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Performance indicators during international rugby union matches are influenced by a combination of physiological and contextual variables

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Title: Performance indicators during international rugby union matches are influenced by a combination of physiological and contextual variables

Header: Physiological and contextual predictors of rugby union performance

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Abstract

Objectives: Research has linked physiological (e.g., hormonal, affective, fatigue) outcomes to performance indicators in rugby competition, but no work has integrated and contextualised these factors within a test-match environment. We addressed this gap by monitoring 29 athletes from a training squad across eight international rugby matches.

Methods: Pre-match (8-9 am) measures of salivary testosterone and cortisol concentrations, sleep duration, pulse rate, muscle soreness, stress, mood, and motivation were taken. Contextual factors were playing time, internal training load (ITL), test-match experience, opponent ranking, and crowd size. Performance was indexed by coach and player ratings of performance (CRP, PRP) and quantitative metrics; offloads, turnovers, runs with ball in hand (RWB), tackles, passes, and defenders beaten (DFB).

Results: Morning cortisol, sleep and mood were positively related to CRP and PRP (standardised coefficient estimates from 0.17 to 0.22). Cortisol, sleep, stress, mood and motivation were associated with one (or more) of turnovers, RWB, tackles, passes and DFB (incidence rate ratio [IRR] from 0.74 to 1.40). Playing time was positively related to all quantitative performance indicators (IRR from 1.01 to 1.04) with ITL, opponent ranking, and crowd size predicting selected outputs (IRR from 0.89 to 1.15). The explanatory models varied (conditional R^2 = 0.15 to 0.83) but were generally stronger with both physiological and contextual inputs.

Conclusions: Multiple physiological and contextual factors appear to contribute to player performance in international rugby competition. Measurement of these factors may guide training and management practices, a potential practical consequence but also advancing understanding from marker to causal link.

Key words: Testing; Endocrine; Adaptation; Readiness; Recovery

Practical implications

- A link between sleep duration and several performance indicators in rugby union competition was verified, thereby highlighting the need to quantify and manage individual pre-competition sleeping habits in an elite rugby environment.
- Stress, mood and motivational factors were also related to different indicators of match performance, which underscores a strong behavioural contribution and the potential for prescribing emotion-specific regulation strategies after waking and before competition.
- The physiological tests chosen were not only informative, but also acceptable by athletes and coaches within a rugby test-match environment. Replication of this testing battery in other competitive settings could benefit athletes and coaches from different sports.
- Consideration of modifiable contextual factors (i.e., playing time, internal training load) might guide pre-game preparation and post-match recovery strategies, ideally tailoring these for individual athletes.

1. Introduction

Applied rugby research has highlighted numerous physiological factors that affect, or predict, individual or team performance in competition. This includes testosterone and cortisol,[1, 2] affective (e.g., anxiety) state,[3] motivational drive,[4] and physical fitness.[5, 6] Muscle soreness and damage can also affect recovery after a rugby game[7] and athlete performance, as can sleep characteristics (e.g., duration, efficiency).[8, 9] Some of this work is, however, limited by data collection several weeks before competition and the use of statistical models that do not account for clustering within individuals or between playing positions. To date, limited research has also examined athletes during international rugby union matches.

To develop accurate and ultimately useable models in elite sport, one must also consider contextual factors affecting performance or physiological antecedents of that performance. One example is duration of play, which has a direct impact on rugby-playing performance,[3] and is determined by individual contributions and how a match unfolds. Similarly, opponent strength will likely drive both team strategies and pre-match physical preparation (e.g. training loads), as will prior match outcomes.[10] Crowd size might also be important, particularly for less experienced athletes when participating in rugby internationals.[11] Addressing these issues would provide unique insight into the rugby test-match environment with novel information to guide the assessment, training and management of these athletes.

This study examined match-day associations between physiological and contextual factors and selected performance indicators during several international rugby union matches. The physiological data comprised of salivary hormones, sleep duration, affective and motivational state. Contextual factors included; playing time, training loads, test-match experience, opponent ranking, and crowd size. Both qualitative (e.g., coach and player performance ratings) and quantitative (e.g., offloads, turnovers) metrics were used for indexing performance. We broadly hypothesised that different combinations of physiological and contextual factors would be associated with one or more performance outcomes. Since no comparable studies have been conducted on elite rugby players, we made no firm predictions regarding the strength and direction of these associations.

