Manuscript title: Influence of contextual factors, technical performance and movement demands on the subjective task load associated with professional rugby league match-play

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Abstract

Purpose: The aim of the study was to identify the association between several contextual match factors, technical performance and external movement demands on the subjective task load of elite rugby league players. **Methods:** Individual subjective task load, quantified using the National Aeronautics and Space Administration Task Load Index (NASA-TLX), was collected from 29 professional rugby league players from one club competing in the European Super League throughout the 2017 season. The sample consisted of 26 matches, culminating in 441 individual data points. Linear mixed-modelling was adopted to analyze the data for relationships and revealed that various combinations of contextual factors, technical performance and movement demands were associated with subjective task load. **Results:** Greater number of tackles (effect size correlation ± 90% CI; η^2= 0.18 ±0.11), errors (η^2= 0.15 ±0.08) decelerations (η^2= 0.12 ±0.08), increased sprint distance (η^2= 0.13 ±0.08), losing matches (η^2= 0.36 ±0.08) and increased perception of effort (η^2= 0.27 ±0.08) led to *most likely – very likely* increases in subjective total task load. The independent variables included in the final model for subjective mental demand (match outcome, time played and number of accelerations) were *unclear*, excluding a *likely small* correlation with the number of technical errors (η^2= 0.10 ±0.08). **Conclusions:** These data provide a greater understanding of the subjective task load and their association with several contextual factors, technical performance and external movement demands during rugby league competition. Practitioners could use this detailed quantification of internal loads to inform the prescription of recovery sessions and current training practices.

Keywords: *team sport, match demands, mental demand, load, NASA-TLX.*

Introduction

Rugby league match demands have been well reported due to advances in technology and a growing interest in monitoring the 'load' that an athlete undergoes during training[1], match-play[2,3], or both[4]. While much of the research and current applied practice in rugby league measures external loads derived from micro-technology (GPS and accelerometers etc[2,5,6]), these measures simply describe the activity that a player has completed and might not accurately reflect the physiological or perceptual demands imposed on the individual [7]. Internal loads are adopted as a method of quantifying the response (physiological and perceptual) to these external loads, with session rating of perceived exertion (*s*RPE) traditionally used as a valid, non-invasive and inexpensive measurement tool[8] to determine the perceived exercise intensity associated with rugby league training[1] and match-play[2,5,9].

The widespread quantification of exercise intensity using *s*RPE combined with exercise duration (i.e. *s*RPE-TL), is considered a global measure of internal load[1,2]. Differential RPE (*d*RPE) has also been proposed to discriminate between the internal loads (perceived breathlessness, leg and upper-body muscle exertion and cognitive demands) associated with various rugby training practices (e.g. repeated high intensity efforts and skills training)[10]. However, these global measures might oversimplify the multifactorial psychophysiological construct of match-play[11], whereby the reductionist method of gaining one (*s*RPE) or several (*d*RPE) ratings of internal load might lack the sensitivity to measure unique loads associated with rugby training and competition (e.g. collision)[12]. Other subjective measures exist, including the NASA task load index (NASA-TLX)[13], a multidimensional scale used to obtain subjective workload estimates determined from six subscales (mental demand, physical demand, temporal demand, performance, effort and frustration) thought to contribute to 'global load' during all tasks. Originally designed to discriminate tasks of varying mental and physical demands during aviation, the NASA-TLX has since been used in other non-aviation disciplines, including endurance performance, to discriminate tasks with varying mental (e.g. mental fatigue) and physical demands (e.g. 5 km running)[14]. To date, the NASA-TLX has not been used to quantify the subjective task load during team sport performance. The reliability and validity of the NASA-TLX is reported to be adequate to detect meaningful changes in subjective task load across various industries including aviation, medical and military tasks[15].

Numerous factors contribute to the task load (i.e. the cost of performing a task on the individual[13]) experienced by players during team sport competition. Indeed, the dynamic psychophysiological demands experienced by players are constructed from the task demands (e.g. external demands of match-play), the contextual factors under which the task is performed (e.g. playing home or away), and the skills, behaviour and perceptions of that individual[16]. The technical and physical demands of rugby league competition are often considered 'important' if they differentiate successful and less successful teams (i.e. match outcome and playing standard)[17,18], and it is plausible that these important task demands likely impact the mental and physical cost (i.e. task load) experienced by players. Given that the NASA-TLX can differentiate several sources of task load (e.g. mental and physical demands), the extent to which these task loads are related to the task demands (e.g. technical and movement demands) is worth exploring. Although external demands of match-play are well documented and the effects of several contextual factors on movement demands have been explored (e.g. opposition quality alters the amount of high speed running)[19], to the authors' knowledge no study has described the effect contextual factors might have on a player's subjective task load during team sport match-play. This is particularly important given that contextual factors likely alter the experienced cognitive and physical demands experienced by players, that might well impact player fatigue[20]. Such information on the subjective task load of matches (i.e. how the loads experienced are perceived by the individual) would therefore be useful when prescribing training that acts to simulate not only movement and physiological demands, but also to elicit a particular construct of subjective task load (e.g. mental demand). The aims of this study were twofold: (i) to describe the subjective task load of rugby league match-play using the NASA-TLX and (ii), to determine the association between subjective task load and several contextual match factors, technical performance and external movement demands.

Methods

Study Design

A longitudinal observational study design was used to examine the effect of selected contextual factors, technical performance and movement demands on elite rugby league players' subjective task load, quantified by the National Aeronautics and Space Administration Task Load Index (NASA-TLX)[13] and *s*RPE[8]. Subjective task load was collected from elite professional rugby league players from one club competing in the European Super League throughout the 2017 season (February – September). Data were collected during match-play (GPS, performance analysis and contextual data) and during the subsequent 'recovery session' the day after each match (subjective task load and perception of effort) at the same time of day (9:00 – 11:00 am).

