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SPORTS PERFORMANCE

Mental fatigue and technical performance in elite rugby league

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ABSTRACT

The aims of this study were to determine the impact of elite rugby league competition on mental fatigue; and to investigate how mental fatigue influenced in-match technical performance. Twenty elite male rugby league players recorded their pre- and post-game subjective mental fatigue and had their technical performance analysed during matches across one competition season. Metrics were created to assess in-match technical performance and described the percentage of positive, neutral, and negative involvements for each player, while accounting for the context and difficulty of each involvement. Self-reported mental fatigue increased from pre-game to post-game (maximum a posteriori estimation [MAP] = 33.1, 95% high-density interval [HDI] = 26.9–39.8), with backs reporting higher changes in mental fatigue than forwards (MAP = 18.0, 95% HDI = 9.7–26.9). Larger increases in mental fatigue from pre-game to post-game were negatively associated with the adjusted percentage of positive involvements metric (MAP = −2.1, 95% HDI = −5.6 to 1.1). Elite rugby league players reported increased mental fatigue following competitive games, with backs reporting a greater increase than forwards. Mental fatigue impacted technical performance, whereby participants had a lower percentage of positive involvements when they reported being more mentally fatigued.

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Team sports; performance analysis; cognitive fatigue; mental exertion; football

Introduction

Rugby league is a physically demanding, full-contact team sport that involves a mix of repeated bouts of high-intensity (e.g., sprinting, physical collisions, tackling), and low-intensity activity (e.g., standing, walking), as well as the execution of a variety of technical skills (Johnston & Morrison, 2016; Kempton et al., 2013). Throughout an 80-minute game of rugby league, players must stay alert and continuously make tactical attacking and defensive decisions to advance up the field to score tries, or defend their own try-line (Johnston & Morrison, 2016). These tactical decisions and the subsequent execution of these movements often occur under intense time pressure, physical fatigue, and in high "risk" or high "reward" situations (e.g., conceding or scoring a try) (Johnston & Morrison, 2016; Twist & Highton, 2013). Furthermore, the unpredictable nature of opposition and competition are likely to increase the mental demand of the game, with reports of stochastic simulated rugby league protocols as being more mentally demanding than traditional simulations, which tend to be cyclic and repetitive in nature (Mullen, Twist, & Highton, 2021). Match-related fatigue in rugby league has been described to manifest as sensations of tiredness and related decreased muscle performance and function (Twist & Highton, 2013). While this match-related fatigue is associated with the reduction of optimal technical skill execution in rugby league (Kempton et al., 2013) the specific influence of mental fatigue has not yet been explored in the sport.

Mental fatigue is a psychobiological state characterised by feelings of "tiredness" and a "lack of energy", and is caused by periods of prolonged, demanding cognitive activity (Boksem & Tops, 2008; Marcora et al., 2009). Indicators of mental fatigue manifest subjectively (e.g., feelings of tiredness, decreased motivation and alertness), behaviourally (e.g., decreased reaction time or accuracy on cognitive tasks), and/or physiologically (e.g., changes in brain activity) (Boksem & Tops, 2008; Mullen, Twist, & Highton, 2021). Mental fatigue has been shown to impair decision-making, and technical skill execution across team invasion sports such as soccer and basketball (Gantois et al., 2019; Moreira et al., 2018; Smith et al., 2016, 2017). For example, passing accuracy in both soccer and basketball have been found to decrease following mentally fatiguing protocols (Moreira et al., 2018; Smith et al., 2016). While the skill requirements of these sports differ to those in rugby league, there are similarities in terms of their competition demands (such as the high-intensity, intermittent nature) and the requirement of players to continually attend to their surroundings and teammates (Johnston & Morrison, 2016; Moreira et al., 2018; Smith et al., 2016).

Mental fatigue research in sport has used cognitive tests such as the Stroop task e.g (Martin et al., 2019; Smith et al., 2016), or the AX-continuous performance test e.g (Marcora et al., 2009), to induce mental fatigue. However, such cognitive tests do not resemble the demands of sporting

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competition (Russell et al., 2020; Smith et al., 2017) and therefore, the need to use more ecologically valid procedures to induce mental fatigue is an area to be addressed in research (Filipas et al., 2021; Magdaleno, 2020; Russell et al., 2019). For example, it has been shown that viewing game footage may induce mental fatigue (Filipas et al., 2021; Magdaleno, 2020) a task more relevant for athletes as they are likely to be involved in video sessions with coaching staff prior to competition (Filipas et al., 2021). Magdaleno (2020) found that subjective levels of mental fatigue measured after watching soccer game footage were the same as those reported after completing the Stroop test (Magdaleno, 2020). In addition, Filipas et al. (2021) showed that mental fatigue was induced by watching a 30-minute basketball tactical video and despite its small effect, was enough to impair subsequent free throw accuracy (Filipas et al., 2021). These results suggest that match-related activities have the potential to induce mental fatigue.

While laboratory-based studies have provided evidence that mental fatigue impairs physical and technical skills, research on the presence and influence of mental fatigue during sporting competition is lacking (Fortes et al., 2020; Russell et al., 2020; Smith et al., 2017). Research in rugby league has shown that elite players experience fatigue-related decreases in technical skill performance throughout a competition game, with Kempton et al. (2013) showing that ball players had lower quality skill performance in the final stages of gametime (Kempton et al., 2013). However, their results investigated fatigue more broadly rather than focusing on physical and/or mental fatigue specifically (Kempton et al., 2013). Russell and colleagues (2020) emphasised the distinction between mental and physical fatigue as two related, but separate constructs, and provided evidence that mental fatigue was present in competition (Russell et al., 2020). Investigating elite developmental athletes, they found that mental fatigue was increased following a 60-minute netball game when compared to pre-game mental fatigue, providing evidence that the demands of elite sporting competition may induce mental fatigue (Russell et al., 2020). The focus of this study, however, was on developmental athletes, and though they were elite, it has been suggested that experience at a professional level may play a role in mitigating the effect of mental fatigue on performance (Russell et al., 2019). At an elite level, Mullen and colleagues (2021) successfully used the NASA-TLX questionnaire to explore the subjective task load of rugby players, including the mental demand of the game (Mullen, Twist, Daniels, et al., 2021). They found that there were small increases in subjective mental and physical demand when players made more errors and more defensive tackles (respectively) (Mullen, Twist, Daniels, et al., 2021). Understanding how the demands of competition influence mental fatigue and athlete performance is important in monitoring, and consequently mitigating, the effects of mental fatigue on an athlete's performance in competition (Russell et al., 2019, 2020).