2. Methods

A training squad of male rugby players (n=40) were initially recruited. No pre-screening was necessary, as this cohort completed regular medical and health assessments. The study inclusion criteria were participation in at least two (from 8) international rugby matches and game time of at least 10 minutes per match.[12] The final cohort (n=29) comprised of 13 backs and 16 forwards with a respective mean (±SD) age of 28.8±2.8 and 27.8±3.4 years, height of 1.84±0.06 and 1.91±0.10 m, mass of 91.5±9.0 and 111±9.5 kg, and test-match experience of 33.5±28.5 and 23.4±18.1 games. Participants received full instructions of the study protocols and benefits, before providing informed consent. Ethical approval (Number 2010.001R) was granted by the Human Research Ethics Committee at Swansea University, UK.

The participants were monitored across eight international rugby union matches during the 2010 International Autumn Series and 2011 Six Nations Championship. These competitions were played using a home (n=6) and away (n=2) format, resulting in three wins and five losses for this team. A training-camp environment was entered before (<2 weeks) each competition, where training structure, nutritional intake, sleeping habits, and environmental stressors were strictly controlled. Training during this period (4-5 days a week, 1-3 sessions per day) primarily focused on technical and tactical development, supplemented with physical conditioning and recovery sessions. A structured format was followed on match-day, starting with a team breakfast (8:00 to 9:00 am) approximately 30-40 minutes after waking.

A team trainer and assistant collected the study measures, as described below, prior to breakfast. The same individuals were used across all matches, thus minimizing any variation associated with different testers. A saliva sample (~1 mL) was provided by passive drool and stored in a -80°C freezer.[13] Each sample was assayed in duplicate for testosterone and cortisol using enzyme-linked immunoassay kits (Salimetrics LLC, USA). The kits had a sensitivity limit of 1 pg/ml (testosterone) and 0.07 ng/ml (cortisol). Each athletes' samples were tested in the same plate to eliminate inter-assay variation (~10%).[2] Due to logistical constraints, no samples were taken during one away match. Missing data points were interpolated from samples taken 2-3 days before, and after, every competition and available match samples using a time-series imputation model; Kalman smoother fitted by maximum likelihood.[14]

The number of hours slept to the nearest 30 minutes was recorded, as was general muscle soreness, on a Likert scale (from 1 = extremely low up to 10 = maximal) that focused on the larger muscle groups of the legs, back and chest. Resting pulse rate was measured with a pulse oximeter (AccuMed). With the athlete seated, the oximeter was placed on the index finger and the lowest pulse rate recorded over three minutes. Oximetry-derived pulse rate correlates well (r=0.91) with heart rate measured by electrocardiography.[15] Stress, mood and motivation to compete were also scored on a Likert scale (from 1 = extremely low / poor up to 10 = maximal / excellent). Data were collected with a time-framed question, "How do you feel right now?". These psychological measures are routinely used by this cohort.

Playing time was the first contextual variable of interest, as it directly affects other match variables. Internal training load (ITL) was monitored to quantify physical stressors in rugby.[16] Briefly, a rating of perceived exertion (0-10 Likert scale) was recorded after each training session and match in the previous seven days and multiplied by activity duration (in minutes) to determine ITL.[17] These results were pooled to calculate a summative ITL score. The quality of each opposing team, based on world rankings (https://www.world.rugby/rankings/), was recorded (between 1 and 12). Participant experience, in terms of test matches played, and crowd size per match were other factors of interest. Match venue was not included as a contextual variable, due to expected bias with the ratio of home (n=6) to away (n=2) games.

All matches started at a similar time of day, from 2:30 pm to 5:15 pm (local time), and were played in two periods of 40 minutes. Each game was preceded by a standard warm-up (<1 hour) and a final team briefing (<15 minutes) before kick-off. Several metrics were taken to index athlete performance. First, three professional coaches rated player performance on a Likert scale (1 = extremely poor up to 10 = excellent), similar to other rugby studies.[2, 4] The ratings were based on several factors (e.g., points scored, try assists, line breaks, errors, turnovers, penalties conceded) and individual abilities, rather than different expectations when facing opponents with different skill levels. These ratings showed good inter-rater reliability (Intra-class correlations [ICC] = 0.58 to 0.85) and internal consistency (Cronbach's alpha = 0.80 to 0.94). Data were aggregated to derive a single coach rating of performance (CRP). The players also self-rated their own performance (PRP) using the same Likert scale.