Participants and Contextual Data

With ethics approval from the Faculty of Medicine, Dentistry and Life Sciences Ethics Committee [1278/17/TM/SES] and written informed consent from the club and players, 29 professional rugby league players (age= 26 ± 4 years; body mass= 94 ± 10 kg; stature= 182 ± 6 cm) were recruited for the study. Players were from the same club competing in the European Super League and were categorized according to playing positions as adjustables (half-back, hooker, stand-off and loose forward, *n*=8), outside backs (fullback, winger and centre, *n*=11) and hit-up forwards (prop and second row, *n*=10). The inclusion criteria required players to have entered the field of play during a match and to have attended the subsequent recovery session at the club's training ground 13-15 hours afterwards. Individual data were excluded when players were unable to attend the recovery session the day after a match (*n*=18), due to concussion (*n*=8), musculoskeletal injury (*n*=3) or non-injury related reasons (*n*=7). Whole match data were excluded when a recovery session was not provided within 24 hours after the match (*n*=4). Therefore, data were collected from 26 matches (league, *n*=19; play-offs, *n*=7), involving 29 players, culminating in 441 individual data points. Throughout the competitive season, 16 matches were won, 13 were lost, with one draw. Match data were subcategorised according to season phase; early (February - April; *n*=9), mid (April - July; *n*=10) and late (July - September; *n*=7). Opposition quality was determined as 'high' (*n*=11) or 'low' (*n*=15), depending on league position at the end of both the ordinary season and play-offs using a median split. This method created an uneven split of teams, given that opposition could be considered as both "high" and "low" quality at different times of the year. Data were reported on 13 home and 13 away fixtures. Most matches took place on Thursday and Friday evenings (8:00 pm; *n*=22), with the remaining fixtures on Saturday and Sunday afternoons (3:00 pm; *n*=4).

Procedures

Movement Demands

Players were pre-fitted with a playing jersey that housed a 10 Hz GPS unit between the scapulae (Viper pod, STATSports, Co. Down, Ireland). GPS units were activated before the pre-match warm-up (~40 min before kick-off). The same units were worn by players for each match to avoid inter-unit variation. Data were 'split' live by the same individual into playing halves and individual interchange bouts during the match. The reliability and validity of these GPS units are described elsewhere[21,22]. Previously reported thresholds were used for low intensity activity (<14 $km{\cdot}h^{-1}$) and high speed running (≥14 $km{\cdot}h^{-1}$)[23], sprint distance (>20 $km{\cdot}h^{-1}$)[2] and high metabolic power (>20 $W{\cdot}kg^{-1}$)[24]. Data were later downloaded and analyzed using STATSports software (Viper PSA software, STATSports, Co. Down, Ireland), to calculate mean speed covered in total, low intensity activity and high speed running ($m{\cdot}min^{-1}$), sprints (*n*), sprint distance (distance covered >20 $km{\cdot}h^{-1}$), total accelerations and decelerations (*n;* >3$m{\cdot}s^{2}$ for at least 0.5 s – automatically calculated by the GPS software) and time spent at high metabolic power >20 $W{\cdot}kg^{-1}$ (s).

Technical Demands

Performance analysis was conducted and supplied with permission by Opta Sports (Opta Sportsdata Limited, Leeds,UK) using video footage of each match. Performance analysis data were provided in spreadsheets (Excel v2013, Microsoft Inc., Redmond, U.S.A). Data were subsequently reported on several key performance indicators as suggested by the coaching staff at the club, which were: number of passes, tackles, missed tackles, carries, metres and errors made. Video footage were coded according to specific Opta rugby league operational definitions. Previously published data demonstrated high levels of inter-operator reliability of independent Opta operators (kappa values 0.92 and 0.94; intra-class correlation coefficients = 0.88-1.00, and standardised typical errors = 0.00-0.37)[25].

Subjective Task Load and Perceptual Measures

Players were instructed to reflect on the entire time spent "on-field" during the match played the day before and to complete the non-digital version of the NASA-TLX[13] without consulting teammates. These perceptual measures were recorded under the same conditions during the recovery session the morning after each match (13-15 h post-match). The delay in reporting these subjective measures was due to limited access to these players immediately after match play. Previous research suggests that a 24 h recall is an accurate method of gaining perceptual measures (e.g. *s*RPE), with similar ratings regardless of the time after exercise (30 min *cf.* 24 h)[26]. Players rated six subscales of task load (mental demand, physical demand, temporal demand, performance, effort and frustration), with written definitions of the subscales available throughout. The original definitions were modified to include language familiar to the players (e.g. the word 'task' was replaced with 'match'). Each subscale was presented as a 10 cm line with visual anchors at either end (e.g. low/high). Numerical values were not displayed, but the scale ranged from 0-100 AU. Data were recorded to the nearest 5 AU. A weighted scoring of the six subscales was also performed using 15 pairwise comparisons between each subscale (e.g. mental demand *cf.* effort). Participants were instructed to circle the descriptor that represents the most important contributor to task load during the match. The weighted score corresponds to the number of times each subscale is selected as being the most important contributor to global task load. A task load (weighted rating) score was then calculated by multiplying the weighted score by the rated score for each individual subscale. Finally, a global task load score was then produced by summing the weighted rating for each descriptor, and dividing by the total weights (*n*=15). During the same recovery session and immediately before completing the NASA-TLX, players were required to report *s*RPE (0-10 scale)[8] relating to the match.

Statistical Analyses

Eight separate two-level linear mixed models were constructed to determine the influence of skill performance, contextual factors and movement demands performed during match-play on each dependant variable (each subscale of the NASA-TLX; weighted rating, total subjective task load and *s*RPE; Table 1). Individual players were included as random factors. When creating the model (Table 1) a "step-up" approach was employed starting with an "unconditional" null-model, whereby only the level two random factors (player) were included[27]. Subsequently, each level one fixed effect (covariate) was introduced to the model and retained if the model was significantly altered (P<0.05) as determined by the maximum likelihood ratio and χ^2 statistic. As the intercept, derived from the convergence of all random slopes (individual players), resulted in a height of x = 0, and none of the continuous fixed factors were measured at 0 (e.g. 0 m distance), the data was mean centred to shift the origin of the intercept. The *t*-statistic, from the final model, was converted to an effect size correlation (η^2) with 90% confidence intervals (90% CI)[28]. To supplement the interpretation of the analysis, the likelihood of the observed effect was determined using a pre-designed spreadsheet[29] and considered according to the quantitative chances of a true effect with following qualitative descriptors; *almost certainly not* (<1%), *very unlikely* (1-5%), *unlikely* (5-25%), *possibly* (25-75%), *likely* (75-97.5%), *very likely* (97.5-99%), *almost certainly* (>99%)[30]. Effect size correlations were interpreted as < 0.1, *trivial*; 0.1-0.3, *small*; 0.3-0.5, *moderate*; 0.5-0.7, *large*; 0.7-0.9, *very large*; 0.90-0.99, *almost perfect*; 1.0, *perfect*[30]. Statistical packages for social sciences (SPSS, version 24; SPSS Inc., Chicago, IL, USA) was used to construct the linear mixed models.

