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Original Research

Determining the Barriers to the Use of Post-match Fatigue Monitoring in the Rugby Codes: A Concept Mapping Study

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ABSTRACT

Topics in Exercise Science and Kinesiology Volume 5: Issue 1, Article 3, 2024. The rugby codes (i.e., rugby union, rugby league, rugby sevens [termed 'rugby']) are team-sports that impose complex physical demands upon players which in-turn, leads to domain-specific fatigue (e.g., neuromuscular, cardio-autonomic). Quantifying post-match fatigue through various methods and metrics is important to monitor player fatigue status, which influences training readiness. The specific and general barriers limiting the use of post-match fatigue monitoring in rugby are not presently known. Therefore, the aims of this study were to identify specific and general barriers (clusters of specific barriers) to the use of post-match fatigue monitoring methods and metrics in rugby across the domains of neuromuscular performance, cardio-autonomic, tissue biomarker, and self-reported fatigue, and which of these specific barriers were considered important to overcome and feasible to overcome. An international cohort of subject matter experts (SME) in rugby completed a two-round online questionnaire survey (Round One; n = 42, Round Two; n = 13), with the responses collected and analysed using Concept Mapping. Specific barrier statements were generated based on the SME responses to Round One, which were structured and then rated by the SME for importance to overcome and feasibility to overcome in Round Two. Five clusters of specific barriers (representing the general barriers) were determined based on analyses of the SME responses: 1. 'Budget and Equipment', 2. 'Data and Testing Considerations', 3. 'Player and Coach Perceptions', 4. 'Test Appropriateness', and 5. 'Time and Space'. For both importance to overcome and feasibility to overcome, the 'Data and Testing Considerations' had the highest overall rating and contained the largest number of specific barriers which rated highly. These findings should be considered when identifying which post-match fatigue monitoring methods and metrics to implement in rugby, and potentially other sports.

KEY WORDS: Fatigue, monitoring, rugby, Concept Mapping

INTRODUCTION

The rugby football codes, rugby union, rugby league, and rugby sevens (hereafter termed 'rugby') are team-based sports characterised by intermittent, high-intensity exercise activities that incorporate frequent bouts of sprinting, accelerations, decelerations, and collisions (8, 15, 20, 28). Within rugby match-play, these physical actions (a construct termed the 'external load') often leads to post-match fatigue, and a delayed time-course of recovery (1, 31). Moreover, deleterious changes in post-match objective and subjective fatigue measures appear strongly related to the volume and frequency of running total distance, decelerations, and collisions (34, 47). Increased fatigue and delays in recovery in the days following match-play can have a negative impact on the readiness of the player to train and their training performance, with readiness inversely related to the players fatigue state at a given time (i.e., player readiness is higher when fatigue is lower, and vice versa). The fatigue state of the player and their readiness to train and perform at that time are related and are often used synonymously (6, 13). In rugby and in other team sports, there is evidence that increased fatigue and delayed recovery can increase the risk of illness and/or injury (16), and have a potential negative influence on subsequent match performance and/or indicate more persistent negative issues (e.g., overtraining) (29).

Fatigue in rugby is a highly complex and multidimensional latent construct (29). As a latent construct, fatigue can not be measured directly, but must be inferred through various potential subdimensions (4, 18) (hereafter termed 'domains'), with there being a multitude of different metrics, analysis methods and monitoring systems aimed to quantify these domains (e.g., neuromuscular, cardio-autonomic, tissue biomarker, self-reported fatigue) (1, 13, 24, 25, 46). Briefly, tests such as the countermovement jump and plyometric pushup and quantifying height, flight time, force, and power are the most commonly implemented methods and metrics to quantify the neuromuscular performance fatigue domain in the rugby football codes (1, 29). Other commonly used methods and metrics to quantify aspects of the different domains of fatigue in rugby include mood and soreness (self-reported fatigue), heart-rate variability (cardio-autonomic fatigue), and muscle damage (e.g., creatine kinase, myoglobin [tissue biomarkers]) (12, 13, 29, 50, 51). When monitored longitudinally, these tests can be used to monitor adaptation to training (e.g., strength, power, cardiovascular fitness), as the primary aim during the pre-season period (23). When monitored in the short-term, these tests can be used to monitor fatigue status pre- to post-match, or in between matches, information which is necessary for minimizing fatigue between matches, as the primary aim during the in-season period and during pre-season trial matches. Individual monitoring of fatigue in-season is important to identify the players who are and are not returning to their individual baseline state between matches (14). Given the variety of methods and metrics with which to capture fatigue, it can be difficult for support staff (including sports scientists, strength and conditioning coaches, etc.) to identify and select which methods and metrics they should use when attempting to monitor post-match fatigue, and its various dimensions (30). When assessing which methods and metrics to use, it is necessary to determine and understand both the facilitators (e.g., efficiency) and the barriers (e.g., resources) to the implementation of these fatigue monitoring practices.

