McLellan & Lovell, 2012; Twist et al., 2012). It is previously acknowledged that collisions result in muscle damage during rugby union (Lacome et al., 2018; West et al., 2014). Post-match responses to external load experienced by a player, usually results in an acute reduction in NMF status, demonstrating an internal response in order to prevent further fatigue and minimise excessive muscle damage (Dalleau et al., 1998; Garrett et al., 2023; Garrett et al., 2018). It is thought that fatigue induced by locomotion is characterized by tissue damage evoked by active lengthening of skeletal muscle during high-intensity activity (Garrett et al., 2023; Twist et al., 2012). Twist et al. (2012) previously observed that players involved in a greater number of contacts demonstrate the greatest subsequent reductions in lower limb NMF status. Accordingly, it is plausible that players involved in more contacts/collisions during a rugby match may experience an increased loading on the lower limb musculature resulting from an increase in the number of accelerations and decelerations performed as part of the contact and/or during the tackle itself (Twist et al., 2012). Increases in accelerations and decelerations result in increased muscle damage that would then be manifested as impaired neuromuscular function (Twist et al., 2012). Moreover, specific structural damage exists when experiencing collisions (Naughton et al., 2018), which may exacerbate the level of post-match muscle damage experienced by a player (West et al., 2014). The increase in the RLI variable observed in the present findings, may therefore, potentially demonstrate this protective mechanism to tissue lengthening, which occurs when running speed is increased. In support of this notion, Small et al. (2009) previously demonstrated reduced maximum combined hip flexion and knee extension angle to result in a decreased stride length and increase in stride frequency, in the presence of fatigue during the Soccer-specific Aerobic Field Test (i.e., $SAFT_{90}$). An increased vertical accelerometer activity is likely representative of an increased stride frequency (Leduc, Tee, et al., 2020). The current findings suggest a prevention in the excessive lengthening of muscle tissue, thus illustrating this potential protective effect observed whilst performing SRTs. Nevertheless, such causally informed speculations should be investigated using experimental designs with scientific rigour. Due to the observational and applied approach, such conclusions are beyond the scope of this research. The precise mechanisms responsible for the observed findings of the SRT-stride in practice, therefore, remain elusive. Nonetheless, this is the first study to assess the effect of match load variables on outcome measures gathered from SRT-stride. This applied observational study further reinforces the usefulness of the SRT-stride to assess player NMF status during training following exposure to match load.

Limitations

In addition to highlighting and discussing the novel findings collected in using an ecologically valid approach, several limitations are acknowledged. The global absence of a gold standard reference measure to assess NMF remains problematic. Indeed, despite recent advances in technology enabling application in the field, the use of solely accelerometer obtained data to extrapolate a fatigue status remains debateable. Obtaining a greater understanding of the aetiological mechanisms associated with the observed SRT related variables changes, would provide further insight into the fatigue construct assessed by such tests and aid subsequent interpretation and management. Additionally, measures of leg stiffness and other kinematic parameters may fluctuate during SRTs and potentially mediate the relationship between NMF aetiology and observed changes in accelerometer load. Accordingly, a combination of exploratory physiology (i.e., central, peripheral fatigue) and biomechanical (stride characteristics) parameters would assist practitioners to identify and manage NMF in practice with greater certainty. Another limitation worthy of mention is the lack of control of players at MD + 2. Due to the observational approach, players performed their usual recovery strategies after the first testing at MD + 1. Hence, this may impact the results observed at MD + 2 in this specific context, and the ability to draw conclusions regarding direct impact of match load on subsequent SRT. Nonetheless, this approach is reflective of real-world constraints, in that implementation of athlete recovery protocols are prioritised over minimising the potential influence of such recovery on a MD + 2 SRT variables. It is however, recommended that further studies account for the potential influence of recovery kinetics with a higher degree of control when evaluating SRT methods.

Conclusions

The findings of this study indicate the SRT-stride may be more sensitive to changes in player NMF status induced by rugby union match load, than the SRT-jog. These findings support prior research using the SRT-stride for monitoring NMF status in team sport athletes. Future research is needed to investigate the associated mechanisms involved with responses observed using differing SRT protocols as well as the effect of speed and turning angles across multiple team sport populations to further reinforce the construct validity of SRT procedures as a measure of neuromuscular function. However, the present findings indicate that when seeking to assess player NMF status, it is for now, better to stride rather than jog.

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Authors' contributions

CL and JMG conceived the article ideas and design; CL, JMG, and SR drafted, revised, and edited the manuscript; assisted in revising and editing the manuscript. All authors have read and approved the final version of the manuscript and agree with the order of the presentation of the authors.

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