Other performance indicators were sourced from a website (http://en.espn.co.uk/rugby/), namely; offloads, turnovers, runs with ball in hand (RWB), tackles made, passes and defenders beaten (DFB). The operational definition for each performance indicator can be viewed as a supplement (Table S1). Other statistics (e.g., tries scored, try assists) were available, but not analysed due to a very low frequency of events or extreme overdispersion that might bias our estimates. Descriptive means for the physiological, contextual and performance measures are displayed in Table 1. The measured variables totalled 159 observations, compared to eight observations for opponent ranking and crowd size. Where appropriate, an intra-class correlation coefficient (ICC) was computed to determine the similarity (i.e., reliability) of observed responses within individual players.

Insert Table 1 here.

A linear mixed model was used to investigate relationships between the physiological and contextual measures and qualitative performance indicators. To predict the quantitative outputs, we applied a generalised linear mixed model specified with a Poisson error distribution. Separate models were constructed for selecting random (intercept only) and fixed effects. To select random effects, an empty model was compared to one including participant and playing position with the conditional Akaike's Information Criterion (AIC). Fixed effects were selected using AIC comparisons for small samples. The physiological and contextual measures were entered as independent variables, after which all combinations were ranked (on AIC minimisation) and the best model chosen for analysis. Model fit was determined using a marginal (i.e., fixed effects) and conditional (i.e., fixed and random effects) R^2. Diagnostic testing of residuals revealed that all assumptions were met with no signs of overdispersion and collinearity. All analyses were conducted in the R package.[18]

To aid interpretation, the coefficient estimates for each predictor of CRP and PRP were standardised, as an effect size statistic. Data are presented with a 95% confidence interval (CI) to gauge the precision of these estimates. The predictor coefficients for the remaining outputs were exponentiated to derive an incidence rate ratio (IRR) with a 95% CI, as a more interpretable statistic. Please note that since predictors were selected by AIC comparisons, not all variables met a common threshold (e.g., $p<0.05$) used to denote statistical significance.

3. Results

Only variables identified from the model-fitting procedures are presented in Figures 1 and 2. Regarding the performance ratings, morning cortisol concentration and mood state were positively related to CRP (Figure 1A), whilst stress level was positively associated with PRP (Figure 1B). The marginal R^2 was weak for CRP (0.07) and PRP (0.03), but model fit improved slightly for these respective outcomes (0.19 and 0.15) based on the conditional R^2.

Insert Figure 1 here.

Playing time was positively related to offloads, whereby a one unit increase in playing time equated to a 1.01 factor change in this outcome (Figure 2A). Most physiological measures were related to one or more of turnovers (Figure 2B), RWB (Figure 2C), tackles (Figure 2D), passes (Figure 2E) and DFB (Figure 2F). The exceptions were testosterone, pulse rate and soreness. The contextual variables of playing time, opponent ranking and crowd size were also positively associated with one or more quantitative performance indicators (IRR from

1.01 up to 1.15), whilst ITL had a positive effect on turnovers (IRR = 1.05) and passes (IRR = 1.02), but a negative effect on tackles made (IRR = 0.98) and DFB (IRR = 0.89). Model fit for explaining the variance in each output differed considerably, but the conditional R^2 (0.34 to 0.83) was consistently stronger than the marginal R^2 (0.06 to 0.48).

Insert Figure 2 here.

Finally, we repeated the dredging procedure for selecting fixed effects, but minus the interpolated hormonal values. Subsequent model selections (data not shown) revealed that morning cortisol was no longer related to either CRP, turnovers or passes, whereas all other relationships were unaffected. A summary of the relationships identified and their directionality (positive or negative) are depicted in Table 2. The final linear and generalised linear mixed-model outputs are presented in Tables S2, S3 and S4.

Insert Table 2 here.

4. Discussion

This study is the first to examine the influence of physiological and contextual variables on athlete performance during international rugby union matches. Most physiological variables were related to one or more performance indicators. Contextual variables affecting performance included; playing time, ITL, opponent, and crowd size. In general, combining both factors improved model fit for predicting the quantitative performance outputs.