There are only two studies examining the facilitators to the implementation of fatigue monitoring measures and metrics, and the barriers to the use of monitoring strategies within rugby (43, 52). Firstly, Starling & Lambert (43) surveyed 55 coaches and support staff across varying levels of professionalism within rugby union regarding their perceptions of facilitating characteristics when implementing fatigue monitoring protocols. Respondents indicated that a preferred monitoring protocol should give immediate feedback, be time efficient, easy to administer, inexpensive, non-fatiguing to players, and to be able to be administered to the whole team simultaneously (43). Secondly, a study by West et al. (52) surveyed 12 support staff involved in professional Rugby Union in the United Kingdom on their monitoring practices. Identified barriers to implementation of fatigue monitoring included test validity and reliability, and financial, equipment, and resource constraints (52). More broadly across team sport, research has identified additional barriers, citing the perceptions of applying evidence-based practice (i.e. integrating experiential or research information to guide and support decision making) as an obstacle to monitoring (41). This latter finding indicates that there are factors which can be considered as general barriers – that is barriers to monitoring which apply regardless of the method or sport under consideration. Equally, there were barriers to fatigue monitoring that were specific to the monitoring method under consideration and these were perceived to exist in the professional setting (52). It is there expected, due to limitations in resources (e.g., staff, knowledge, skills, equipment, funding), that general and specific barriers to the use of post-match fatigue monitoring exist across the semi-professional, amateur, and junior-developmental rugby settings, but this is currently not known.

From the perspective of implementation, it is not known which specific and general barriers (e.g., financial limitations, physical resource constraints) for the use of post-match fatigue monitoring exist across rugby and across the different levels of professionalism. In this context, specific barriers refers to identified barriers to a given monitoring method or metric, whilst general barriers refers to barriers to monitoring which exist across methods and metrics. To determine those specific and general barriers, this study used the Concept Mapping method which is a mixed-methods approach to generate and organise opinions around a specific topic of interest using a group of subject matter experts (SME). Concept Mapping involves a structured framework for collecting SME qualitative responses and aggregating those responses to provide quantitative data on the specific barriers and clusters of specific barriers (representing general barriers), and the importance and feasibility to overcome of the specific and general barriers. Other methods that are commonly used to characterise barriers to implementation use predominantly subjective approaches to data collection and analysis (e.g., through interviews, focus groups and surveys) (7). The Concept Mapping method was first described by Trochim (45) and has been employed in sport to investigate barriers to the implementation of an injury prevention programme in soccer (9), a sports-specific injury risk reduction programme for women (5), and the design of mental health support (48).

Therefore, the aims of this study were to use Concept Mapping to identify which specific and general barriers to the use of post-match fatigue monitoring methods and metrics in rugby exist across the domains of neuromuscular performance (1, 10), cardio-autonomic (3, 11, 36), tissue biomarkers (1, 24), and self-reported fatigue (40), and which of the specific barriers and clusters of specific barriers (representing the general barriers) were considered important and feasible to overcome across the rugby codes and levels of professionalism.

METHODS

Participants

Participants were SME working within male rugby football codes who initially responded to a social media advertisement or were identified and contacted through publicly available contact information or existing professional networks of the researchers. To ensure that a diverse range of stakeholder groups were represented, SME from both rugby support staff (e.g., sports scientists, strength and conditioning coaches, performance analysts, technical/tactical coaches) who were currently working in rugby, and academic research institutions were eligible to participate (35, 38). Potential SME were contacted in both predominantly anglophone and non-anglophone countries where rugby is played (e.g., France). Research academics were considered eligible as SME if they had ≥3 publications in monitoring of match-demands and/or post-match fatigue monitoring in rugby, which is consistent with prior mixed-methods research in sport (35, 38). The SME provided information regarding their age, rugby code (i.e., rugby union, rugby league, rugby sevens) they worked in, current role, and years of experience in this role.