The aims for this study were twofold: firstly, to determine the impact of elite rugby league competition on mental fatigue, and secondly, to investigate how mental fatigue influences in-game technical skill performance. It was hypothesised that post-game mental fatigue would be higher than pre-game mental fatigue; and that there would be a negative relationship between mental fatigue and technical performance, such that increased mental fatigue would be associated with poorer technical skill performance.

Materials and methods

Twenty elite male rugby league players (25.7 ± 4.1 years old; 5.1 ± 4.1 years' experience playing at the highest level of a domestic professional competition; $n = 10$ backs, $n = 10$ forwards) provided informed consent to participate in this longitudinal, observational study. Ethical approval was granted by the Human Research Ethics Committee at the University of Canberra (project number 3351). Participants were recruited from a single team competing in the highest level of rugby league competition in Australia, as determined by convenience sampling (Russell et al., 2020).

Participants completed mental fatigue pre-game and post-game surveys across nineteen competition matches. The surveys included a visual analogue scale (VAS); a validated tool that has been used previously to measure subjective mental fatigue on a scale of 0–100 (Martin et al., 2019; Russell et al., 2020; Smith et al., 2016, 2017) and has been described elsewhere e.g (Johnston & Morrison, 2016; Kempton et al., 2013). In addition to the VAS, the pre-game survey also asked the participants to report whether they had ingested caffeine in the last two hours. The beneficial impact of caffeine on physical performance when mentally fatigued has been reported previously (Azevedo et al., 2016). The post-game survey included the same VAS as the pre-game survey (with adjusted "post-game" wording), and the NASA Task Load Index (NASA-TLX (Martin et al., 2019), which consisted of subscales regarding mental demand, physical demand, temporal demand, perceived performance, perceived effort, and frustration (measured as non-weighted values using a 0–100 VAS). The NASA-TLX has been successfully implemented in rugby league previously (Fortes et al., 2020) and was used to contextualise and quantify the subjective workload of the game. All surveys were created in Qualtrics (https://www.qualtrics.com), sent to participants via SMS messaging, and were answered by participants on their own devices. The participants were instructed to complete the pre-game survey two hours before the game started, and the post-game survey one hour after the game ended. The actual completed times were 2 h ±29 mins before the game started, and 1 h ±2 h 39 mins after the game ended. The times that the players were instructed to complete the questionnaires were chosen following discussions with the team support staff about pre- and post-game logistics. Previous research suggests this time frame is appropriate, with little difference in perceptual measures taken between 30 min and 24 hours post-session (Scantlebury et al., 2018).

Video footage from television broadcasts of fourteen games were accessed and data related to individual player involvements ($n = 18{,}623$ total involvements) were captured using a custom notational analysis system in Microsoft Excel. Variables captured were related to the match context, action type and context, and specific action outcome. Specific action outcomes

Table 1. Performance analysis variables used to create the player performance metrics.

Variable	Definition (levels/units of measurement)
Game location	The venue where the game was played (Home, Away, Neutral).
Temperature	Average temperature at the game location (°C).
Wind	Wind speed at the game location (km/h).
Rain	Presence of rain at the game location (Yes, No).
Dew	Presence of dew at the game location (Yes, No).
Kick-off time	Time the game started (Afternoon: before 17:30, Night: from 17:30).
Points difference	Score of reference team minus the score of the opposition team at the time of the player involvement.
Player position	The position the player is currently playing at time of involvement (Backs: fullback, winger, centre, five-eighth, halfback, Forwards: prop, hooker, 2nd row, lock).
Interchange status	Whether the player played the full game or is an interchange player (Full game, Interchange).
Cumulative time on field	The cumulative time the player has been on the field at the time of the involvement (Minutes).
Action	The type of action. See Table 2.
Action descriptors	Describes the context of the action. See Table 3.
Action outcome	Describes the outcome of the action. These were captured as specific outcomes initially, before being grouped into general outcomes for modelling. See Table 4.

Table 2. Action types and their operational definitions.

Variable	Operational Definition
Kick off	A place kick (i.e., after being placed on the ground) from the centre of the halfway line on the field, completed at the beginning of the game and after points have been scored; the team against which the points have been scored kick off
Catch from kick	Following a kick from the opposition or their teammate, player attempts to make contact with the ball to take possession
Ball carry	Player travels more than two steps in any direction while in possession of the ball
Tackle	Player engages in physical contact with opponent carrying the ball to prevent, hold up, or stop the opposition advancing the ball towards the defender's goal line
Play the ball	Player brings the ball into play after a tackle; player transfers possession to a teammate by rolling the ball under their feet
Dummy half pick up	Player acting as dummy half retrieves ball from teammate who has played the ball.
Pass	Player attempts to transfer possession of the ball to a teammate by throwing the ball
Offload	Player attempts to pass or "offload" the ball to a teammate whilst being tackled
Receive from pass	Following a pass or offload, player makes contact with the ball in order to take possession
Collect	Following a scramble play or contest for possession, player makes contact with the ball to take possession.
Kick	Player deliberately strikes the ball with their foot to create an attacking advantage or gain a territorial advantage.
Conversion attempt	Player attempts to kick the ball between the opponents' goal posts and over the cross bar on the full after a try is scored to potentially gain an additional two points
Penalty goal	Player attempts to kick the ball between the opponents' goal posts and over the cross bar on the full when a penalty has been awarded to potentially gain two points
Kick for touch	Player attempts to kick the ball back into touch on the full after being awarded a penalty kick to gain ground
Field goal	Player attempts to drop kick the ball between the opponents' goal posts and over the crossbar on the full to score a goal
Goal line drop out	Player attempts to drop kick the ball from the centre of the goal line or from the centre of the 20-metres line to bring the ball back into play
Intercept	Player makes contact with the ball to take possession from a pass between the opposition
Try attempt	Player attempts to score a try by placing the ball down in the opposition's in-goal area

were also grouped based on whether they were positive, negative, or neutral outcomes. The variables and operational definitions were based on performance indicators used previously in the rugby league literature (Kempton et al., 2013; National Rugby League; Woods et al., 2018) and have been provided in Tables 1–4.

Data were analysed using R (version 4.2.2) in RStudio (version 2023.03.0 + 386, Posit Software, PBC, https://posit.co). With reference to the primary aim, a Bayesian linear mixed model with a random intercept for each participant was used to compare pre- and post-game mental fatigue. The interaction between timepoint (pre-game, post-game) and player position (forward, back) was tested, and caffeine (no, yes) was included as a covariate. Mildly informative priors were specified, and were informed from similar research conducted in netball (Russell et al., 2020).