Of the physiological measures, sleep was the most consistent predictor of performance. More sleep was followed by a higher PRP with more counts on RWB, passes and DFB, thereby confirming the need to monitor and manage sleep in elite rugby athletes.[8, 9, 19] Sleep was also positively related to turnovers, perhaps as a corollary effect of these activities. Notably, sleep duration (~9 hours) was longer than reports on elite rugby players, either pre-match (i.e.,~7.5 hours) or post-match (i.e., ~6-7 hours),[9] and other seasonal phases (i.e., ~6.5 hours).[8, 19] Sleep was estimated in this study, whereas the cited work used polysomnography and actigraphy to assess sleep. One study was however conducted in a sleep laboratory[8] and this may itself induce some sleep loss. Still, a deeper understanding of the impact of sleep on match performance could be achieved by examining other salient features, such as sleep behaviours (e.g., time in bed, efficiency) and architecture (e.g., sleep waves, rapid eye movements).[8]

Mood was the next best physiological predictor of athlete performance. An elevated mood in the morning was related to a higher CRP and more tackles, but also less DFB. Mood fluctuates after a professional rugby match for up to three days[20, 21] and winning (vs. losing) produces pleasant emotional outcomes, whilst lowering arousal and stress.[22] It is not clear if a previous win or loss, or individual perceptions of that outcome, can promote sustained changes in emotional state that persist until the next encounter. One must also consider other psychological stressors (e.g., coaching climate, performance reviews, home-life) in elite rugby settings,[16, 23] as the emotion regulation process is inherently social and interpersonal.

A higher morning cortisol concentration was associated with a better CRP and less turnovers and passes. In other rugby studies, cortisol was positively related to muscle strength[24, 25] and strength adaptations,[26] indicating a metabolic or neuromuscular mechanism that might transfer to rugby-match activities. The anticipatory cortisol response, which is partly governed by basal secretion, can also affect match preparation via cognitive processing and attentional control.[27] Since these predictions were only identified with inclusion of imputed cortisol values, the results should be interpreted with extreme caution. Testosterone was a poor predictor of player performance, perhaps reflecting its role as a social hormone[28] where other psychological factors (e.g., social status, outcomes of prior contests) come into play and expected transiency in these behaviours that could not be captured with a single hormonal measure taken several hours earlier.

The quantitative performance measures were affected by several, and often overlapping, contextual factors with playing time positively related to each output. This is not unexpected, as longer periods of on-field play afford more opportunities to execute playing tasks, although individual performance might differ with time played within each half.[3] The ranking of each opponent affected RWB, tackles, passes and DFB, such that better outputs were achieved against relatively weaker (i.e., higher ranked) teams. Better outcomes on these metrics were also achieved in the presence of a larger crowd; an environmental contributor to distress or eustress and emotion regulation.[3, 11] Our work further highlights the importance of training prescription, whereby a higher ITL (in the preceding 7 days) was associated with more turnovers and passes, but a corresponding reduction in tackles made and DFB. Other contextual factors (e.g., between-match recovery, previous match outcome) can affect ITL in rugby.[10] Understanding the dynamic interplay between environmental contingencies and training optimisation is a challenge faced by most coaches and trainers in sport.

Integrating contextual and physiological data produced stronger predictive models that, we argue, represent the complexities of elite sport. This is evident from the moderate to strong conditional R^2 for turnovers (34%), RWB (58%), tackles (65%), passes (83%) and DFB (51%), where 4-6 measures contributed to each explanatory model. The fitted models for CRP and PRP were however relatively weak ($R^2 \leq 19\%$). Such a difference could reflect the subjective nature of these assessments and, as a single global score, they fail to account for performance changes within a rugby match.[3] The weaker marginal R^2 for each performance indicator is also informative. This suggests that the naïve pooling of data, without accounting for random effects (e.g., individual or positional differences), might mask the true nature of these relationships. The indicators selected warrant further consideration. Although widely used in rugby research and practice, debate continues regarding those metrics that best describe or discriminate rugby performance on an individual, positional and team level.[12, 29, 30]

Conducting studies during international competition does present some challenges, such as a lack of control regarding training and environmental stressors, and an inability to collect data closer to an event. In addition, match performance might depend on other internal (e.g., team strategies, culture) and external (e.g., weather, ground conditions) factors that were not measured. Likewise, other patterns of change (e.g., mid-week hormonal responses) unobserved by us could be relevant to rugby performance.[2, 31] The models developed must also be interpreted with certain caveats. First, a limited number of performance indicators were modelled, and our findings may not necessarily transfer to other rugby teams. Second, by pooling observations the estimates include both individual differences and changes over time. With more intensive athlete monitoring, it would be possible to disaggregate the within- and between-person effects of a given predictor, similar to recent work on female athletes.[32]

5. Conclusion

This study identified multiple contextual and physiological factors affecting athlete performance during international rugby union matches. When integrated, these factors explained a substantial portion of different performance indicators that arguably underpin, or reflect, match-play success. Thus, the measurement of these factors may guide training and management practices to ensure a higher level, and more consistent, performance.