******* Insert Table 1 about here *******

Results

Positional comparisons of the performance analysis and movement demands were averaged and described for contextual purposes (Table 2).

******* Insert Table 2 about here *******

As shown in Figure 1, average data for the NASA-TLX revealed relatively greater weighted ratings for the subscales of effort and physical demand compared to mental demand, temporal demand, performance and frustration.

******* Insert Figure 1 about here *******

All independent variables included in the final model for subjective mental demand (match outcome, time played and number of accelerations) had an *unclear* relationship, excluding a *likely small* correlation with the number of errors (η^2= 0.10 ±0.08; Figure 2). Defensive tackling efforts (η^2= 0.19 ±0.12) resulted in *very likely small* increases in subjective physical demand (Figure 2). *Most likely small* increases were also observed in subjective physical demand after matches that were won (η^2= 0.21 ±0.08), with increased *s*RPE (η^2= 0.34 ±0.08) and with greater time spent at high metabolic power (>20 W·kg; η^2= 0.16 ±0.06). Time spent on the field during matches resulted in a *likely small* increase in subjective temporal demand (η^2= 0.11 ±0.08), with hit-up forwards reporting a *very likely small* decrease in temporal demand compared to adjustables (η^2= 0.21 ±0.13; Figure 2). Players reported performance as being better (lower rating = better performance) with *very likely small* decreases in subjective performance when matches where won (η^2= -0.12 ±0.09) and perception of effort was higher (η^2= -0.13 ±0.09). Effort was *most likely* higher when matches were won (*small*; η^2= 0.28 ±0.08), playing against higher quality opposition (*small*; η^2= 0.19 ±0.08) and when players perception of effort was higher (*moderate*; η^2= 0.38 ±0.07). Players performing more interchange bouts reported a small but *very likely* increase in effort (η^2= 0.13 ±0.08; Figure 2). Winning matches (*moderate*; η^2= -0.48 ±0.07) and increased *s*RPE (*small*; η^2= -0.21 ±0.09) resulted in a *most likely* decrease in subjective frustration. Conversely, an increase in the number of errors during the match resulted in a *very likely small* increase in frustration (η^2= 0.15 ±0.08; Figure 2).

Greater number of tackles (η^2= 0.18 ±0.11), errors (η^2= 0.15 ±0.08) decelerations (η^2= 0.12 ±0.08) and increased sprint distance (η^2= 0.13 ±0.08) during matches resulted in *very likely small* increases in total task load (Figure 3). Losing matches (η^2= 0.36 ±0.08) and increased perception of effort (η^2= 0.27 ±0.08) led to *most likely moderate* and *small* increases in total task load, respectively. Conversely, fewer carries (η^2= -0.18 ±0.09) and accelerations (η^2= -0.14 ±0.08) during match-play was associated with a *most likely* and *very likely small* increase in total subjective task load, respectively. Finally, greater number of tackles (η^2= 0.24 ±0.09), carries (η^2= 0.11 ±0.08), increased time spent on the field (η^2= 0.27 ±0.09) and when players covered more relative distance (η^2= 0.15 ±0.08) meant *very likely* and *most likely small* increases in *s*RPE (Figure 3).

******* Insert Figure 2 about here *******

******* Insert Figure 3 about here *******

Discussion

This study is the first to describe the external loads and internal responses associated with elite rugby league match-play using a multidimensional rating technique (NASA-TLX), whilst attempting to describe the specific contextual, performance and movement characteristics associated with the subjective ratings of the NASA-TLX. Positional differences in the technical performance characteristics, such as number of tackles (outside backs ~10 *cf.* hit-up forwards and adjustables ~25) and number of passes (adjustables ~40 *cf.* hit-up forwards ~3 and outside backs ~5), reflect the specific role requirements of these positions. However, positional differences were only significantly related with the perceived temporal demand of matches; that is, hit-up forwards perceived temporal demand to be greater (*very likely small*) than other positional groups (outside backs and adjustables). Such positional differences likely reflect the tactical decisions of the coach, where hit-up forwards are required to 'impact' the outcome of a match within a shorter period of time (~50 min) than whole match players (~80 min)[31], culminating with an increased time pressure and perceived temporal demand. These data provide a greater understanding of the overall external loads and internal responses of rugby league match-play, beyond reporting the external loads (GPS) and a global measure of internal load (*s*RPE-TL).

The mental demand associated with rugby league competition has not been explored before. In this study, no meaningful associations were observed between the reported match variables (i.e. contextual, technical performance and movement demands) and subjective mental demand, excluding a *likely small* increase in mental demand when players made more errors (Figure 2). These findings are in contrast to Mashiko and colleagues[32], whereby altered mental loads and associated mental fatigue measured using profile of mood state were speculatively attributed to changes in position-specific activity profiles during rugby union match-play, despite not measuring the movement or technical demands. Whilst the number of errors made during matches have been established as important determinants of team success and match outcome (e.g. more successful teams commit fewer errors)[33], it is unlikely that committing technical errors will exclusively increase perceived mental demand. Rather, the situation whereby 'errors' occur will likely inform a player's perception of mental demand. More specifically, errors are likely to occur towards the latter stages of a match and after a peak 5 min period[34], meaning that skilled actions in association with fatigue might increase the mental demands on a player. Alternatively, given that correlations cannot establish causality, it is possible that a greater mental demand in a match results in more errors. This is in agreement with studies reporting that mentally demanding tasks before[35] and during[36] exercise can increase the number of errors during laboratory-based (concomitant exercise and computer based vigilance task)[36] and field-based accuracy tasks (sport-specific skill assessment, LSPT)[35].

