Exercise Physiology

Evaluation of signal-to-noise ratios of practical neuromuscular tests

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Abstract - Aim: Although several tests have been used for monitoring neuromuscular function, their sensitivity to fatigue in athletes of team-based sports remains inconclusive. This study investigated the signal-to-noise ratio (SNR) of countermovement jump (CMJ), squat jump (SJ), sprint performance of 10 and 30 m (Sp-10 m; and Sp-30 m, respectively), and mechanical properties of sprints obtained through the MySprint app. **Methods:** Thirteen national rugby sevens players performed eight CMJ and SJ, and four sprint trials for baseline assessment, repeating all tests at 24-, 48-, and 72-h after a sport-specific fatigue protocol. Data analysis was performed using a linear multilevel modelling procedure through established Bayesian methods. Acceptable sensitivity was assumed for measures with SNR equal to or below -1. **Results:** The highest mean estimates of SNR at all moments were found in rate of force in 10 m (RF-10 m) (posterior mode: -2.15 to -2.33), followed by CMJ, SJ, Sp-30 m, maximal power output (P_{max}), peak of rate of force (RF_{peak}), and theoretical and measured maximal horizontal velocity (V_0, and V_{max}), which showed similar mean values of SNR at 24-, 48-, and 72-h after exercise (posterior mode: -1.29 to -1.80). **Conclusions:** These results suggest that measures more specific to the task performed during the fatigue protocol showed higher sensitivity. Therefore, tests considering physiological and biomechanical determinants of rugby gestures should be used for fatigue monitoring.

Keywords: signal-to-noise ratio, vertical jumps, sprint performance, horizontal mechanical profile.

Introduction

Fatigue monitoring is an essential practice adopted by conditioning professionals to prevent the chronic manifestation of fatigue and to effectively manage training loads, thereby reducing the risk of non-functional overreaching, injuries, and illnesses[1]. In this process, the performance during explosive movements has been used to monitor muscle fatigue in athletes[1,2] due to reliance on intact neuromuscular function. In field-based team sports, specifically rugby sevens, impairments in explosive force can occur due to the repetitive nature of high-demand activities, such as accelerations, decelerations, changes of direction, and jumps[3,4]. These fatigue-induced changes may last for several days[5] and are often tracked by jump and sprint tests, which, unlike other indirect markers, are feasible and movement-specific to the lower limbs[6]. However, particularly for sprint tests, the use of time-based variables could have limitations for monitoring purposes over extended time courses since they seem to be sensitive to detect fatigue only acutely[7,8].

To overcome such limitations, assessing changes in the mechanical properties of sprints could be useful. This kind of analysis could distinguish the effect of high-demand activities on force and velocity capabilities, which determine the overall sprint performance (i.e., acceleration and maximal velocity)[9]. Previous studies have shown that fatigue typically elicited in matches and training sessions of team sports tends to affect velocity to a higher extent than force[10,11]. Also, successive sprints and decelerations performed in team sports are associated with increased risk of tissue damage[12], which can harm the contractile apparatus of muscle[13,14] and the efficiency of the stretching-shortening cycle (SSC)[15]. Since the acceleration phase seems to be determined by force and the maximal velocity, in part, by SSC[16], capabilities related to maximal velocity could be more sensitive to the specific fatigue generated by team sports gestures. Therefore, the analysis of variables derived from the mechanical horizontal profile could provide an in-depth understanding of the effects of fatigue on different aspects and phases of sprints. This method allows one to quantify different capabilities, including theoretical (V_0) and measured maximal horizontal velocity (V_{max}), theoretical maximal horizontal force (F_0), maximal power output (P_{max}), rate of force in 10 m (RF-10 m), peak of rate of force (RF_{peak}), rate of decrease in rate of force (D_{RF}), and slope of the linear force-velocity relationship (FV). Such variables can be easily obtained through *MySprint* (MyS) (Apple Inc., Cupertino, CA, USA), a validated[17] commercial application capable of quantifying mechanical aspects estimated from simple sprints.

Monitoring fatigue through practical tests that resemble sport-specific movement patterns is a suitable way to improve ecological validity[1]. This is useful in rugby sevens, where more than 200 m per match are covered at high intensity and sprinting, affecting performance over consecutive days[3,4]. In this scenario, sprint and jump tests represent valid alternatives to maintain specificity. Additionally, such specificity is directly linked to the sensitivity of a measure, which should be considered by coaches in a well-informed decision-making monitoring process. It refers to the potential of a measure to detect meaningful changes in performance[18]. It could be represented by the ratio between the change in performance after a stressful event and the error of the respective measurement[19], being therefore expressed as a signal-to-noise ratio (SNR). In practical settings, this metric should be incorporated into the monitoring process as a parameter to avoid measurements biased by high levels of error. The SNR of some practical tests has also been studied to verify which measures are suitable to monitor fatigue in field-based team sports. Among them, jump height derived from tests like countermovement jump (CMJ) and squat jump (SJ) are commonly used[20,21], with SNR varying from ~0.5 (low) to ~1.5 (acceptable) for basketball, rugby union, and Australian football players[22-24]. Furthermore, the differences between CMJ and SJ in terms of SSC usage[21] could be useful to identify if the fatigue generated by common sports gestures (i.e., SSC impairments) could affect CMJ and SJ performance differently. Therefore, the concomitant analyses of both CMJ and SJ, and the derivatives of mechanical properties of sprinting are required to demonstrate their sensitivity to better discriminate specific fatigue-induced impairments.