To address the secondary aim, performance metrics were created that expressed the percentage of a player's positive, negative, and neutral involvements out of their total expected positive, negative, and neutral involvements (respectively) in a match, which accounted for the context and difficulty of the involvement. To create these metrics, an eXtreme Gradient Boosting (XGB) model was used to determine the probability that a given involvement resulted in a positive, negative, or

Table 3. Action descriptor variables and their operational definitions.

Action variable	Category	Descriptor	Definition
Catch from kick	Type of kick	Low	Ball is kicked below average player height and may bounce along the ground
		Moderate	Ball is kicked above average player height but lower than goal post height
		High	Ball is kicked higher than goal post height (i.e., 16 metres)
	Opposition pressure	No pressure	Opposition is more than 2 metres away from player catching the ball
		Moderate pressure	Opposition is 1–2 metres away from player catching the ball
		High pressure	Opposition is within 1 metres of the player catching the ball
Ball carry	Type of carry	Into or past defensive line	Player carries ball and maintains possession up to or beyond opposition defensive line
		Passed before defensive line	Player transfers possession by passing the ball to a teammate before they reach the opposition defensive line
		Kicked before defensive line	Player transfers possession by kicking the ball before they reach the opposition defensive line
Tackle	Tackler order	Primary	First player to make contact with ball carrier (can be more than one player)
		Secondary	Second player to make contact with ball carrier (can be more than one player)
		Tertiary	Third player to make contact with ball carrier (can be more than one player)
	Location of contact	Above shoulders	Player makes contact with ball carrier above the shoulders, around the neck or head
		Shoulder to hip	Player makes contact with ball carrier between ball carrier's shoulder and hip
		Hip to knee	Player makes contact with ball carrier between ball carrier's hip and knee
		Below knee	Player makes contact with ball carrier below ball carrier's knee
Pass	Pass type	From play the ball	Possession is transferred by passing the ball from one player to another after a play the ball
		From scrum	Possession is transferred by passing the ball from one player to another after a scrum play
		From open play	Possession is transferred by passing the ball from one player to another in open play (e.g., while players are on the run)
		From a restart	Possession is transferred by passing the ball from one player to another after a restart
Offload	Opportunity to offload	Clear opportunity to offload	Player has the ball carrying arm free, teammates are within 2 metres of offloading player and are in a position to receive the ball; opposition players are not within 1 metre of the offloading player and are not in a position to intercept the offload
		No clear opportunity to offload	Player is wrapped up by opposition tackling players, teammates are more than 2 metres away from offloading player and are not in a position to receive the ball; opposition players are within 1 metre of the offloading player and are in a position to intercept the offload
Receive from pass	Level of difficulty	Pass on target	Pass is made in an area easy for receiver to catch; pass is within comfortable reach for receiver to catch – e.g., towards receiver's torso
		Pass off target	Pass is made in an area that is difficult for receiver to catch and/or requires the receiver to change their line of motion – e.g., above head, forward of player, behind receiving player, at player's legs
		Forward pass	Illegal pass is made to an area in front of front of the passer
		From offload	Possession is transferred to the receiving player
Collect	Type of play	From opposition play	Player makes contact with the ball to take possession following an unstructured or scramble play from the opposition where there is a contest for possession (For example, an opposition player offloads the ball whilst being tackled, but their teammate is unable to collect; the ball becomes loose on the field and the reference team gain possession)
		From team play	Player makes contact with the ball to take possession following an unstructured or scramble play from their teammates where there is a contest for possession (For example, a reference team player offloads the ball whilst being tackled, but their teammate is unable to collect; the ball becomes loose on the field but the reference team regains possession)
Kick	Opposition pressure	No pressure	Opposition is more than 2 metres away from player kicking the ball
		Moderate pressure	Opposition is 1–2 metres away from player kicking the ball
		High pressure	Opposition is within 1 metres of the player kicking the ball
	Secondary: Type of kick	Low	Ball is kicked below average player height and may bounce along the ground
		Moderate	Ball is kicked above average player height but lower than goal post height
		High	Ball is kicked higher than goal post height (i.e., 16 metres)
Conversion attempt	Location of conversion attempt	In front of posts	Kick taken directly in front of the goal posts
		Left of posts	Kick is taken in an area from the left goal post to 10 metres out from left sideline
		Right of posts	Kick is taken in an area from the right goal post to 10 metres out from right sideline
		From left sideline	Kick is taken in an area from 10 metres out from left sideline to left sideline
		From right sideline	Kick is taken in an area from 10 metres out from right sideline to right sideline
Penalty goal	Location of penalty goal attempt	In front of posts	Kick taken directly in front of the goal posts
		Left of posts	Kick is taken in an area from the left goal post to 10 metres out from left sideline
		Right of posts	Kick is taken in an area from the right goal post to 10 metres out from right sideline
		From left sideline	Kick is taken in an area from 10 metres out from left sideline to left sideline
		From right sideline	Kick is taken in an area from 10 metres out from right sideline to right sideline

(*Continued*)

Table 3. (Continued).

Action variable	Category	Descriptor	Definition
Field goal attempt	Type of field goal	1-point attempt	Kick is taken from any position in the field of play
		2-point attempt	Kick is taken from 40 metres or more away from the opponents' try line
	Opposition pressure	No pressure	Opposition is more than 2 metres away from player kicking the ball
		Moderate pressure	Opposition is 1–2 metres away from player kicking the ball
		High pressure	Opposition is within 1 metres of the player kicking the ball
Intercept	Type of intercept	From pass	Player takes possession from opposition during a pass
		From offload	Player takes possession from opposition while opposition attempts to offload the ball

neutral outcome, based on a range of features that provided context to the involvement. These features included environmental conditions (e.g., temperature, rain, wind, dew), player details (e.g., playing position, cumulative time on the field, interchange status), action type (e.g., kick, catch, pass, play the ball), and action descriptors describing the specific context of the action (e.g., height of a kick, whether there was opposition pressure on the catcher) (Tables 1–4). The model was trained on a random sample of 70% (n = 13,037 involvements) of the full performance dataset, and the accuracy of the model was tested on the remaining 30% (n = 5,586). The log-loss score for the model was 0.323 (lower is better) compared to a baseline log-loss score of 0.927, while the overall classification accuracy was 0.85 (sensitivity = 0.78, specificity = 0.91 with reference to the positive outcome).