Subjective ratings were similar between subscales of the NASA-TLX (62 - 78 AU), excluding ratings of performance (~40 AU). However, when these ratings were multiplied by the weighted score (i.e. weighted rating), effort, physical demand and mental demand were increased relative to performance, temporal demand and frustration. Subjective physical demand was associated with several contextual (match outcome), perceptual (*s*RPE) and external load measures (tackles, accelerations and time spent at high metabolic power) during match-play. Previously, the physical demands associated with rugby training and matches have been reported using internal (i.e. *s*RPE and *d*RPE) and external (i.e. GPS and accelerometer) load measures[10,31]. In the current study, completing more tackles was associated with an increased subjective physical demand and overall task load (*very likely small*). This reaffirms previous work describing the importance of the tackle within actual[37] and simulated[38-40] rugby league match play. Specifically, previous research demonstrates that collisions will impact a player's internal loads (perception of effort), external loads (sprint performance) and the fatigue response (jump performance) to exercise[37-40]. Despite not quantifying the intensity or type of tackle, our data suggests that the number of tackle involvements defined simply as a "player attempting to halt the progress or dispossess an opponent in possession of the ball" (Opta Sportsdata) will likely impact the overall task load perceived by the player.

This study is the first to apply the NASA-TLX to explore the 'load' placed on rugby league players. Various combinations of contextual factors, technical performance and movement demands were associated with subjective overall task load (NASA-TLX) and rating of perceived exertion (*s*RPE). For example, subjective total task load was informed by the number of tackles, carries and errors made, match outcome, perception of effort, number of accelerations and decelerations and total sprint distance. Session RPE, in contrast, was related to fewer match variables, including the number of tackles and carries made, playing time and total distance covered. Conversely, the subjective ratings of effort derived from the NASA-TLX were not informed by movement or physical demands but rather several contextual (quality of opposition, match outcome, number of interchanges; *small*) and perceptual (*s*RPE; *moderate*) factors. For example, when matches were won and played against better quality opposition, subjective effort was *most likely* higher (*small* standardised effects). These data suggest that the global NASA-TLX and *s*RPE reflect different loads associated with rugby league match-play. The NASA-TLX is a measure that provides greater detail when determining specific and subjective overall task load associated with rugby league competition, beyond the conventional method of reporting a single measure of perceived exertion. As such, this study supports the use of a NASA-TLX to explore the multifaceted demands on rugby league players, which might further enhance our understanding of match demands beyond RPE. Furthermore, these data suggest that global load measures (*s*RPE and NASA-TLX) are not just a 'response' to the external loads (i.e. movement and technical demands), but are also dependant on the context of performance (e.g. opposition quality and match outcome). Therefore, coaches and practitioners should consider the contextual scenarios under which the match loads are performed, and wherever possible should incorporate a player-centred approach to load monitoring.

Practical Applications

These data reaffirm that varying combinations of match characteristics interact to inform an individual's internal load associated with rugby league competition[12]. Indeed, this detailed quantification of internal loads might enable practitioners to better understand the internal load responses of their players, which could inform the prescription of recovery sessions and current training practices. Given that training should prepare players for the specific demands of match performance, these data could benefit coaches and practitioners when developing training practices by replicating not only the external (physical demands) and internal loads (physiological and perceptual) of rugby league matches, but also how these factors interact to inform subjective task load. Training sessions could include combinations of technical performance or movement variables to elicit specific subjective task loads. For example, based on the findings of the current study, practitioners might manipulate the subjective physical demands imposed on players by including varying number of tackles and time spent at high metabolic power during training practices. Coaches might also consider imitating collisions, ball carries and opportunities for players to make errors to better replicate match-play, given their association with overall task load and subjective mental demand (i.e. errors) in the current study. While these data offer insight to the contributors to total task load that might be used to design appropriate training practices, it is unknown whether these findings would elicit similar internal responses during training compared to match-play. For example, contextual factors such as match outcome and opposition quality would be difficult to replicate. Future research should consider quantifying the subjective task loads associated with current training practices.

In the current study, the NASA-TLX were conveniently reported during the recovery session after match-play and took players <5 min to complete (non-digital version), highlighting the ease of its application. However, the effect of time between matches and reporting NASA-TLX is currently unknown and could be considered a limitation of this investigation. Another limitation of the current study is that the method of reporting accelerations (number of accelerations $>3 m \cdot s^2$) will likely exclude those acceleration efforts that are performed at lower velocities (e.g. wrestling). Indeed, future studies might wish to explore the subjective task loads of rugby league training and competition using more contemporary external load metrics to quantify accelerations.

Conclusions

This study is the first to describe the external loads and internal responses associated with elite rugby league match-play using a multidimensional rating technique (NASA-TLX), whilst attempting to describe the specific contextual, performance and movement characteristics associated with the subjective ratings of the NASA-TLX. These findings suggest that the NASA-TLX is a worthwhile measure that provides greater detail when determining specific subjective loads and overall task load associated with rugby league competition, beyond the conventional method of reporting a single measure of perceived exertion. Taken together, these data support the use of NASA-TLX as a practical measure of internal global load. These data also highlight the complexity of rugby league competition, with several match related factors informing and comprising a player's global subjective task load.