Accordingly, this study aimed to investigate the sensitivity of MyS variables (i.e., V_0; V_{max}, F_0, P_{max}, RF-10 m, RF_{peak}, D_{RF}, FV), CMJ, SJ, and 10- and 30-m sprint performances (Sp-10 m and Sp-30 m, respectively) at 24-, 48-, and 72-h after a fatigue protocol specific for team-based sports on rugby sevens players. It was hypothesized that measures with a higher contribution of SSC, such as CMJ, Sp-30 m, V0, and Vmax, would display greater sensitivity to the fatigue generated by the specific protocol.

Methods

Participants

Thirteen male national-level rugby sevens players (mean ± standard deviation [SD]; age: 23 ± 4 years, body mass: 86 ± 9 kg, stature: 180 ± 5 cm) took part in this study. Athletes were in a competitive period, with an overall weekly training volume of 8 h, including strength, power, speed, and rugby training sessions. Participants were informed of the risks and discomforts associated with the experiments before giving their written informed consent to participate. This study was conducted according to the Declaration of Helsinki and was approved (number 87294718.5.0000.0118) by the Ethics Committee in Human Research of the Santa Catarina State University. All participants were instructed to maintain a consistent fluid and dietary intake during the experimental period, not to perform strenuous exercise, and to abstain from alcohol and caffeine 24 h before each visit.

Experimental design

An experiment was designed to assess and compare the sensitivity of different tests traditionally used for monitoring neuromuscular status. Participants attended the laboratory on five days, including a familiarization session, and four consecutive visits were performed at the same time of the day (±2 h) to minimize the effects of circadian variation. Baseline measurements of CMJ, SJ, and sprint parameters were evaluated before a protocol of fatigue and used for standardizing the data obtained from the same tests applied 24-, 48-, and 72-h after the fatigue protocol (Figure 1).

Procedures

Each testing session started with a standardized warm-up consisting of a 5-min treadmill walking with 0° inclination at 5 km · h^{-1} and three submaximal CMJs (50% of their maximal, subjectively), followed by the CMJ test. After that, athletes rested for 3 min, performed three submaximal SJ (~50% of their maximal), and initiated the SJ test. The jump tests consisted of eight maximal jumps interspaced by 90 s of rest. Following jump tests, a ~5-min outdoor warm-up (consisting of sprint drills and three 3-s accelerations) followed by 5 min of passive rest was performed before the completion of four 30-m sprints separated by 3 min of passive rest. All visits were composed of the same procedure, except for the second day of testing, where the participants were submitted to the tests twice, i.e., before and immediately after the protocol of fatigue.

Jump tests

During CMJ assessment, all jumps were performed with arms akimbo and preceded by a quick countermovement in a comfortable and reliable depth. For SJ

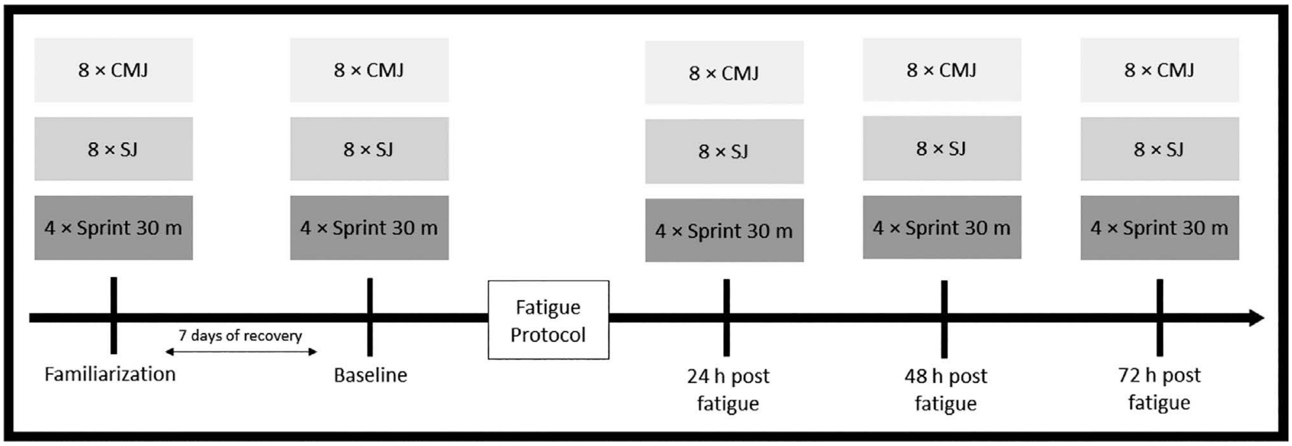

Figure 1 - Experimental design of the study. CMJ, countermovement jump; SJ, squat jump.

measurements, the subjects were instructed to stay in a squat position at a self-selected depth of ~90° for 2 s before the jump. If a countermovement gesture was detected before the jump, the attempt was invalidated and repeated. Each trial was performed on a portable force platform (Custom made, Aquatic Biomechanics Research Laboratory, Santa Catarina State University, Brazil) at a sampling rate of 1500 Hz. The signal was subsequently smoothed by a low-pass Butterworth digital filter with a frequency of 17 Hz. The jump height (*h*) of each procedure was calculated from Equation (1), as follows:

$$h\ (m) = \frac{g \times t^2}{8} \qquad (1)$$

where g is gravitation acceleration (i.e., 9.81 m · s^{-2}) and t is the flight time in seconds. The average of eight trials of each jump test was used for further analysis to improve the sensitivity of the jump height[18].