Protocol

Concept Mapping: There are four fundamental steps in the collection and analysis of data within the Concept Mapping framework; preparation, generating the ideas, structuring the statements, and the Concept Mapping analysis (21, 45). The use of these four steps in the present study is described in the Procedure section. Throughout the information collection periods, qualitative and quantitative information was collected using the web-based survey platform Qualtrics (Qualtrics, Utah, USA). Ethical approval for the study was obtained from the relevant institute Human Ethics Committee (HRECS211532). This research was carried out in accordance with the ethical standards of the International Journal of Exercise Science (33). The participants were provided with participant and consent information and provided informed consent through the survey platform prior to both the ideas generation and structuring the statements survey rounds (refer to Procedure section below).

Step 1 – Preparation: Potential SME were invited to participate using a social media advertisement, through professional networks of the researchers, and directly through publicly available Email addresses and contact information (27). Those who agreed to participate were Emailed a link to the Round One survey. The initial brainstorming and ideas generation survey Round One (Step 2) was open for four weeks. The SME were sent a reminder Email 24 hours prior to the survey closure. Potential SME were contacted again through social media, professional networks, and through publicly available Email addresses for the structuring of statements process in survey Round Two (Step 3). This process was open for five weeks, and SME were sent a reminder 24 hours prior to the survey closure.

Step 2 - Ideas generation: To obtain SME opinions on the barriers for the use of post-match fatigue monitoring measures and metrics for the domains of neuromuscular performance, cardio-autonomic, tissue biomarker, and self-reported fatigue, SME were asked to provide a brief statement (i.e., one thought) about the barriers that exist to fatigue monitoring in each domain. The domains were chosen, from existing domains, based on the extensive review of findings of previous reviews and applied studies of fatigue measures and metrics in rugby (1, 12, 29, 46), and the extensive research and applied experience of the researchers who conducted the present study. The SME could provide multiple statements for these measures and metrics if they believed multiple barriers were present.

Ideas analysis: The statements were then reviewed and revised by one researcher (MN) to ensure they were relevant to the project aims, that each idea was presented only once for each fatigue domain, and to improve (where necessary) the clarity and comprehension of these statements. To assess the appropriateness of the revisions, a second researcher (TS) independently assessed a subset of 35 of the original unedited responses, and produced an independent revised statement list, with the revised statements then compared between raters using percentage agreement and 95% agreement attained. As with other Concept Mapping analysis (5, 21), this process was undertaken by identifying and removing statements which were not related to the project aims, identifying and dividing compound statements (i.e., more than one idea), identifying and removing duplicate statements, and identifying and editing statements as required to maximise clarity of the meaning of the statement. The SME contributed statements directly for the separate domains and there were identified barriers for each of the neuromuscular performance, cardio-autonomic, tissue biomarker, and self-reported assessment domains.

Step 3 - Statement sorting: The SME sorted the synthesised statements into groups, with the SME instructed to group the statements according to how similar in meaning the statements were to each other, and to name each group based on their opinion of what the groups' theme was. The SME could put single statements into separate groups if they thought the statements were unrelated to the other statements in each domain (i.e., neuromuscular performance, cardio-autonomic, tissue biomarker, and self-report tests). The SME were instructed to put each statement into a group, and to not create groups such as 'other' or 'various'. They were not instructed as to the number of groups to create, or the number of groups that are usually created using this method.

Statement rating: Following the statement sorting, the SME were asked to rate each statement on two dimensions; importance to overcome, and feasibility to overcome (38). For importance to overcome, SME were asked to rate the statements using a 5-point Likert scale; 1: Not at all important, 2: Slightly important, 3: Moderately important, 4: Very important, and 5: Extremely important. For feasibility to overcome, SME were asked to rate the statements using a 5-point Likert scale; 1: Extremely difficult, 2: Somewhat difficult, 3: Neither easy nor difficult, 4: Somewhat easy, and 5: Extremely easy.