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References

1. Lovell TW, Sirotic AC, Impellizzeri FM, Coutts AJ. Factors affecting perception of effort (session rating of perceived exertion) during rugby league training. *Int J Sports Physiol Perf.* 2013;8(1):62-69.
2. Waldron M, Twist C, Highton J, Worsfold P, Daniels M. Movement and physiological match demands of elite rugby league using portable global positioning systems. *J Sports Sci.* 2011;29(11):1223-1230.
3. Hausler J, Halaki M, Orr R. Application of global positioning system and microsensor technology in competitive rugby league match-play: a systematic review and meta-analysis. *Sports Med.* 2016;46(4):559-588.
4. Twist C, Highton J, Daniels M, Mill N, Close G. Player responses to match and training demands during an intensified fixture schedule in professional rugby league: a case study. *Int J Sports Physiol Perf.* 2017;12(8):1093-1099.
5. Johnston RD, Gibson NV, Twist C, Gabbett TJ, MacNay SA, MacFarlane NG. Physiological responses to an intensified period of rugby league competition. *J Strength Cond Res.* 2013;27(3):643-654.
6. McLellan CP, Lovell DI, Gass GC. Performance analysis of elite rugby league match play using global positioning systems. *J Strength Cond Res.* 2011;25(6):1703-1710.
7. Fox JL, Stanton R, Sargent C, Wintour S-A, Scanlan AT. The association between training load and performance in team sports: a systematic review. *Sports Med.* 2018;48(12):2743-2774.
8. Foster C, Florhaug JA, Franklin J, et al. A new approach to monitoring exercise training. *J Strength Cond Res.* 2001;15(1):109-115.
9. McLean BD, Coutts AJ, Kelly V, McGuigan MR, Cormack SJ. Neuromuscular, endocrine, and perceptual fatigue responses during different length between-match microcycles in professional rugby league players. *Int J Sports Physiol Perf.* 2010;5(3):367-383.
10. McLaren SJ, Smith A, Spears IR, Weston M. A detailed quantification of differential ratings of perceived exertion during team-sport training. *J Sci Med Sport.* 2017;20(3):290-295.

11. Weston M, Siegler J, Bahnert A, McBrien J, Lovell R. The application of differential ratings of perceived exertion to Australian Football League matches. *J Sci Med Sport.* 2015;18(6):704-708.
12. Lambert MI, Borresen J. Measuring training load in sports. *Int J Sports Physiol Perf.* 2010;5(3):406-411.
13. Hart SG, Staveland LE. Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In: *Adv Psychology.* Vol 52. Elsevier; 1988:139-183.
14. Pageaux B, Lepers R, Dietz KC, Marcora SM. Response inhibition impairs subsequent self-paced endurance performance. *Eur J App Physiol.* 2014;114(5):1095-1105.
15. Hart SG. NASA-task load index (NASA-TLX); 20 years later. Paper presented at: Proceedings of the Human Factors and Ergonomics Society Annual Meeting2006.
16. DiDomenico A, Nussbaum MA. Interactive effects of physical and mental workload on subjective workload assessment. *Int J Ind Ergo.* 2008;38(11-12):977-983.
17. Hulin BT, Gabbett TJ, Kearney S, Corvo A. Physical demands of match play in successful and less-successful elite rugby league teams. *Int J Sports Physiol Perf.* 2015;10(6):703-710.
18. Parmar N, James N, Hughes M, Jones H, Hearne G. Team performance indicators that predict match outcome and points difference in professional rugby league. *Int J Perf Analysis Sport.* 2017;17(6):1044-1056.
19. Kempton T, Coutts AJ. Factors affecting exercise intensity in professional rugby league match-play. *J Sci Med Sport.* 2016;19(6):504-508.
20. Aitken B, MacMahon C. Shared Demands Between Cognitive and Physical Tasks May Drive Negative Effects of Fatigue: A Focused Review. *Front Sports Act Living.* 2019;1(45).
21. Beato M, Devereux G, Stiff A. Validity and reliability of global positioning system units (STATSports Viper) for measuring distance and peak speed in sports. *J Strength Cond Res.* 2018;32(10):2831-2837.
22. Beato M, de Keijzer KL. The inter-unit and inter-model reliability of GNSS STATSports Apex and Viper units in measuring peak speed over 5, 10, 15, 20 and 30 meters. *Biology of Sport.* 2019;36(4):317.
23. Waldron M, Highton J, Twist C. The reliability of a rugby league movement-simulation protocol designed to replicate the performance of interchanged players. *Int J Sports Physiol Perf.* 2013;8(5):483-489.
24. Kempton T, Sirotic AC, Rampinini E, Coutts AJ. Metabolic power demands of rugby league match play. *Int J Sports Physiol Perf.* 2015;10(1):23-28.
25. Liu H, Hopkins W, Gómez AM, Molinuevo SJ. Inter-operator reliability of live football match statistics from OPTA Sportsdata. *Int J Perf Analysis Sport.* 2013;13(3):803-821.
26. Scantlebury S, Till K, Sawczuk T, Phibbs P, Jones B. Validity of Retrospective session rating of perceived exertion to quantify training load in youth athletes. *J Strength Cond Res.* 2018;32(7):1975-1980.
27. West BT, Welch KB, Galecki AT. *Linear mixed models: a practical guide using statistical software.* Chapman and Hall/CRC; 2014.
28. Rosnow RL, Rosenthal R, Rubin DB. Contrasts and correlations in effect-size estimation. *Psych Sci.* 2000;11(6):446-453.
29. Hopkins WG. A scale of magnitudes for effect statistics. *A New View of Statistics.* 2002;502:411.

30. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sport Exerc.* 2009;41(1):3-13.
31. Waldron M, Highton J, Daniels M, Twist C. Preliminary evidence of transient fatigue and pacing during interchanges in rugby league. *Int J Sports Physiol Perf.* 2013;8(2):157-164.
32. Mashiko T, Umeda T, Nakaji S, Sugawara K. Position related analysis of the appearance of and relationship between post-match physical and mental fatigue in university rugby football players. *Brit J Sports Med.* 2004;38(5):617-621.
33. Kempton T, Sirotic AC, Coutts AJ. A comparison of physical and technical performance profiles between successful and less-successful professional rugby league teams. *Int J Sports Physiol Perf.* 2017;12(4):520-526.
34. Kempton T, Sirotic AC, Cameron M, Coutts AJ. Match-related fatigue reduces physical and technical performance during elite rugby league match-play: a case study. *J Sports Sci.* 2013;31(16):1770-1780.
35. Smith MR, Coutts AJ, Merlini M, Deprez D, Lenoir M, Marcora SM. Mental fatigue impairs soccer-specific physical and technical performance. *Med Sci Sports Exerc.* 2016;48(2):267-276.
36. Greig M, Marchant D, Lovell R, Clough P, McNaughton L. A continuous mental task decreases the physiological response to soccer-specific intermittent exercise. *Brit J Sports Med.* 2007;41(12):908-913.
37. Twist C, Waldron M, Highton J, Burt D, Daniels M. Neuromuscular, biochemical and perceptual post-match fatigue in professional rugby league forwards and backs. *J Sports Sci.* 2012;30(4):359-367.
38. Johnston RD, Gabbett TJ, Seibold AJ, Jenkins DG. Influence of physical contact on neuromuscular fatigue and markers of muscle damage following small-sided games. *J Sci Med Sport.* 2014;17(5):535-540.
39. Mullen T, Highton J, Twist C. The internal and external responses to a forward-specific rugby league simulation protocol performed with and without physical contact. *Int J Sports Physiol Perf.* 2015;10(6):746-753.
40. Norris JP, Highton J, Hughes SF, Twist C. The effects of physical contact type on the internal and external demands during a rugby league match simulation protocol. *J Sports Sci.* 2016;34(19):1859-1866.

Table legends

Table 1. Technical performance analysis, contextual and movement demand covariates included in the models.

Table 2. Descriptive technical performance analysis, time played, number of interchanges and movement demand match data for each positional group and match average (Mean ± SD).

Figure legends

Figure 1. NASA- Task Load Index rating and weighted rating of the six subscales. Mean (black line) with individual plots (grey circles).

Figure 2. Standardised effects (effect size correlation; η^2, ± 90% confidence intervals) of individual, contextual, internal and external load measures on the six subscales of the NASA-TLX (weighted rating). **=possibly*, ***=likely*, ****=very likely*, *****=most likely*. MD= mental demand, PD= physical demand, TD= temporal demand, P= performance, E= effort, F= frustration. HMP= high metabolic power (s). HUF= hit-up forwards. OB= outside backs.

Figure 3. Standardised effects (effect size correlation; η^2, ± 90% confidence intervals) of individual, contextual, internal and external load measures on; A=total task load (NASA-TLX), B=session RPE. **=possibly*, ***=likely*, ****=very likely*, *****=most likely*.

Table 1. Technical performance analysis, contextual and movement demand covariates included in the final models.

Level of data	Variable	Data	Classification
Level 2 *(random factor)*	Player		
Level 1			
(*dependant variables*)	*NASA – Subjective Task Load Index*		
	Total	Continuous	
	Mental Demand	Continuous	
	Physical Demand	Continuous	
	Temporal Demand	Continuous	
	Performance	Continuous	
	Effort	Continuous	
	Frustration	Continuous	
	*s*RPE	Continuous	
Covariates (*fixed factors*)	Tackles	Continuous	Number
	Carries	Continuous	Number
	Errors	Continuous	Number
	Position	Dummy	OB [0], A [1], HUF [2]
	Opposition quality	Dummy	High [0], low [1]
	Season phase	Dummy	Early [0], mid [1], late [2]
	Match location	Dummy	Home [0], away [1]
	Match Outcome	Dummy	Win [0], loss [1]
	*s*RPE	Continuous	AU
	Total time	Continuous	Time (min)
	Interchanges	Continuous	Number
	Distance per min	Continuous	$m \cdot min^{-1}$
	Accelerations	Continuous	Number
	Decelerations	Continuous	Number
	Sprints	Continuous	Number
	Sprint distance	Continuous	Distance (m)
	High metabolic power	Continuous	Time (s)

sRPE = session rating of perceived exertion; OB= outside backs; A = adjustables; HUF = hit-up forwards.

Table 2. Descriptive technical performance analysis, time played, number of interchanges and movement demand match data for each positional group and match average (Mean ± SD).

	Adjustables (*n* = 127)	Outside backs (*n* = 130)	Hit-up forwards (*n* = 184)	Match (*n* = 441)
Technical demands				
Passes (*n*)	40 ± 37	5 ± 5	3 ± 4	14 ± 26
Tackles (*n*)	26 ± 14	9 ± 7	25 ± 8	21 ± 13
Carries (*n*)	7 ± 4	13 ± 4	12 ± 5	11 ± 5
Errors (*n*)	1 ± 1	1 ± 1	1 ± 1	1 ± 1
Penalties (*n*)	1 ± 1	0 ± 1	1 ± 1	1 ± 1
Movement demands				
Time played (min)	73 ± 24	91 ± 8	54 ± 19	70 ± 24
Interchanges (*n*)	1 ± 1	0 ± 0	2 ± 1	1 ± 1
Distance (m)	6735 ± 2214	7792 ± 919	4707 ± 1597	6184 ± 2116
Distance ($m \cdot min^{-1}$)	91 ± 5	85 ± 6	86 ± 5	87 ± 6
Accelerations (*n*)	520 ± 185	551 ± 71	362 ± 117	462 ± 156
Decelerations (*n*)	503 ± 179	513 ± 70	349 ± 109	441 ± 147
Sprints (*n*)	13 ± 6	25 ± 6	11 ± 7	16 ± 9
Sprint distance (m)	238 ± 117	482 ± 135	195 ± 132	291 ± 178
High metabolic power (s)	480 ± 180	480 ± 60	300 ± 120	420 ± 120