Sprints performances

The 0-10 and 0-30 m sprint times were measured with three pairs of wireless photocells (Witty System, Microgate, Bolzano, Italy). The starting line was placed 0.5 m behind the first photocell, and subjects were instructed to sprint as fast as possible, from a standing start, over the 30-m timing gate. The average sprint times from the four consecutive trials were used for further analysis.

MySprint analyses

All sprint trials were recorded using an iPad Pro (Apple Inc., Cupertino, CA, USA) and analyzed posteriorly with a simple and validated[17] application named *MySprint* (MyS) (Apple Inc., Cupertino, CA, USA). The equipment was assembled according to the instructions present in the study of Romero-Franco et al.[17] and adapted for a distance of 30 m. The iPad was fixed to a tripod positioned at the 15 m marker and 10 m perpendicularly to the track, allowing for filming the entire sprint from the side. Due to the parallax effect caused by filming from a fixed point, each marker was placed at adjusted positions to ensure that subjects were viewed exactly when their hips were crossing the markers at the distances of 5-, 10-, 15-, 20-, 25-, and 30-m from the starting line. Altogether, eight variables were extracted from the app, including V_0, V_{max}, F_0, RF-10 m, RF_{peak}, D_{RF}, P_{max}, and FV[9]. The average value of each one was used in further analysis.

Fatigue protocol

The fatigue protocol was designed by Howatson and Milak[13] and consists of 15 × 30 m sprints interposed by 60 s of rest. Each sprint was performed in the same way as described above, but followed by forced deceleration within a 10 m zone. Participants were instructed to perform maximal effort across all fifteen sprints, and verbal encouragement was provided during all repetitions.

Statistical analysis

Analyses were performed by established Bayesian inference methods using statistical software R (v4.0; R Core Team [2020], Vienna, Austria) and its graphical interface RStudio (v1.2.5). The package brms[25] was used to fit Bayesian models using Stan[26]. The change from baseline to 24-, 48-, and 72-h was analysed as percentages.

A linear multilevel modelling procedure using a distributional model (a.k.a., scale-location)[27], was conducted with the estimated mean response and the residual unexplained standard deviation (SD) with predictors (see Supplementary file Equation 1). The model included the measures (CMJ, SJ, Sp-30 m, Sp-10 m, V_0, V_{max}, F_0, RF-10 m, RF_{peak}, D_{RF}, P_{max}, and FV), time (expressed in continuous hours: 24, 48, and 72), and the interaction between measures and time as fixed effects. Random effects were the varying intercepts and slopes for the interaction between subjects and measures, i.e., an index variable that allocates a unique value for each crossing of the two variables (e.g., subject a−CMJ, subject a−SJ, subject b−D_{RF},

…). The random effects were reported as standard deviations (SD - σ), indicating the variability in responses between subjects at the intercept and the time course of changes in each measure. The residual (unexplained) SD (σ_{res}) was modelled using a log-transformation to ensure positive values, and after analysis, it was back-transformed to the original scale using an exponential function[28]. For log-$\sigma_{res,}$ the fixed effects were each measure (CMJ, SJ, Sp-30 m, Sp-10 m, V_0, V_{max}, F_0, RF-10 m, RF_{peak}, D_{RF}, P_{max}, and FV), and the random effects were the varying intercepts for each variable derived from the interaction between subject and measure ($\tau_{\sigma res}$ - representing the between-subjects SD for each residual SD in each measure). The logarithms of σ_{res} and $\tau_{\sigma res}$ were back-transformed using an exponential function, resulting in $\tau_{\sigma res}$ reported in a times-divide (×/÷) format.

The model fitting process involved the use of the Markov chain Monte Carlo (MCMC) method, specifically the No-U-Turn sampler (NUTS) implemented in Stan. The prior distributions were intentionally set to be weakly informative, which means their influence on the estimates was kept relatively small[29] (Supplementary file Equation 1). The calculation of SNR was performed by taking the posterior estimated response (change) at each time-point (24-, 48-, and 72-h) for each measure, and then dividing it by the σ_{res} of that measure[19]. This resulted in a Cohen's d_z standardized effect size. To assess the probabilities, the percentage of the posterior distribution located below 0 and -1 for the mean percentage change and SNR, respectively, was calculated. Measures with an SNR equal to or below -1 were considered to have an acceptable sensitivity, meaning that the signal was larger than the noise. When presenting the observed data, means ± SD were used, unless stated otherwise. For the posterior data, the mode with the highest density 95% credible intervals (CrI) was reported. This means that the interval was chosen in such a way that there is a 95% probability that the true population parameter falls within it[30].

Results

Due to technical issues, MyS and SJ measurements could be analyzed in only 9 subjects. Table 1 presents the observed data (mean ± SD) at each time-point and the observed change from baseline to 24-, 48-, and 72-h for each measure.

Figure 2 presents the model posterior estimates of intercepts ($\beta_{Intercept}$) and time slope coefficients (β_{time}), the heterogeneity in the coefficients ($\sigma_{\beta Intercept}$ and $\sigma_{\beta time}$), and the residual unexplained heterogeneity mean value of each measure (σ_{res}) and the heterogeneity between subjects of residual σ_{res} ($\tau_{\sigma res}$). The β_{time} coefficients showed no important effect of time on the estimated changes in the measures (near 0), except for CMJ and D_{RF} measures were every extra 1-h produced an extra small impairment and improvement of -0.039% [-0.089%, 0.019%] and 0.028% [-0.078%, 0.139%], respectively. The highest σ_{res} [95% CrI] estimates were observed for SJ (4.37% [2.62%, 7.44%]) and CMJ (4.17% [2.74%, 5.89%]).