Next, the model was applied to the match performance dataset to determine the probability of positive, negative, and neutral outcomes for each individual involvement, based on the contextual features. These probabilities were then summed for each player in each match to calculate the expected total number of positive and negative involvements. For example, if a player had 3 involvements in a match and the probabilities that each would result in a positive outcome were 0.30, 0.20, and 0.20, the expected number of positive involvements for that player in a match would be 0.30 + 0.20 + 0.20 = 0.70. The same process was applied to calculate the expected number of negative involvements. The process of summing the probabilities of each event to calculate the expected number of events is derived from the concept of the "expected value" in probability theory, and is commonly used in performance metrics such as xG (expected goals in soccer) (Whitmore, 2021).

Adjusted performance metrics were then created by calculating the percentage of observed positive involvements out of expected positive involvements, and the percentage of negative positive involvements out of expected negative involvements. This was done to create an adjusted percentage that "rewarded" players that successfully executed more difficult actions (i.e., actions with a lower probability of resulting in a positive outcome). The same adjustment was applied to the percentage of observed negative involvements, to "penalise" players that unsuccessfully executed less difficult actions (i.e., actions with a lower probability of resulting in a negative outcome). The adjusted percentage of positive involvements and adjusted percentage of negative involvements were used as the measures of technical performance.

Next, a Bayesian linear mixed model with a random intercept for each participant was used to determine how self-reported mental fatigue influenced technical performance (adjusted percentage of positive and negative involvements). Change in mental fatigue from pre- to post-game (centred and scaled) was included as the primary independent variable, and pre-game mental fatigue (centred and scaled) and caffeine (no, yes) were included as covariates. An additional truncation term was included in each model to specify that the model expectation (for adjusted percentage of positive and negative involvements) could not be less than 0.

To contextualise the subjective workload of the games and compare this between positions, a Bayesian linear mixed model with a random intercept for each participant was used to model each NASA TLX subscale (mental demand, physical demand, temporal demand, frustration, perceived performance, perceived effort). For each model, player position (forward, back) was included as the main independent variable, and caffeine (no, yes) was included as a covariate. An additional truncation term was included in each NASA TLX model to specify the lower and upper bounds of the response. That is, the model expectation for each of the NASA TLX variables could not be less than 0 and more than 100.

The posterior distributions of the marginal effects from the Bayesian models are presented as the maximum a posteriori estimation (MAP), 95% high density intervals (HDI), probability of direction (PD), and proportion of the 95% HDI within a region of practical equivalence (ROPE) (Kruschke, 2018; Makowski et al., 2019) unless otherwise specified. The ROPEs were calculated as ±0.2 times the standard deviation of the response variable (equivalent to a small effect size (Cohen, 1988; Kruschke, 2018) when modelling the NASA TLX subscales and mental fatigue pre to post game. For the linear mixed models to determine the influence of mental fatigue on technical performance, the ROPE was defined as ±1.6% points, which represented 1 extra or 1 less positive or negative

Table 4. Action outcomes and their operational definitions.

Action variable	Specific Outcome	Definition	General Outcome
Kick off	In-play	Ball is kicked within the field of play and play resumes	Neutral
	Out on full	Ball is kicked outside of field of play	Negative
	Kicked to sideline with bounce	Ball is kicked within the field of play then bounces out over the sideline	Positive
Catch from kick	Caught	Ball is securely received by player	Positive
	Dropped behind	Ball is not caught and is fumbled so that it lands behind the player	Negative
	Dropped knock on	Ball is not caught and is fumbled so that it lands in front of the player	Negative
	Missed	Player does not make contact with the ball	Negative
	Received and tackled in goal	Player receives ball and is tackled in goal, resulting in a forced drop out for the reference team	Negative
	Received and not tackled in goal	Player receives ball and is not tackled in goal	Positive
Ball carry	Line break	Player runs through (i.e., "breaks") the opposition defensive line without being tackled or incurring physical contact or player crosses the try line and scores a try	Positive
	Loose carry	Player fumbles and loses possession of the ball while being tackled	Negative
	Stripped	Opposition player removes the ball from the ball carrying player's possession (can occur if there is only one opposition player in the tackle)	Negative
	Penalty for	Opposition infringement which results in a penalty for the reference team	Positive
	Penalty against	Reference team infringement which results a penalty for the opposition team	Negative
	Tackled and possession maintained	Player is tackled by opposition and maintains possession of the ball	Neutral
	Possession transferred	Player passes the ball to another player	Neutral
	Possession turned over	Reference team does not complete their tackle set or kicks the ball, resulting in the opposition gaining possession of the ball	Negative
Tackle	Missed	Player does not make contact with opposition; player does not make adequate contact to slow opposition's advance. Opposition is able to run through or break through the reference team's defensive line without being tackled or incurring impeding physical contact	Negative
	Made – grounded where contact was made	Player tackles ball carrier to the ground where contact is made	Positive
	Made – held where contact was made	Player wraps up ball carrier during a tackle and prevents them from moving or advancing forward after contact, or transferring possession of the ball	Positive
	Made – ball carrier driven back	Player successfully pushes ball carrier backwards after contact; opposition is forced to take more than two steps backwards	Positive
	Made – ball carrier drives forward	Player performs a tackle, but the ball carrier advances forward after contact; the ball carrier takes more than two steps forward with intent (i.e., ball carrier does not just fall forward)	Negative
	Penalty against	Tackling player makes an infringement during the tackle e.g., ball is illegally stripped during tackle, high tackle, other ruck infringement	Negative
	Penalty against – player sent to sin bin	Tacking player makes a dangerous tackle (e.g., high tackles with direct contact with head or neck deemed as forceful, dangerous throws, shoulder charges, crushing tackles) or professional foul resulting in them being sent to off the field for 10 minutes	Negative
	Penalty against – player sent off	Tackling player makes a dangerous tackle or professional foul resulting in them being sent off for the rest of the game	Negative
	Strip	Player removes the ball from the opposition player's possession; no penalty incurred	Positive
	Incomplete	Player is unable to tackle ball carrier to the ground or wrap them up and hold them; the ball carrier is able to make an offload or a pass	Negative
Play the ball	Possession maintained	Player successfully completes play the ball and dummy half securely receives ball	Neutral
	Penalty for	Opposition commits an infringement during the play the ball that results in a penalty for the reference team (e.g., opposition illegally interferes with the player's ability to complete play the ball; opposition is offside)	Positive
	Set restart	Opposition commits an infringement during the play the ball that results in a set restart for the reference team (e.g., ruck infringement)	Positive
	Incorrect play the ball (error)	Player loses control of the ball as they complete the play the ball action, resulting in a turnover	Negative
Dummy half pick up	Possession maintained	Player successfully retrieves the ball from their teammate and is in position to pass or carry	Neutral
	Possession lost	Player loses control of the ball as they retrieve it, resulting in a turnover	Negative
Pass	Pass on target	Pass is made in an area easy for receiver to catch; pass is within comfortable reach for receiver to catch – e.g., at receiver's torso	Neutral
	Pass off target	Pass is made in an area that is difficult for receiver to catch and/or requires the receiver to change their line of motion – e.g., above head, forward of player, behind receiving player, at player's legs	Negative
	Forward pass	Illegal pass is made to an area in front of front of the passer	Negative
	Intercepted	Opposition player makes contact with the ball and take possession while player is passing to a teammate	Negative
Offload	Possession maintained	Offload is successful and possession is transferred to teammate	Positive
	Possession lost	Offload is unsuccessful; ball does not make it to teammate	Negative

(*Continued*)

Table 4. (Continued).