Statistical Analysis

Step 4 – Concept mapping analysis: The techniques that are applied in the Concept Mapping analysis are described in detail elsewhere (see Kane and Trochim (21). In synopsis, to understand the similarity between statements (i.e. the specific barriers), the statements were analysed using multidimensional scaling to locate each statement within a two-dimensional 'point map'. The location of each statement on the point map is based on the grouping of each statement as originally undertaken by the SME. Hierarchical cluster analysis was then applied to partition the statements on the point map into clusters of related statements based on how similarly these were categorised by the SME. The cluster analysis uses Wards method of agglomerative clustering (49), which is designed to minimise the variance within the clusters by finding the smallest within-cluster sum of squared error increase as the statements are iteratively combined (i.e. clustered) (2, 49). As entering the data for category groupings into the analysis involved a degree of researcher subjectivity (e.g., whether a grouping was congruent or incongruent for a given theme), two of the researchers (MN, TS) independently assessed a subset of six randomly selected SME data to determine the intraclass correlation coefficient (ICC) for the number of groupings as a measure of interrater reliability. The interrater reliability was excellent (ICC = 0.962) (22). The stress index, a measure of how the point map data correspond to the original SME input data was calculated. The stress index is a score between 0 and 1, with a higher value representing greater discrepancy between the SME input data and the two-dimensional point mapped data (21). The typical range of stress index for Concept Mapping projects is 0.205 – 0.365 (21).

There is no commonly accepted automated method for selecting the number of clusters appropriate for a specific study, due to the structure of the data being different between studies (9, 21). Therefore, to select an appropriate number of clusters, and as with prior research (9), the researchers independently visually examined the cluster maps for each clustering solution from ten clusters to five clusters. During this process the researchers examined which statements were merged into which clusters as the number of clusters was reduced. The aim of this process was to find the cluster number that retained the most useful detail between clusters, whilst also merging clusters that logically belonged together, and to ensure that the number of clusters did not 'overfit' to the data (i.e. each statement in its own cluster) (21). Five clusters was chosen as the minimum as clusters fewer than five caused very large cluster coverage which resulted in statements being included within the same cluster which did not logically belong together (i.e., they related to different concepts). For the present Concept Mapping analysis, the statements generated are considered the specific barriers to the use of post-match fatigue monitoring methods and metrics, and the clusters of statements are considered as representing general barriers.

Importance to overcome and feasibility to overcome rating descriptive statistics (mean and standard deviation [SD]) for each statement were calculated, and used to generate 'Go-Zones' which are included in two-dimensional scatterplots (21). Within this figure are quadrants which are produced by the division of the scatterplot based dividing line on the horizontal and vertical axis at the mean rating for each dimension (importance to overcome and feasibility to overcome) across all statements. The Go-Zones are the upper right of these quadrants and identify the barriers which are considered more important to overcome (x-axis) and more feasible to overcome (y-axis) relative to the average. Correspondingly, barriers in the lower left quadrant have lower than average importance and feasibility to overcome, while the off-diagonal quadrants are above average for one variable and below average for the other. In the current analysis, the Go-Zones therefore provide a description as to barriers which are rated of higher and lower importance and feasibility by the SME, and such information may be of use to practitioners when choosing where to focus their resources on overcoming such barriers.

Data were analysed in RStudio (RStudio, Boston, MA) using the 'R-CMap' open-source software package (2) for R programming language (R Foundation for Statistical Computing, Vienna, Austria). Statistically significant p values or measures of effect are to be reported as per the International Journal of Exercise Science guidelines (19). However, Concept Mapping does not rely on statistical significance or comparisons using effect size statistics (22). All necessary data and their interpretation are presented.

RESULTS

There were 64 respondents who indicated their interest prior to Round One. In total, 42 SME completed the survey Round One (66% response rate), and these SME were employed in the United Kingdom (43%), Australia (36%), Ireland (7%), New Zealand (5%), France (2%), Russia (2%), South Africa (2%), and an unspecified location (2%) (32). From this, 13 SME completed the subsequent survey Round Two (31% response rate). The SME who responded were recruited from an international cohort (n = 7 countries), and the characteristics of the SME are summarized in Table 1.