Figure 3 presents the conditional effects of the percentage change in each measure from baseline to 24-, 48-, and 72-h. Concerning the magnitude of the mean changes (when expressed as percentages), the highest credible point of the posterior distributions (i.e., the mode), it was observed the largest change magnitudes in jump-derived measures CMJ (-5.89% to -6.77%) and SJ (-6.41% to -6.23%), and in the P_{max} (4.33% to 4.57%). Moderate changes occurred in the Sp-30 m, F_0, RF-10 m, RF_{peak}, V_0,

Table 1 - Observed means ± SD (n) at each time-point and the change to Pre of each measure.

Measure	Time-point				Change to pre		
	Pre	24-h	48-h	72-h	24-h	48-h	72-h
CMJ (cm)	34.29 ± 6.33	32.18 ± 6.72	32.10 ± 7.21	32.48 ± 6.13	-2.11 ± 1.86	-2.18 ± 1.75	-1.81 ± 2.19
SJ (cm)	29.35 ± 4.22	27.78 ± 3.75	27.28 ± 3.97	28.08 ± 3.08	-1.58 ± 2.21	-2.08 ± 2.10	-1.28 ± 2.32
Sp-30 m (s)	4.35 ± 0.20	4.43 ± 0.22	4.45 ± 0.23	4.46 ± 0.22	0.07 ± 0.06	0.09 ± 0.07	0.08 ± 0.12
Sp-10 m (s)	1.83 ± 0.11	1.85 ± 0.08	1.85 ± 0.1	1.86 ± 0.1	0.01 ± 0.04	0.02 ± 0.05	0.02 ± 0.06
V_0 (m/s)	8.61 ± 0.42	8.44 ± 0.51	8.38 ± 0.56	8.47 ± 0.39	-0.17 ± 0.17	-0.23 ± 0.21	-0.14 ± 0.18
V_{max} (m/s)	8.37 ± 0.41	8.21 ± 0.48	8.15 ± 0.53	8.16 ± 0.40	-0.16 ± 0.15	-0.22 ± 0.18	-0.21 ± 3.59
F_0 (N)	764. 17 ± 91.86	747.82 ± 96.73	741.16 ± 106.80	750.66 ± 105.35	-16.35 ± 29.41	-23.01 ± 43.41	-13.51 ± 51.71
RF-10 m (%)	0.32 ± 0.01	0.32 ± 0.01	0.32 ± 0.02	0.32 ± 0.02	-0.01 ± 0.00	-0.01 ± 0.01	-0.01 ± 0.01
RF_{peak} (%)	55.67 ± 3.26	54.83 ± 3.74	54.42 ± 4.25	54.68 ± 4.14	-0.83 ± 1.09	-1.25 ± 1.62	-0.82 ± 1.91
D_{RF}	-0.09 ± 0.01	-0.09 ± 0.01	-0.09 ± 0.01	-0.1 ± 0.01	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01
P_{max} (W)	1651. 09 ± 251.82	1585.64 ± 269.92	1561. 33 ± 273.33	1626.40 ± 249.53	-65.46 ± 56.26	-89.76 ± 94.46	-24.69 ± 111.35
FV	-89.44 ± 8.91	-89.26 ± 9.19	-89.02 ± 11.03	-91.01 ± 10.75	0.18 ± 4.63	0.42 ± 5.60	-1.57 ± 6.24

CMJ, countermovement jump; SJ, squat jump; Sp-30 m, 30 m sprint performance; Sp-10 m, 10 m sprint performance; V_0, theoretical maximal horizontal velocity; V_{max}, measured maximal horizontal velocity; F_0, theoretical maximal horizontal force; P_{max}, maximal power output; RF-10 m, rate of force in 10 m; RF_{peak}, peak of rate of force; D_{RF}, rate of decrease in rate of force; FV, slope of the linear force-velocity relationship.