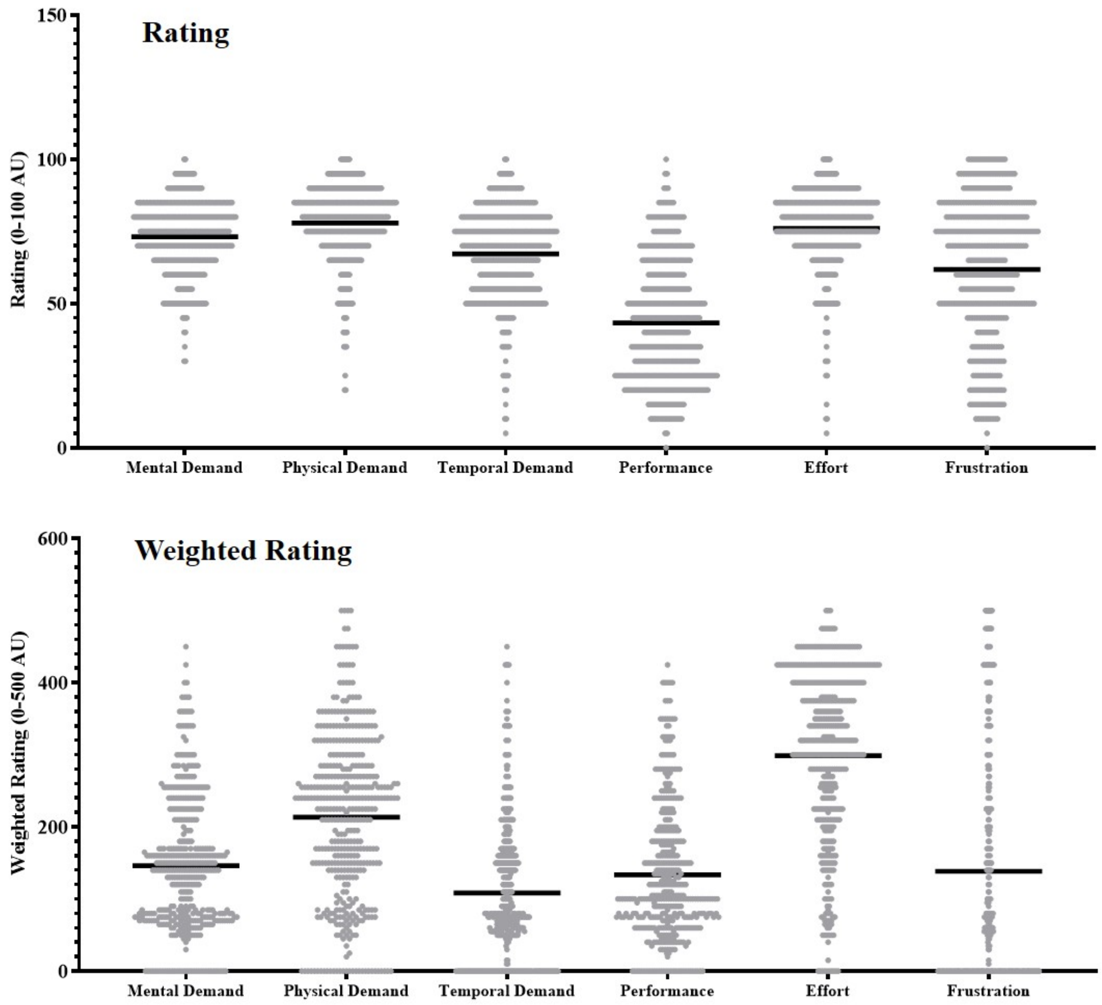
Rating
150
100
50
0
Rating (0-100 AU)
Mental Demand
Physical Demand
Temporal Demand
Performance
Effort
Frustration
Weighted Rating
600
400
200
0
Weighted Rating (0-500 AU)
Mental Demand
Physical Demand
Temporal Demand
Performance
Effort
Frustration

Figure 1.

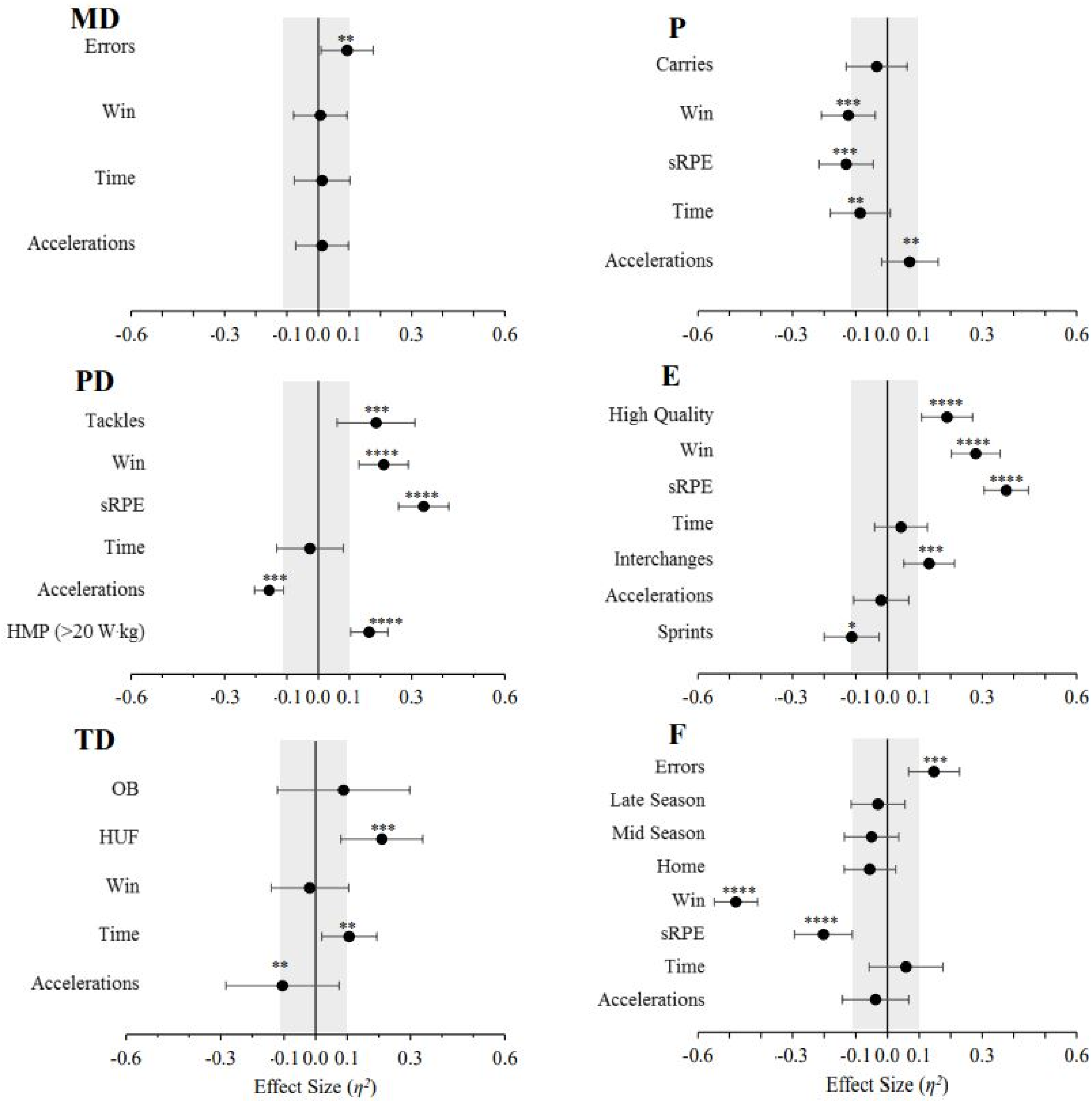
MD
Errors
Win
Time
Accelerations
P
Carries
Win
sRPE
Time
Accelerations
PD
Tackles
Win
sRPE
Time
Accelerations
HMP (>20 W·kg)
E
High Quality
Win
sRPE
Time
Interchanges
Accelerations
Sprints
TD
OB
HUF
Win
Time
Accelerations
F
Errors
Late Season
Mid Season
Home
Win
sRPE
Time
Accelerations
-0.6 -0.3 -0.1 0.0 0.1 0.3 0.6
Effect Size (η^2)