Ideas generated: Following the synthesis, removal, and editing of statements for coherency, 35 statements were provided for SME to sort and rate (Table 2).

Statement sorting: The 13 SME in Round Two sorted each of the 35 statements into groups (mean number of groups, 7.4; range, 4-10).

Statement rating: The 13 SME in Round Two rated each of the 35 statements for importance to overcome, and feasibility to overcome. Statement 18 'Needing consistency and categorisation across multiple CA testing occasions to collect valid, reliable, and meaningful data.' For the cardio-autonomic (CA) domain received the highest mean importance to overcome rating (4.54/5.00) (Table 2). Statement 6 'Limited space to administer the NM test(s).' for neuromuscular performance (NM) testing had the highest mean feasibility to overcome rating (3.54/5.00) (Table 2). Conversely, Statement 6 'Limited space to administer the NM test', and Statement 2 'A limited budget to procure the equipment and implement these NM tests' had the lowest mean importance to overcome (2.23/5.00) and feasibility to overcome (1.69/5.00) ratings, respectively (Table 2). The same statement may be rated differently in the context of the domain of fatigue that the statement was rated for. For example, 'Limited access to the testing equipment' was identified as a specific barrier for cardio-autonomic fatigue (CA), and tissue biomarker (TB) fatigue domains but rated differently by the SME across importance to overcome and feasibility to overcome (Table 2).

Table 1. Characteristics of subject matter experts (SME) who responded in the Survey Round One (Step 2), and the Survey Round Two (Step 3).

	Survey Round One (Step 2) (n = 42)	Survey Round Two (Step 3) (n = 13)
Age (Years)		
Mean (SD)	35.0 (7.4)	38.1 (8.6)
Experience in a Similar Role (Years)		
Mean (SD)	11.7 (8.3)	12.9 (6.9)
Rugby Code (n)		
Rugby Union	21 (47%)	6 (32%)
Rugby League	17 (38%)	6 (32%)
Rugby Sevens	3 (7%)	3 (16%)
Other§	4 (9%)	4 (21%)
Current Role (n)		
Support Staff#	37 (74%)	9 (64%)
Research Academic	13 (26%)	5 (36%)
Professionalism (n)		
Professional	31 (63%)	8 (44%)
Non-professional^	18 (37%)	10 (56%)

Rugby Code, Current Role, and Professionalism may exceed SME number as SME could indicate they worked in more than one Rugby Code, hold more than one Current Role, and work in a rugby code at more than one level of Professionalism. Percentages in parenthesis represent the percentage of the total for that category and may exceed 100% in total due to rounding. § Includes where SME indicated they worked across other sports in addition to rugby including field hockey, athletics, and soccer. # Includes sports scientists, strength and conditioning coaches, high performance managers, and technical/tactical coaches. ^ Includes semi-professional, developmental (i.e., junior, academy, school etc.), and amateur levels.

Table 2. Statements generated during the Concept Mapping brainstorming (Step 2) and structuring of the statements processes (Step 3), and the results of the Concept Mapping analyses (Step 4) including the cluster the statement fit within, the domain with which the subject matter experts (SME) considered the statement, and the importance to overcome and feasibility to overcome ratings for each statement.

Statement Number	Statement	Mean rating (1-5) for Importance to overcome	Feasibility to overcome	Go-Zone quadrant§
Budget and Equipment		**3.77**	**2.22**	
24	A limited budget to procure the TB equipment and implement these tests.	4.15	1.85	2
30	Limited access to the TB testing equipment.	4.08	1.92	2
11	Limited access to the CA testing equipment.	3.77	2.85	**1**
28	Lack of a suitable TB testing environment.	3.77	2.23	2
12	A limited budget to procure the CA equipment and implement these tests.	3.69	2.69	3
1	Limited access to the NM testing equipment.	3.46	2.31	4
2	A limited budget to procure the NM equipment and implement these tests.	3.46	1.69	4
Data and Testing Considerations		**4.10**	**2.92**	