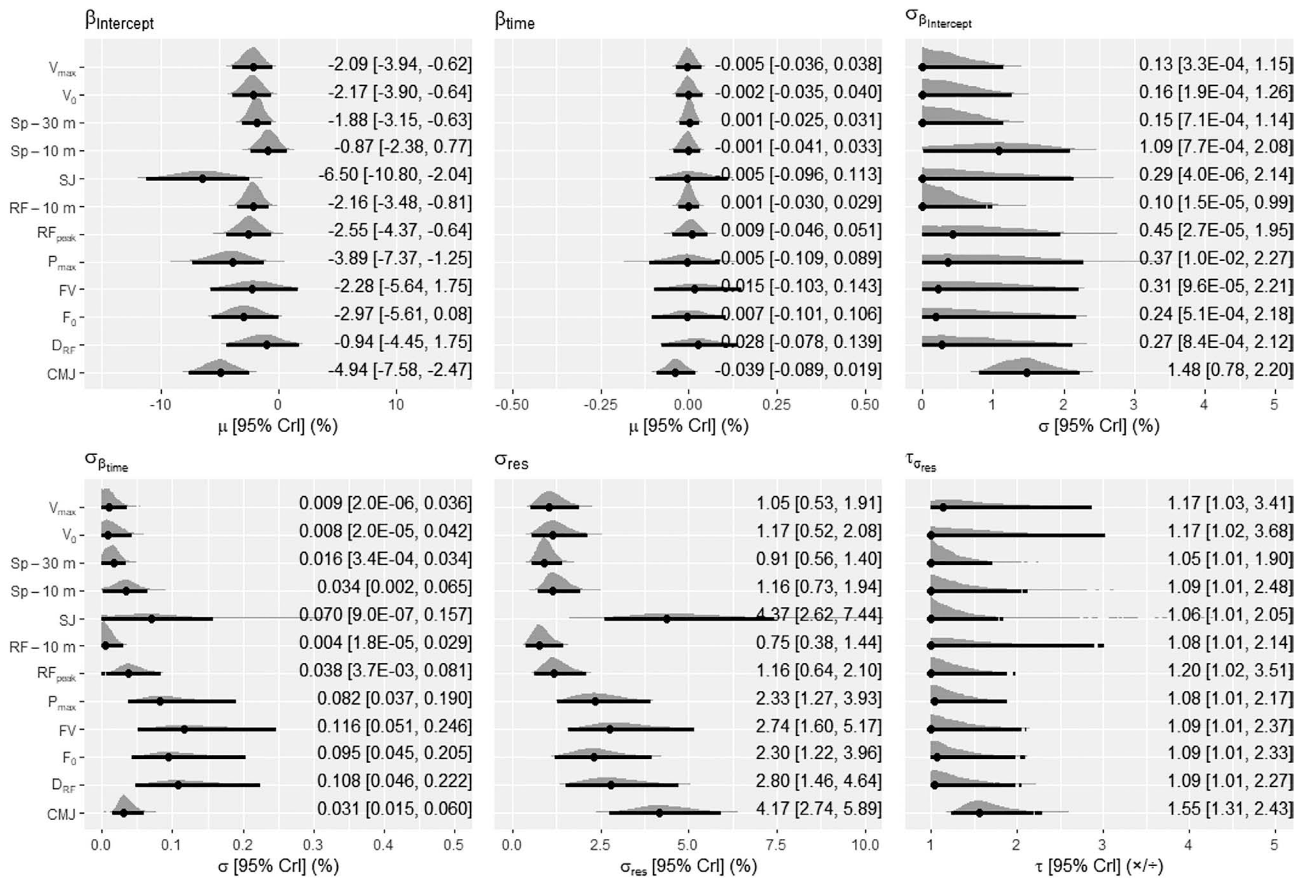

Figure 2 - Posterior estimates of the statistical model coefficients of population-level estimate intercept (A) and time slope (B), group-levels of subject's variability on intercept (C) and slope (D), the residual unexplained heterogeneity (E), and the between-subjects variability of residual SD (F) for each measure. Dots and error bars are the posterior mode and 95% credible intervals boundaries, respectively. The texts in each graph are the posterior modes [95% CrI]. CrI, credible intervals; μ, [mu] estimated posterior mean; σ, [sigma] estimated posterior standard deviation; τ, [tau] estimated posterior SD of residual unexplained SD as times-divide form.

and V_{max} (~1.5-2.7%). Finally, the smallest most credible changes were observed in Sp-10m, D_{RF}, and FV (-1.66% to -0.30%).

Figure 4 presents the conditional effects of the SNR in each measure from Pre to 24-, 48-, and 72-h. Since all measures showed higher probabilities to be impaired (Figure 3), the SNR values less than -1 means that the signal was higher than the noise (i.e., change > σ_{res}), and values higher than -1 means that the noise was higher than the signal (i.e., change < σ_{res}). The highest mean estimates of SNR at all moments were displayed by RF-10 m (posterior mode: -2.15 to -2.33), followed by Sp-30 m, P_{max}, RF_{peak}, V0, and V_{max}, which showed similar mean values of SNR across 24-, 48-, and 72-h after exercise (posterior mode: -1.41 to -1.80). CMJ also had similar mean estimates to SJ at 24-h (posterior mode: -1.32 vs -1.29), but not at 48-h (posterior mode: -1.54 vs -1.30), and 72-h (posterior mode: -1.74 vs -1.33), with high probabilities of SNR be equal to or below -1 being observed for the former (97.98% vs 78.70% at 24-h, 96.44% vs 75.48% at 48-h, and 87.48% vs 69.24% at 72-h, respectively). While the SNR of F_0 remained close to -1 during all moments (posterior mode: -0.96 to -1.10), D_{RF} and FV were the measurements with the smallest sensitivity observed (posterior mode: -0.06 to -0.51).

Discussion

Fatigue monitoring is a crucial process to guide decision-making related to load management strategies. Its accuracy depends on the use of measures with enough sensitivity to capture meaningful changes in performance. Under this perspective, this study aimed to evaluate the sensitivity of CMJ, SJ, sprint performance, and mechanical properties of sprint performance through analysis of SNR up to 72 h after exercise in rugby players. The main findings partially confirm the initial hypothesis, with higher values of SNR being displayed by variables strongly associated with the stretching-shortening cycle, such as CMJ, Sp-30 m, V_0, V_{max}, and P_{max}. On the other hand, high SRN was also observed for RF-10 m and