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Figure 1. Standardized coefficients (95% CI) for the models predicting the coach ratings of player performance (**A**) and player self-ratings of performance (**B**). Significant at *p<0.10, **p<0.05, ***p<0.01

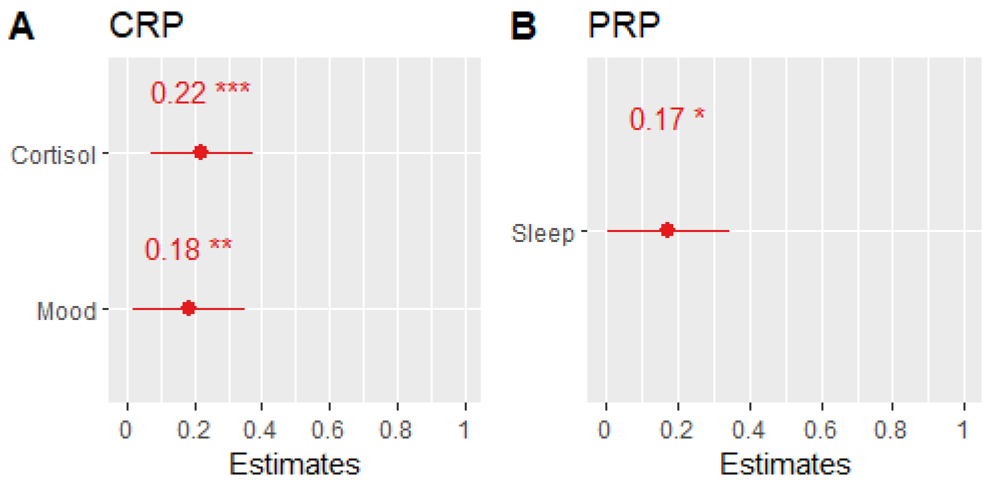

Figure 2. Incidence rate ratios (95% CI) for the models predicting offloads (**A**), turnovers (**B**), runs with ball in hand (**C**), tackles made (**D**), passes (**E**) and defenders beaten (**F**). Internal training load (ITL) is scaled, whereby 1 unit = 100. Crowd size is scaled, whereby 1 unit = 1000. Significant at *p<0.10, **p<0.05, ***p<0.01