18	Needing consistency and standardisation across multiple CA testing occasions to collect valid, reliable, and meaningful data.	4.54	2.38	2
31	Skill limitations in ability to collect TB and analyse the collected data.	4.38	2.85	**1**
26	The quantity of the information able to be analysed from the TB data.	4.31	3.00	**1**
20	Unclear how the CA data will be used to influence subsequent training.	4.23	3.00	**1**
25	Unclear how the TB data will be used to influence subsequent training.	4.23	2.77	**1**
19	Skill limitations in ability to collect CA and analyse the collected data.	4.08	3.38	**1**
35	Poor sensitivity of the SR subjective scales.	4.08	2.62	**1**
16	Limited research on the effectiveness of these CA test(s).	3.77	2.85	**1**
32	A preference to use qualitative information such as conversations and discussions than SR.	3.31	3.46	3
Player and Coach Perceptions		**3.72**	**2.75**	
3	Limited coaching staff buy-in to the importance of NM testing procedures	3.92	2.77	**1**
5	Limited player buy-in to the importance of CA testing procedures.	3.92	2.92	**1**
15	Limited player buy-in to the importance of NM testing procedures.	3.92	2.69	**1**
21	Limited coaching staff buy-in to the importance of TB testing procedures.	3.85	2.15	2
29	Limited player buy-in to the importance of TB testing procedures.	3.85	2.38	2
13	Limited coaching staff buy-in to the importance of CA testing procedures.	3.77	2.85	**1**
33	Limited player buy-in due to the repetitive nature of the SR tests.	3.62	3.23	3
34	Coaching staff doesn't want players too mentally taxed by filling out SR ratings.	2.92	3.00	3
Test Appropriateness		**3.23**	**2.62**	
23	Too difficult and invasive to use TB with the athlete population.	3.92	2.00	2
8	Monotony of athletes with NM testing procedures affecting data integrity.	3.08	2.85	3
22	Not appropriate to use TB with younger athletes.	3.00	2.54	4
9	Player discomfort with the NM testing procedures.	2.92	3.08	3
Time and Space		**3.48**	**2.58**	
4	Limited contact time with players to use NM.	4.00	2.15	2
14	Limited contact time with players to use CA.	3.92	2.38	2
27	Limited contact time with players to use TB.	3.85	2.31	2
10	Difficulty to implement CA tests in the training environment.	3.69	2.31	4

17	Limited time in the schedule to administer the CA test(s).	3.62	2.62	3
7	Limited time in the schedule to administer the NM test(s).	3.08	2.77	3
6	Limited space to administer the NM test(s).	2.23	3.54	3

CA – Cardio-autonomic, NM – Neuromuscular performance, SR – Self-report, TB – Tissue biomarkers. § Go-Zone quadrants; 1, top right; 2, bottom right; 3, top left; 4, bottom left. See 'Procedures' for further information on the how each of the GoZone quadrants was determined, and Figure 2 for the GoZone figure containing the quadrants.