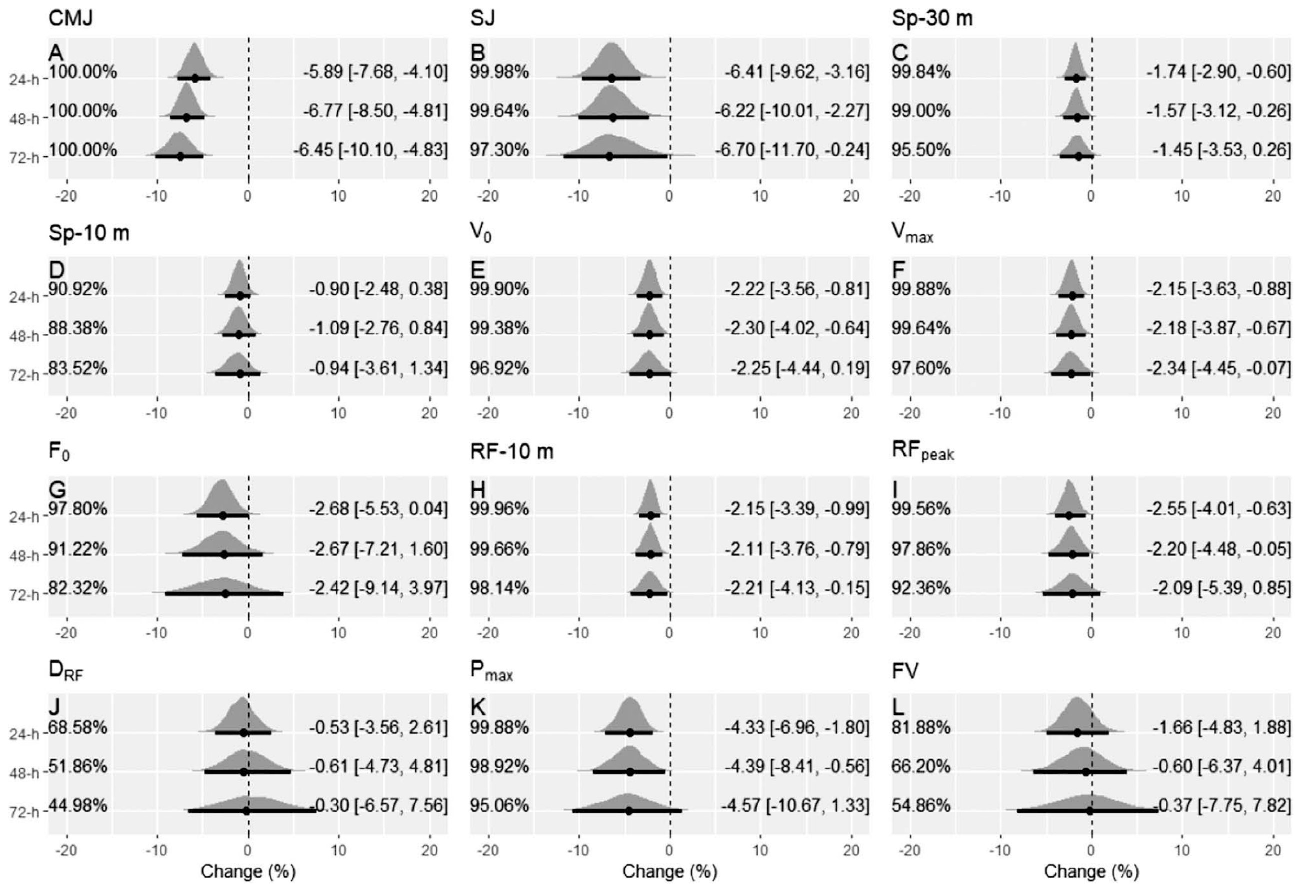

Figure 3 - Conditional posterior effects of changes from Pre to 24-, 48-, and 72-h in each measure. Dots and error bars are the posterior mode and 95% credible intervals boundaries, respectively. The texts in each graph are the modes [95% CrI] (right) and percentages of posterior density distributions located below 0 (left). CMJ, countermovement jump; SJ, squat jump; Sp-30 m, 30 m sprint performance; Sp-10 m, 10 m sprint performance; V_0, theoretical maximal horizontal velocity; V_{max}, measured maximal horizontal velocity; F_0, theoretical maximal horizontal force; P_{max}, maximal power output; RF-10 m, rate of force in 10 m; RF_{peak}, peak of rate of force; D_{RF}, rate of decrease in rate of force; FV, slope of the linear force-velocity relationship.

RF_{peak}, which are more related to maximal force capacity and the acceleration phase of sprints[31,32].

To overcome the limited information of time-based sprints variables and to track the effect of fatigue in biomechanical parameters of sprints, it was investigated the suitability of variables derived from the force-velocity-power profile was investigated and analyzed through the MyS app. Different from V_0 and V_{max}, which were similarly affected by fatigue and displayed at least 80.28% of sensitivity values below -1 across all moments, F0 had mean estimates of SNR close to -1, with just 61%, 57%, and 54% of its posterior distribution equal to or below -1 at 24-, 48-, and 72-h, respectively (Figure 4). In accordance, V_0 but not F_0 loss has been formerly demonstrated in soccer [11] and in rugby sevens players[10], which demonstrates the usefulness of monitoring other variables beyond maximum force. Indeed, even with F_0 presenting low levels of sensitivity, the SRN obtained for RF-10 m and RF_{peak} suggests that fatigue affected the athlete's ability to apply force in the forward direction of movement, especially during the first ten meters. Thus, monitoring such aspects of a sprint may provide more insightful information about the effect of fatigue on performance.