Action variable	Specific Outcome	Definition	General Outcome
Receive from pass	Caught	Ball is securely received by the catching player	Neutral
	Dropped behind	Ball is not caught and is fumbled so that it lands behind the catching player; play is able to resume	Negative
	Dropped forward (knock on)	Ball is not caught and is fumbled so that it lands in front of the catching player, resulting in a knock on	Negative
Collect	Possession gained	Player picks up ball from play after the opposition loses possession	Positive
	Possession maintained	Player picks up ball from play after a teammate loses possession	Neutral
	Possession lost	Player is unable to pick up the ball, and the opposition gain possession of the ball	Negative
	Knock on	Player is unable to pick up ball; ball is fumbled so that it lands forward of the player	Negative
Kick	40/20	Player kicks ball from behind their 40-metre line and the ball finds touch inside the opposition's 20-metre zone; the resulting kick then takes place 20 m in from where the ball first crossed the touch line and no closer than 10 m to the goal line	Positive
	20/40	Player kicks ball from behind their 20-metre line and the ball finds touch inside the opposition's 40-metre zone; the resulting kick then takes place 20 m in from where the ball first crossed the touch line and no closer than 10 m to the goal line	Positive
	Try	Player kicks the ball to a teammate or into space where a teammate can gather the ball and score	Positive
	Possession maintained	Player kicks to their teammate; ball received by teammate and reference team maintains possession	Positive
	Penalty for	Opposition infringement which results in a penalty for the reference team	Positive
	Out on the full	Player kicks the ball outside of the field of play on the full	Negative
	Forced drop-out (dead ball)	Opposition defender knocks the ball out of play, resulting in a dropout where the ball is drop kicked from the centre of the goal line to bring the ball back into play	Positive
	Forced drop-out (tackled in goal)	The reference team tackles the kick receiver in goal, resulting in a dropout where the ball is drop kicked from the centre of the goal line to bring the ball back into play	Positive
	Caught in goal	Opposition player catches the ball on the full in goal, resulting in a 7-tackle set for the opposition restarting from the 20 m line	Negative
	Rolls over dead ball line	Ball rolls over the dead ball line without being touched, resulting in a 7-tackle set for the opposition, restarting from the 20 m line	Negative
	Possession lost	Ball is caught or gathered by the opposition, or the ball bounces over the sideline, resulting in a handover to the opposition	Neutral
Conversion attempt	Made	Goal is kicked (i.e., ball is kicked between the goal posts and above the cross bar), following the scoring of a try; kick attempt is successful	Positive
	Missed	Goal is not kicked (i.e., ball is not kicked between the goal posts or above the cross bar); kick attempt is unsuccessful	Negative
Penalty goal	Made	Goal is kicked (i.e., ball is kicked between the goal posts and above the cross bar), following the rewarding of a penalty goal to the reference team; kick attempt is successful	Positive
	Missed	Goal is not kicked (i.e., ball is not kicked between the goal posts or above the cross bar), following the rewarding of a penalty goal to the reference team; kick attempt is unsuccessful	Negative
Kick for touch	Out	Ball is kicked out of the field of play on the full	Positive
	Stayed in	Ball is kicked and stays inside the field of play on the full	Negative
Field goal attempt	Made	Goal is kicked (i.e., ball is kicked between the goal posts and above the cross bar) from any position in the field of play	Positive
	Missed	Goal is not kicked (i.e., ball is not kicked between the goal posts or above the cross bar) from any position in the field of play	Negative
Goal line drop out	Possession maintained	Ball is retrieved by a teammate and reference team maintain possession of the ball	Positive
	Possession lost	Reference team lose possession of the ball	Neutral
	Kicked out on full	Ball is kicked out of the field of play on the full	Negative
	Kicked to sideline with bounce	Ball is kicked within the field of play then bounces out	Positive
Intercept	Possession gained	Player intercepts a pass or play from the opposition and obtains ball	Positive
	Knock on	Player fumbles ball during an intercept attempt so that it lands forward of the player	Negative
Try Attempt	Try	Reference team score; try allowed	Positive
	No try	Reference team do not score; try disallowed	Negative

involvement for a player with a median number of involvements ($n = 62$). Bayesian modelling was conducted using the "*brms*" R package (Bürkner, 2017) and the performance metrics were created using the "*xgboost" (Chen et al., 2023) and "caret" (Kuhn, 2023) packages*.

Results

Descriptive statistics for mental fatigue and NASA TLX measures for forwards and backs (and related Bayesian inferential statistics for positional comparisons) are presented in Table 5. Mental, physical, and temporal demand were all higher (with at

Table 5. Positional comparison of mental fatigue and subjective workload between forwards and backs.

	Backs ($n = 10$)			Forwards ($n = 10$)				
VAS (0–100)	Mean	Between-player SD	Within-player SD	Mean	Between-player SD	Within-player SD	Probability of Direction	% in ROPE
Pre-game mental fatigue	21.0	23.4	7.1	8.1	7.6	4.5	0.59	19.1
Post-game mental fatigue	42.2	24.7	7.5	31.5	19	12.7	**98.5**	**3.1**
Mental demand	67.2	17.1	9.2	48.7	18.7	14.7	**0.97**	**8.9**
Physical demand	70.0	16.4	7	56.2	18.0	12.8	**0.94**	**13.3**
Temporal demand	62.1	12.5	9.5	53	12.1	9.8	**0.98**	**4.1**
Performance	45.1	18.4	16.7	48.2	20.3	12.6	0.80	37.9
Effort	74.0	16.9	6.9	68.1	18.1	12.3	0.87	24.3
Frustration	60.2	18.8	18.1	53.2	24.1	16.3	0.61	47.5

% in ROPE = percentage of the 95% high-density interval inside the region of practical equivalence. The Probability of Direction and % in ROPE are in reference to the posterior distribution of the marginal effect for playing position (forwards vs backs).