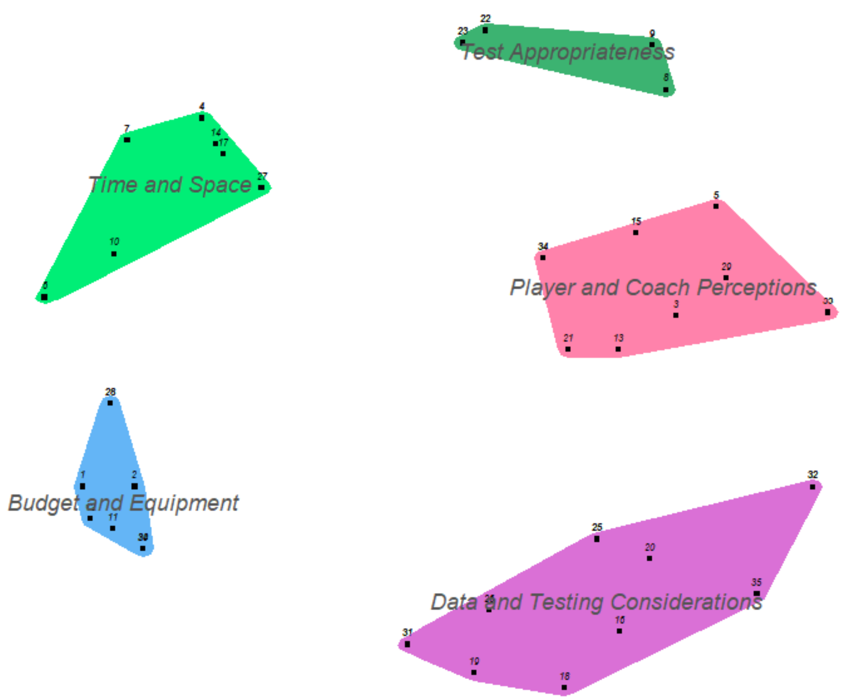

Figure 1. The five-cluster map of the specific barrier statements to the use of post-match fatigue monitoring methods and metrics in the rugby football codes. The numbers are the statement numbers, with statements 24 and 30 overlapping within the Budget and Equipment cluster. The clusters were named by the researchers based on the statement contents of each cluster (39).

Point map: All statements were analysed using multidimensional scaling which is presented in the two-dimensional point map (Figure 1). The point map indicates the degree of similarity between the statements based on the similarity of how the statements were categorised by the SME. Statements which were sorted into groups together by more of the SME and thus considered more similar appear closer to each other on the point map. Conversely, statements which were sorted together by fewer of the SME and thus rated less similar appear further apart from each other on the point map. For example, Statement 14 'Limited contact time with players.' And Statement 17 'Limited time in the schedule to administer the test(s).' for cardio-autonomic testing were rated more similar to each other by the SME, while Statement 18

'Needing consistency and categorisation across multiple testing occasions to collect valid, reliable, and meaningful data.' For cardio-autonomic testing, and Statement 7 'Limited time in the schedule to administer the test.' For neuromuscular performance testing were rated less similar by the SME. The similarity between the two-dimensional point map and the original grouped SME data was assessed as being similar with the stress index of 0.260 being within the typical range of other Concept Mapping studies (0.205 – 0.365) (21).