Based on this scenario, velocity loss was possibly the major factor responsible for reductions in maximal power development (i.e., P_{max}) during later moments post-fatiguing protocol, with similar sensitivity being displayed by V_0, V_{max}, and P_{max}. Although in a smaller magnitude, the response pattern of such measures is in line with a previous study that compared the effect of fatigue between the first and tenth repetition of a repeated-sprint protocol[33]. Unlike our results, they also found an expressive worsening in D_{RF}, indicating an inability of athletes to produce horizontal forces at high velocity. Indeed, we found that similarly to slope of the force-velocity relationship, D_{RF} had some lower changes post-exercise and greater σ_{res} than other measures analyzed, possibly due to short distance of sprint (i.e. 30 m). Consequently, both remained with the smallest SNR values and presented intervals ranging only from 8.74 to 23.08% of sensitivity values lower than -1.

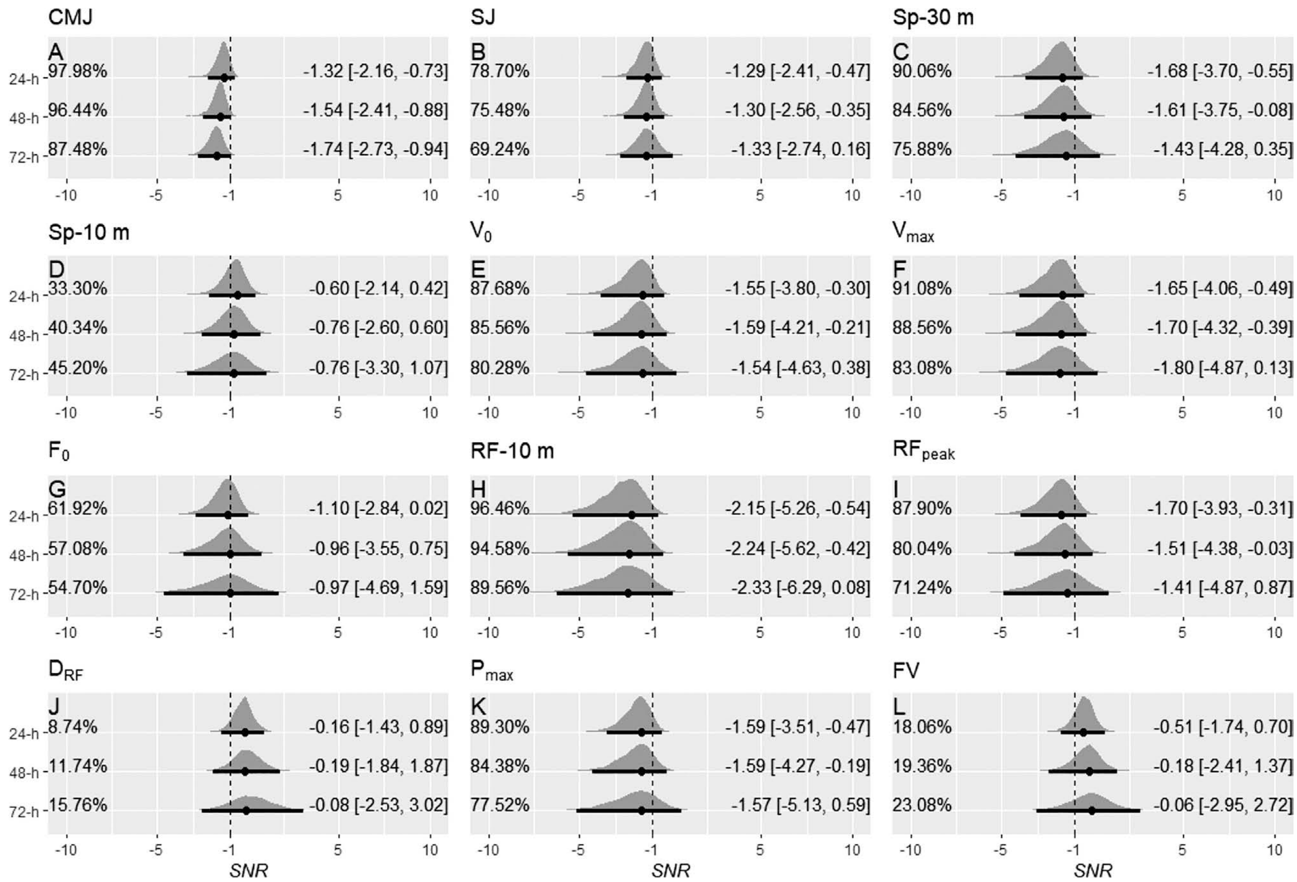

Figure 4 - Conditional posterior effects signal-to-noise-ratio from Pre to 24-, 48-, and 72-h in each measure. Dots and whiskers are the posterior mode and 95% credible intervals boundaries, respectively. The texts in each graph are the modes [95% CrI] and percentages of posterior density distributions below -1. CMJ, countermovement jump; SJ, squat jump; Sp-30 m, 30 m sprint performance; Sp-10 m, 10 m sprint performance; V_0, theoretical maximal horizontal velocity; V_{max}, measured maximal horizontal velocity; F_0, theoretical maximal horizontal force; P_{max}, maximal power output; RF-10 m, rate of force in 10 m; RF_{peak}, peak of rate of force; D_{RF}, rate of decrease in rate of force; FV, slope of the linear force-velocity relationship; SNR, signal-to-noise ratio.