Figure 2.

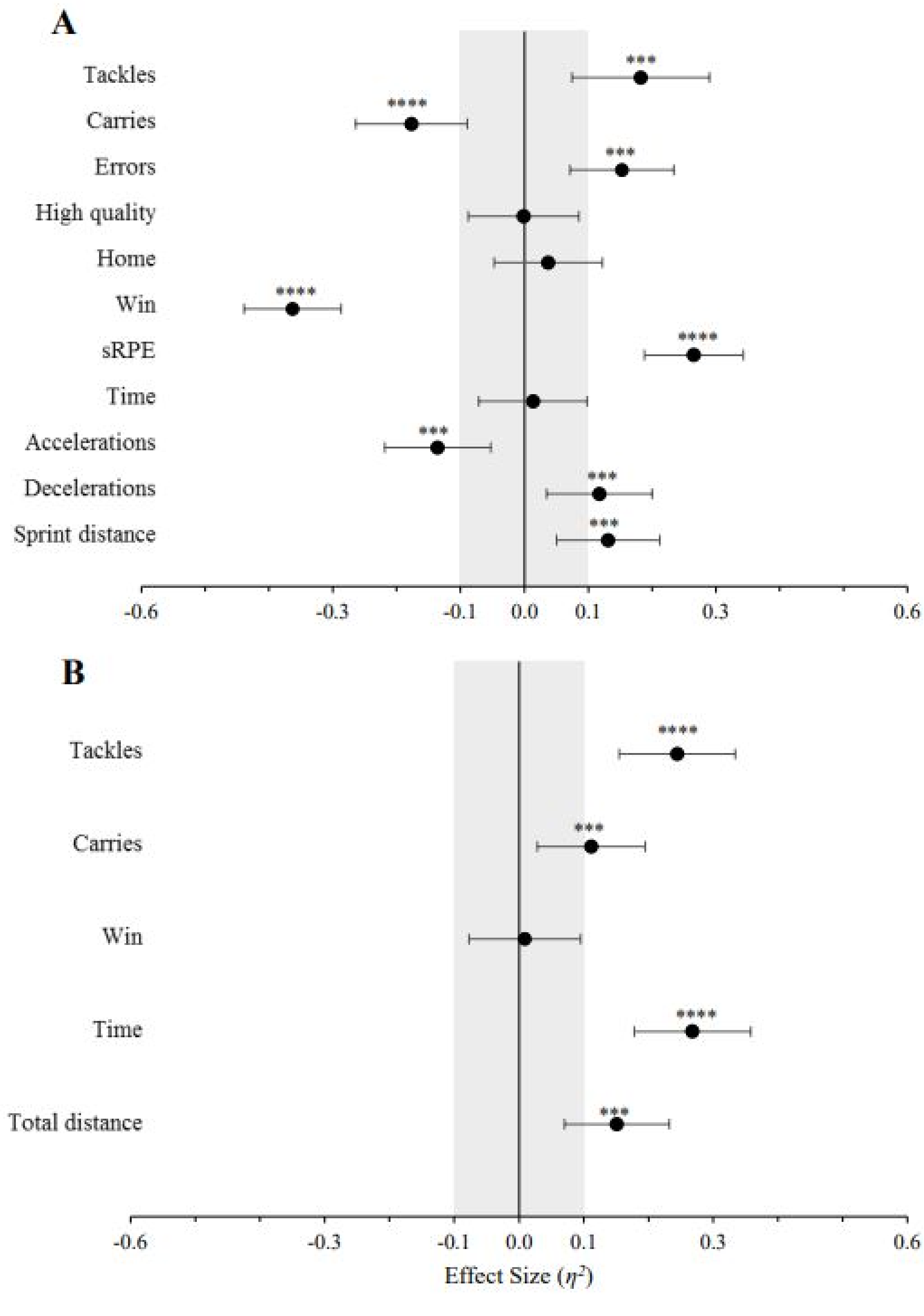
A
Tackles
***
Carries
****
Errors
***
High quality
Home
Win
****
sRPE
****
Time
Accelerations
***
Decelerations
***
Sprint distance
***
-0.6
-0.3
-0.1
0.0
0.1
0.3
0.6
B
Tackles
****
Carries
***
Win
Time
****
Total distance
***
-0.6
-0.3
-0.1
0.0
0.1
0.3
0.6
Effect Size (η^2)

Figure 3.