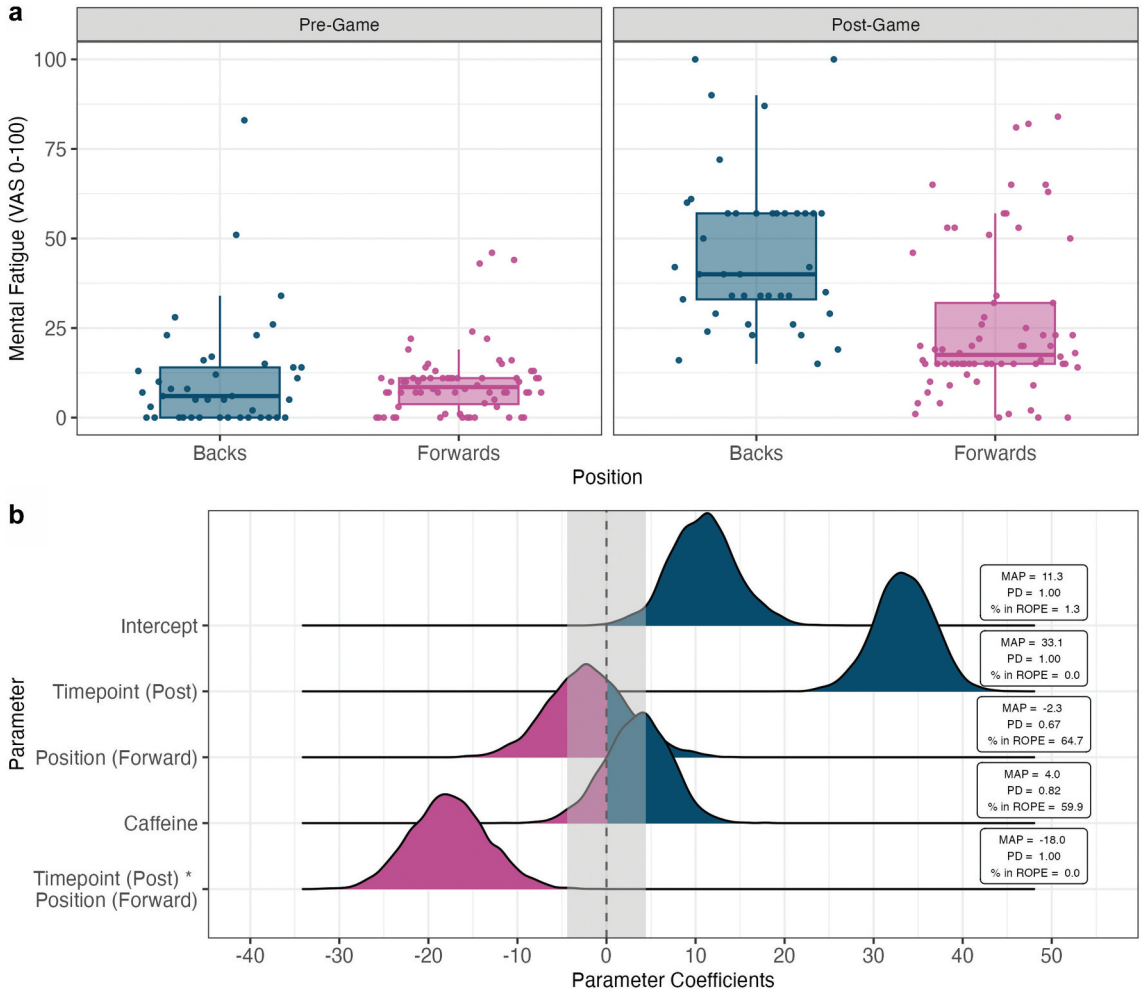

Figure 1. The change in self-reported mental fatigue from pre-game to post-game. Figure 1A presents descriptive statistics for backs and forwards for pre-game and post-game timepoints. Figure 1B shows the posterior distributions of the intercept and slope coefficients (as change in mental fatigue) of fixed effects for the Bayesian linear mixed model. The grey area represents the Region of Practical Equivalence (ROPE). MAP = maximum a posteriori estimation; PD = probability of direction; % in ROPE = proportion of the 95% high-density interval within the ROPE. Timepoint (Post) = marginal effects as post-game vs pre-game; Position (Forwards) = marginal effects of forwards vs backs; Caffeine = marginal effects of caffeine vs no caffeine; Timepoint (Post) * Position (Forward) = interaction effects as the difference in change from pre-game to post-game between forwards and backs.