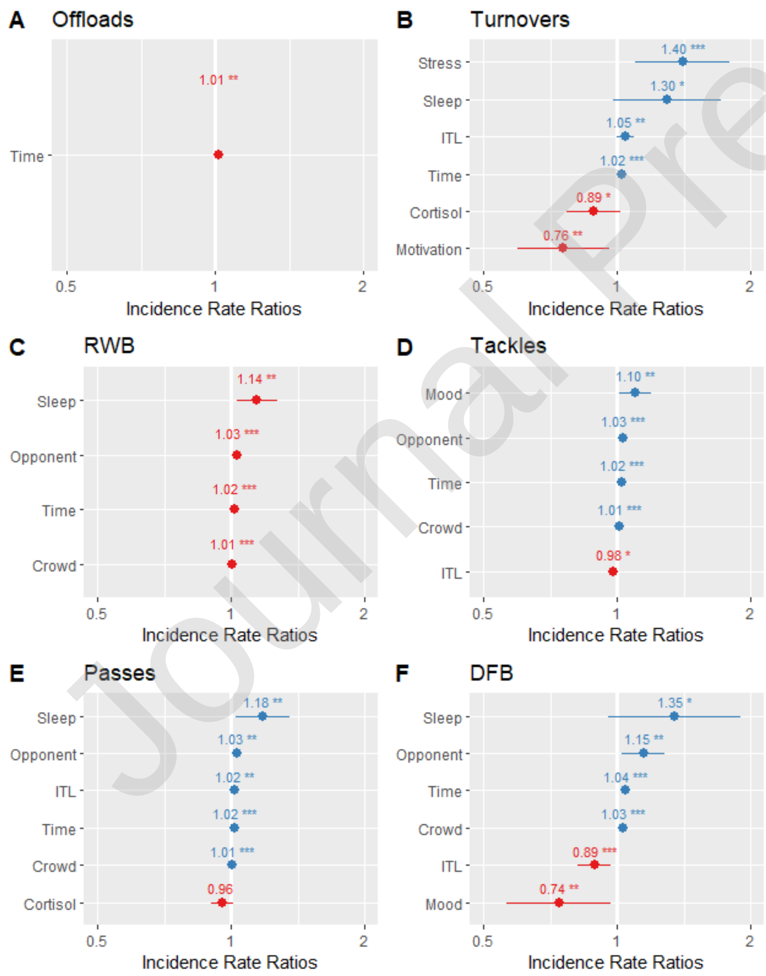

Table 1. Descriptive means for the physiological, contextual and performance variables pooled across eight international rugby union matches. Only data from athletes who played at least 10 mins per match were included (backs = 71 observations, forwards = 88 observations).

Factors	Variables	Position	Mean	Minimum	Maximum	ICC
Physiological	Testosterone[1] (pg/ml)	Backs	150	64	456	0.23
		Forwards	157	90	415	0.17
	Cortisol[1] (ng/ml)	Backs	4.23	1.39	9.14	0.07
		Forwards	4.14	0.74	9.07	0.17
	Sleep (hours)	Backs	9.0	6	10	0.41
		Forwards	8.6	5	10	0.60
	Soreness (1-10)	Backs	6.6	5	9	0.42
		Forwards	7.3	3	10	0.67
	Pulse rate (bpm)	Backs	53	38	66	0.90
		Forwards	52	40	68	0.81
	Stress (1-10)	Backs	6.6	3	9	0.44
		Forwards	7.2	4	10	0.67
	Mood (1-10)	Backs	7.0	3	10	0.40
		Forwards	8.5	5	10	0.54
	Motivation (1-10)	Backs	7.4	5	10	0.56
		Forwards	8.5	5	10	0.63
Contextual	Time (minutes)	Backs	62	11	80	0.26
		Forwards	57	10	80	0.68
	ITL (au)	Backs	1473	505	2861	0.07
		Forwards	1654	318	3088	0.01
	Experience (matches)	Backs	35	0	102	na
		Forwards	29	1	71	na
	Opponent (rank)	na	6.24	1	12	na
	Crowd size (number)	na	55352	18290	82120	na
Performance	CRP (1-10)	Backs	5.6	2.3	7.7	0.16
		Forwards	5.9	3.7	9.0	0.08
	PRP (1-10)	Backs	5.6	3	9	0.19
		Forwards	5.8	3	8	0.12
	Offloads (counts)	Backs	0.7	0	9	0.11
		Forwards	0.5	0	4	0.21
	Turnovers (counts)	Backs	0.7	0	3	0.00
		Forwards	0.4	0	3	0.03
	RWB (counts)	Backs	5.2	0	18	0.43
		Forwards	4.5	0	16	0.39
	Tackles (counts)	Backs	3.6	0	12	0.08
		Forwards	4.5	0	16	0.37
	Passes (counts)	Backs	12.6	0	63	0.74
		Forwards	1.8	0	9	0.22
	DFB (counts)	Backs	0.8	0	6	0.25
		Forwards	0.1	0	2	0.00

KEY: ITL = internal training load, CRP = coach ratings of player performance, PRP = player self-ratings of performance, RWB = runs with ball in hand, DFB = defenders beaten, ICC = intraclass correlation coefficients. [1]Includes imputed hormone values from one match.

Table 2. Summary of positive (+) and negative (-) relationships between the contextual and physiological variables and indicators of match performance.

Variables	CRP	PRP	Offloads	Turnovers	RWB	Tackles	Passes	DFB
Testosterone								
Cortisol[1]	+			-			-	
Sleep		+		+	+		+	+
Soreness								
Pulse rate								
Stress				+				
Mood	+					+		-
Motivation				-				
Time			+	+	+	+	+	+
ITL				+		-	+	-
Experience								
Opponent					+	+	+	+
Crowd size					+	+	+	+

KEY: CRP = coach ratings of player performance, PRP = player self-ratings of performance, RWB = runs with ball in hand, DFB = defenders beaten, ITL = internal training load.
[1]Associations were limited to the dataset containing imputed hormone values from one match.