Different forms of vertical jump have been used to monitor neuromuscular function in practical settings of field-based team sports[20]. Two of the most used are CMJ or SJ; however, which one presents better sensitivity remains unknown. In the current study, the SNR of CMJ was similar to previous research[22,34] but higher than others[23]. Also, the sensitivity of CMJ and SJ seemed to be higher than that presented by Gathercole et al.[8] (SNR = 0.5 ± 1.0 at 24-h), mainly 72-h after the fatigue protocol (SNR = 0.7 ± 1.5). Such inconsistencies can be partially explained by differences in exercise-induced fatigue protocol, method of calculation, study design, and training status of athletes. Relative to our findings, even in the absence of pronounced differences between the σ_{res} of both vertical jumps, these nuances are not negligible. In addition, despite the similarity between their values, the effect of the fatigue protocol resulted in different responses over time, with CMJ displaying narrower CrI around mean estimates than SJ. Thus, the combination of these two factors led to larger intervals of sensitivity values below -1 for CMJ, mainly in the later moments after the fatigue protocol.

Such results are in line with the concept that performances in CMJ and SJ are not determined by the same physiological pathways[21,35]. Indeed, jump preceded by countermovement builds up high muscle stimulation and reduces the muscle slack in fascicles and tendinous tissues, leading to enhanced performance of CMJ compared to SJ[21]. Conversely, this enhancement effect of the stretching-shortening cycle may be impaired by the eccentric overload produced by the fatigue protocol, potentially damaging the contractile apparatus of muscle[13,14]. As SJ is a purely concentric movement[36] that does not directly resemble the specific characteristics related to the stretching-shortening cycle of the fatigue protocol[37], the reductions expected to occur post fatigue protocol would be higher in CMJ. On the other hand, more pronounced differences were observed in sprint performances. The incapacity of Sp-10 m in detecting performance variations greater than σ_{res} resulted in smaller intervals of sensitivity values below -1. For Sp-30 m, despite the trend to reduction in mean estimates of SNR as time progressed, at least 75.88% of its CrI were composed of values equal to or smaller than -1 at all moments (Figure 4). These results suggest that performances in Sp-30 m and Sp-10 m reflect different mechanical and physiological characteristics of the sprint. While Sp-30 m is associated with greater use of the stretching-shortening cycle[38] and the maximum sprinting speed phase[31], Sp-10 m is related to the development of concentric force and the acceleration phase in the sprint[31,32]. Given that, successive decelerations performed during fatigue protocol would be linked to a "testing task-dependent" effect caused by stretching-shortening cycle fatigue[37], which leads to decreased muscle stiffness[39] and damages the elastic components of the muscle responsible for storing and reutilizing elastic power at high velocities[16]. Thus, even though maximum speed is not necessarily developed in 30 m, the performance in Sp-30 m had a more expressive impairment than Sp-10 m.

To the best of our knowledge, this is the first study to monitor neuromuscular function and sensitivity of vertical jump tests (CMJ and SJ), sprint performance of 10- and 30-m, and variables derived from the MyS app in the same individuals up to 72 h after a fatiguing exercise protocol. This study, while the first on this topic, was limited by the non-inclusion of females in the sample. Consequently, the generalizability of the findings is restricted to male rugby players. Future research is needed to investigate sex differences and to examine these issues in athletes across various competitive levels. Although the results obtained cannot be fully extrapolated due to methodological conditions, they indicate that fatigue generated by successive decelerations has more impact on measures highly associated to stretching-shortening cycle such as CMJ[21] and Sp-30 m[38], as well as in the rate of force (RF-10 m and RF_{peak}) velocity (V_0 and V_{max}) and power (P_{max}) components of a sprint in rugby players. The mechanism responsible for these changes are not well described, but they are likely linked to the complex interaction between structural[13] and neural factors caused by stretching-shortening cycle fatigue[37].

Despite our findings highlighting the need to assess the sensitivity of tests used in fatigue monitoring, some limitations demonstrate that they must be interpreted with caution. Primarily, SNR values were all calculated with σ_{res} estimated from non-standard sessions due to methodological constraints. Also, we assumed that the change among the time-points is linear, while non-linear analysis potentially could provide small values of σ_{res}. Nevertheless, changes over time are nearly equal to zero, indicating that in this range of measurements (i.e., 24- to 72-h) the fatigue effects on the measures did not change. Furthermore, although the analyses were based on posterior distributions produced with the MCMC method that mitigates the small sample size limitation[40], the lack of informative prior distributions could affect the posterior distribution of parameters. In this regard, we used weakly informative priors, reducing the influence of priors on the results[29].

Conclusion

To increase the accuracy of decision-making during the fatigue monitoring process, coaches and staff should consider using a test not only for its ability to detect performance changes, but also to evaluate the variation of measurement and verify the rate between these variables to establish a sensitivity value. Based on our data, CMJ and Sp-30 m were more suitable than SJ and Sp-10 m to identify impairments in neuromuscular function over 72-h post-exercise. Additionally, the use of the MyS app as a monitoring tool provided extra information regarding the effect of fatigue in mechanical properties, revealing greater sensitivity of RF-10 m, RF_{peak}, V_0, V_{max}, and P_{max} after successive decelerations. Together, our results suggest a different contribution of the stretching-shortening cycle to performance, which should be considered when choosing a test, especially when fatigue could be caused by accentuated stretching-shortening cycle usage. In addition, monitoring other aspects of sprint performance, such as rate of force, velocity, and power, may help coaches get a deeper understanding of the status of athletes after a given exercise or training session. Finally, it is recommended to use tests that specifically consider the physiological and biomechanical determinants linked to common sports gestures, such as accelerations, decelerations, jumps, and changes of direction.

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Manuscript received on July 15, 2024
Manuscript accepted on October 16, 2025