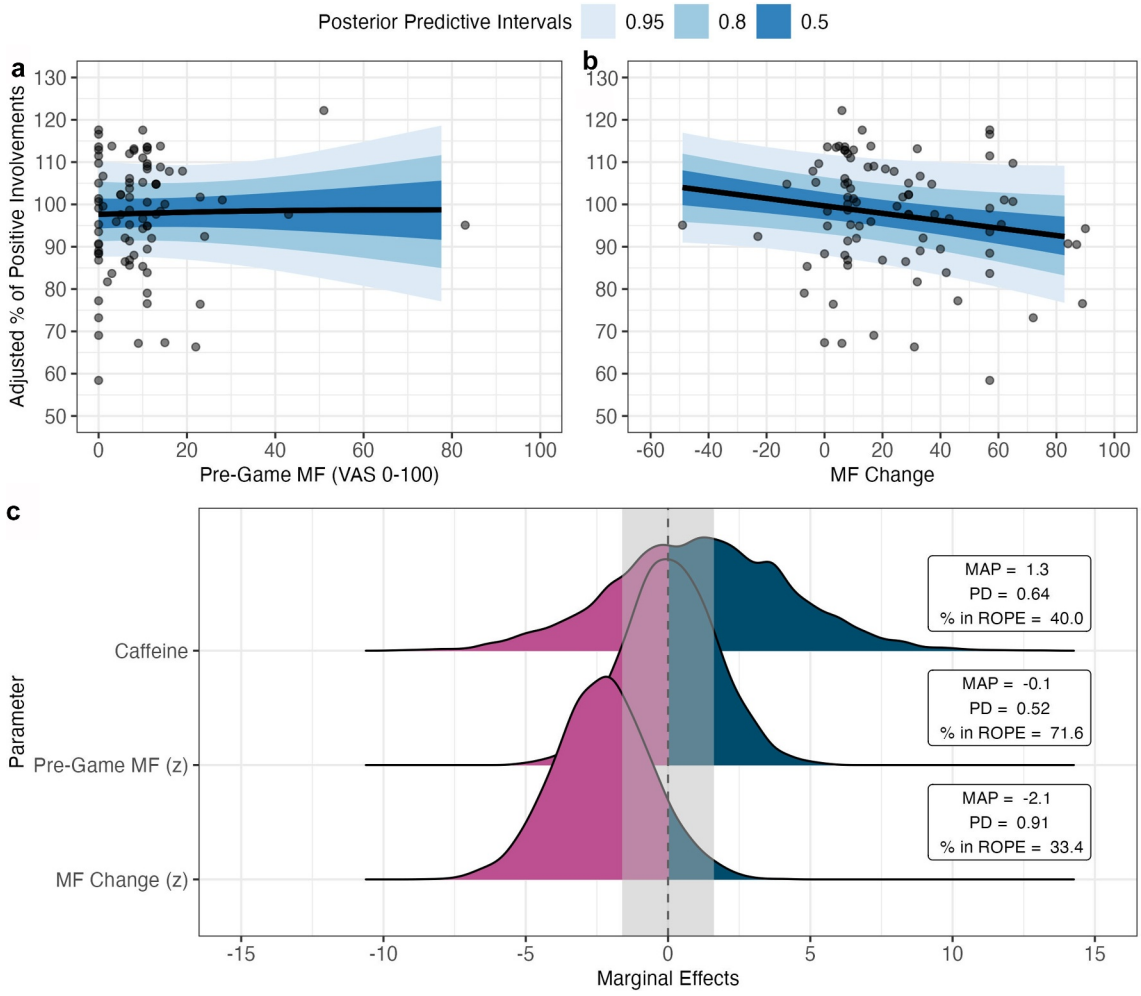

Figure 2. The influence of mental fatigue on adjusted percentage of positive involvements. Figure 2A and 2B show the influence of pre-game mental fatigue and change in mental from pre- to post-game, respectively. Figure 2C shows the posterior distributions for the average marginal effects of a 1 standardised change in each of the model covariates. The grey area represents the Region of Practical Equivalence (ROPE). MAP = maximum a posteriori estimation; PD = probability of direction; % in ROPE = proportion of the 95% high-density interval within the ROPE. MF = mental fatigue.

least 90% probability of direction) among backs than forwards. Caffeine was reported to have been ingested in 39.0% of completed pre-game surveys by backs (16 out of 41), and 57.4% of completed pre-game surveys by forwards (39 out of 68).

In reference to the primary aim, self-reported mental fatigue increased from pre-game to post-game (MAP = 33.1, 95% HDI = 26.9–39.8), with backs reporting higher changes in mental fatigue than forwards (MAP = 18.0, 95% HDI = 9.7–26.9) (Figure 1).

In reference to the second aim, the change in mental fatigue from pre-game to post-game was negatively associated with adjusted percentage of positive involvements. Specifically, an increase in the change in mental fatigue from pre-game to post-game by 1 standard deviation was associated with a decrease in positive involvements by 2.1% points (MAP = −2.1, 95% HDI = −5.6 to 1.1) (Figure 2). For a player with a median number of involvements in a match, this equated to approximately one and a half fewer positive actions. The probability that the standardised effect of mental fatigue change resulted in any decline in the adjusted percentage of positive involvements was 0.91. In addition, the probability that the standardised effect of mental fatigue change resulted in a decline in the adjusted percentage of positive involvements of at least a 1.6% points (at least one fewer positive actions) was 0.67. However, there was less evidence found to suggest an association between mental fatigue and adjusted percentage of negative involvements (Figure 3).

Discussion

In line with the hypothesis for the primary aim, players reported higher levels of mental fatigue post-game compared to pre-game. The results showed partial support for our hypothesis for the second aim, where there was a negative association between self-reported mental fatigue and technical performance, as measured by the adjusted percentage of positive involvements metric (but not when measuring technical performance as the adjusted percentage of negative involvements). A novel aspect of this study was that the measurement of player performance accounted for the context and difficulty of individual involvements, such that players were "rewarded" for successfully executing more difficult actions and were "penalised" for unsuccessfully executing less difficult actions.

In reference to the first aim, our results were similar to the increase and variation in post-game mental fatigue reported by

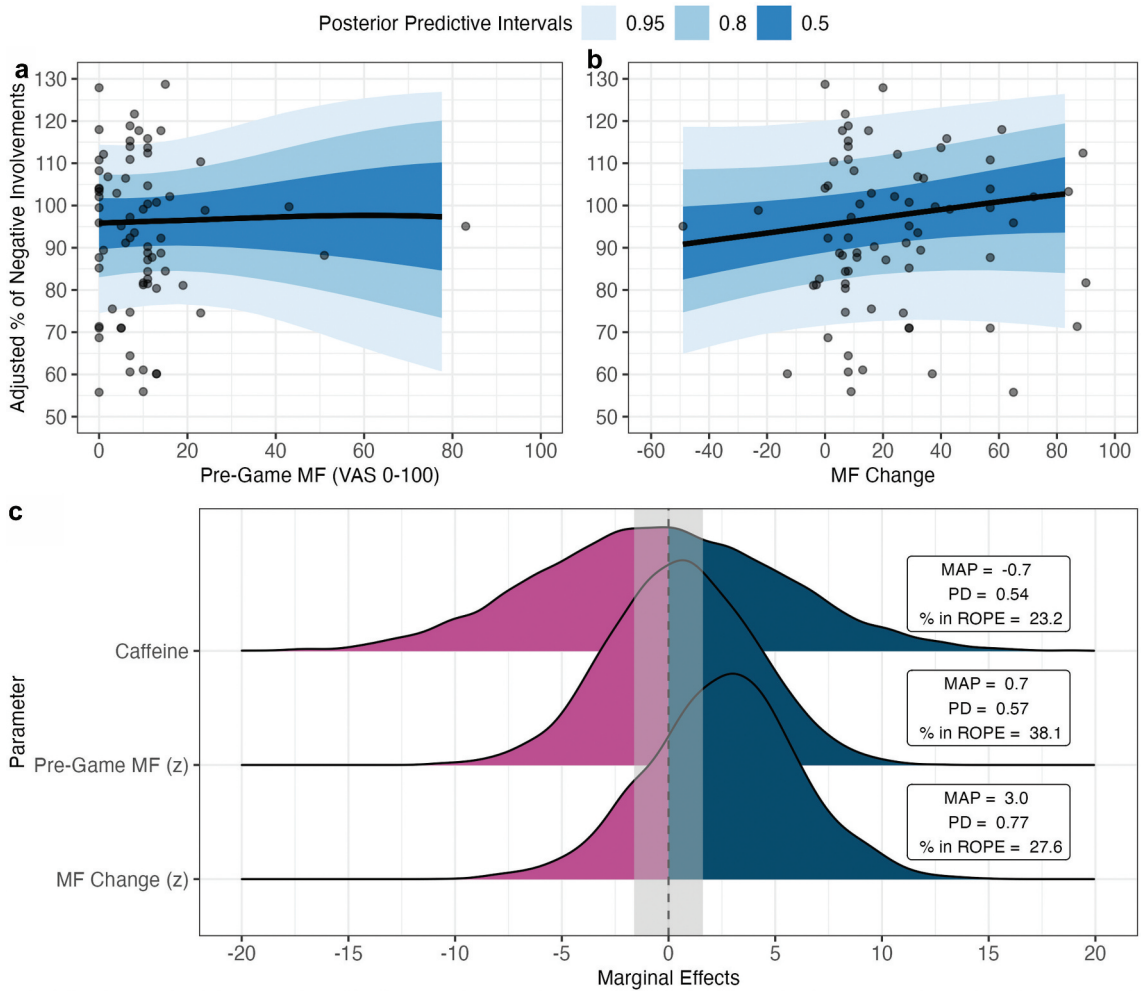

Figure 3. The influence of mental fatigue on adjusted percentage of negative involvements. Figure 3A and 3B show the influence of pre-game mental fatigue and change in mental from pre- to post-game, respectively. Figure 3C shows the posterior distributions for the average marginal effects of a 1 standardised change in each of the model covariates. The grey area represents the Region of Practical Equivalence (ROPE). MAP = maximum a posteriori estimation; PD = probability of direction; % in ROPE = proportion of the 95% high-density interval within the ROPE. MF = mental fatigue.

elite developmental netballers (Russell et al., 2020) and provide further evidence that the demands of sporting competition appear to induce mental fatigue in elite athletes. The results of this study extend the findings of Russell et al (Russell et al., 2020) and show that elite, non-developmental athletes also experience mental fatigue in competition. The variation in pre- and post-game mental fatigue highlights the variety with which individuals may be affected by and respond to mental fatigue. In our study, we found that backs experienced a greater increase in mental fatigue from pre- to post-game compared to forwards. A finding which can be explained by the greater mental, physical, and temporal demands experienced by these players. In rugby league, positional groups have different roles and requirements (Mashiko et al., 2004) with backs typically having "play-maker" and organisation roles (Kempton et al., 2013). Further, backs tend to remain on the field for the whole game, while forwards are routinely interchanged (Kempton et al., 2013). Substitution may allow forward players reprieve from being cognitively engaged with the game. However, Russell et al. have suggested that substitute players may experience additional mental demands on the sideline, such as feedback from coaching staff (Russell et al., 2020). Receiving this feedback may require emotional regulation, and thus could be mentally fatiguing (Russell et al., 2020).

With regards to our second aim, our results provided evidence that match-related mental fatigue impacted technical performance, aligning with the consensus among current research (Sun et al., 2021). Interestingly however, while mental fatigue was associated with a lower (adjusted) percentage of positive involvements, mental fatigue did not seem to result in a higher (adjusted) percentage of negative involvements. Collectively, our findings indicated that players weren't necessarily making more errors when they were mentally fatigued, but they were more likely to have neutral outcomes rather than positive outcomes. For example, a ball carrier might be more inclined to go into contact and accept a tackle (neutral outcome) rather than looking for and executing a successful offload or making a line- or tackle- break (positive outcomes). Similarly, a kicker may be more likely to execute a kick that is retrieved by the opposition (neutral outcome) than forcing a goal-line dropout (positive outcome). Optimising the outcome of player involvements is important for gaining territory,

building and maintaining pressure on the opposition, and increasing the opportunity that a given set will result in a try. For example, previous research has found that 21% of possessions gained from goal-line dropouts resulted in a try (Kempton et al., 2016) and "making quick ground" (e.g., through linebreaks, offloads/support carries, tackle busts) were associated with winning matches (Parmar et al., 2018).

Individual characteristics thought to influence mental fatigue include playing experience and age, and it has been suggested that more experienced elite athletes have a greater resistance to the detrimental effects of mental fatigue on physical performance (Martin et al., 2016; Russell et al., 2019). Findings from both Russell et al. (2019) and Thompson et al. (2021) suggested that more senior athletes with greater playing experience at an elite level are better able to cope with mental fatigue, especially when compared to younger and inexperienced players (Russell et al., 2019; Thompson et al., 2022). In team sports, Vaughan and Laborde (2021) showed that young elite athletes with more expertise and experience performed better on cognitive tasks of attention and working memory, which consequently had a positive relationship with basketball free throw performance (Vaughan & Laborde, 2021). Given the ages and playing experience of the participants in the current study, and the high level of competition they were competing in, participants may have been more adept at coping with the mental fatigue they experienced in the game, and thus avoided making errors. It is also possible that participants opted to play more conservatively when mentally fatigued (e.g., accepting a tackle), resulting in more neutral outcomes, rather than attempt a more favourable action (e.g., an offload) and risk an error.

While we accounted for the influence of caffeine on mental fatigue in our statistical models, external factors that were not measured (including the potential effects of adhering to strict COVID-19 pandemic-related regulations throughout the season) must also be acknowledged when interpreting this study's results as they may have influenced how participants rated their mental fatigue leading up to a game. However, a positive aspect of this study was that we were able to explore the mental fatigue profiles and related technical performance of participants during competition, maximising the ecological validity of our results. It should also be noted that our models did not consider the match importance and time in the season the match occurred, which may have influenced player behaviours. Future studies could also consider how team mental fatigue is associated with match outcome. On a positive note, our study provides a novel method for assessing technical performance, which accounted for the specific in-match context and difficulty of individual player involvements.

In conclusion, our results showed that elite rugby league players reported increased mental fatigue following competitive games, with backs reporting a greater increase in mental fatigue than forwards. We also found evidence to suggest that mental fatigue impacted technical performance, whereby participants had a lower percentage of positive involvements when they reported being more mentally fatigued. However, mental fatigue did not seem to impact the percentage of negative involvements (i.e., errors). Strategies to minimise pre- and in-game mental fatigue should be considered in elite rugby league. Future research would benefit from a larger sample size with a variety of players and more specific position groups (e.g., half-back, lock, five-eighth) to further investigate individualised player responses to mental fatigue in elite rugby league and its relationship to technical skill.

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