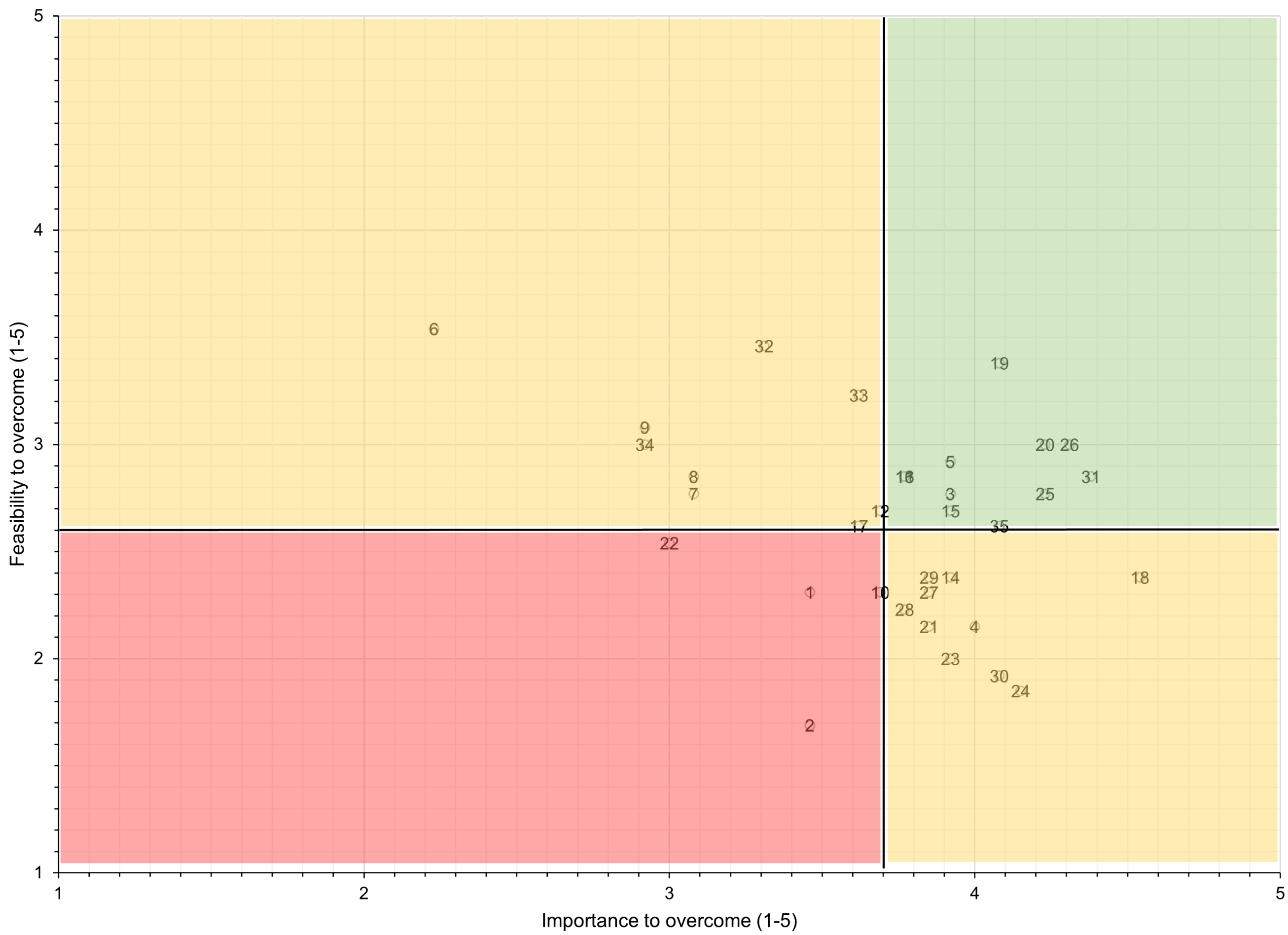

Figure 2. Two-dimensional Go-Zone scatterplot with quadrants for ratings of barriers to the use of post-match fatigue monitoring methods and metrics in the rugby football codes. Quadrants are based on the mean of the mean ratings for importance to overcome (3.7 on 1 – 5 scale), and feasibility to overcome (2.6 on a 1 – 5 scale). Go-Zone quadrants; 1, top right; 2, bottom right; 3, top left; 4, bottom left. NB – Statement 11 and 13 are not visible as they overlap with Statement 16.

Cluster map: After analysing the two-dimensional point map hierarchical cluster analysis, the researchers agreed that a five-cluster map retained the most useful information and therefore a five-cluster map was chosen (Figure 1). Table 2 indicates the statements which comprise each cluster. The five clusters in to which the statements were grouped were: 1. '*Budget and Equipment*' (7 statements), 2. '*Data and Testing Considerations*' (9 statements), 3. '*Player and Coach Perceptions*' (8 statements), 4. '*Test Appropriateness*' (4 statements), and 5. '*Time and Space*' (7 statements) (Table 2; Figure 1). For the clusters, the '*Data and Testing Considerations*' cluster had the highest mean importance to overcome (4.10/5.00) and feasibility to overcome (2.92/5.00). Conversely, the '*Test Appropriateness*' cluster had the lowest mean importance to overcome (3.23/5.00), and the '*Budget and Equipment*' cluster had the lowest mean feasibility to overcome (2.22/5.00) (Table 2).

Go-Zones: Figure 2 contains the mean rating of each statement for both importance to overcome, and feasibility to overcome, along the two-dimensional scatterplot. This Go-Zone figure includes quadrants of statements, with the top right quadrant (in green) rated above the mean for both importance to overcome, and feasibility to overcome (Figure 2). Statements 3, 5, 11, 13, 15, 16, 19, 20, 25, 26, 31, and 35 were included here. Quadrant 2 (bottom right) indicates below the mean for feasibility and above the mean for importance, whilst Quadrant 3 (top left) indicates above the mean for feasibility and below the mean for importance. Quadrant 1 (bottom left) is below the mean for both feasibility and importance. The numerical rating and the Go-Zone quadrant for each statement is provided in Table 2.

DISCUSSION

The aims of this study were to determine the specific and general barriers to the use of post-match fatigue monitoring methods and metrics in the rugby football codes, and it is the first study to use Concept Mapping to identify these specific and general barriers (i.e., clusters). The use of a mixed-methods approach, such as Concept Mapping, enabled the identification of general barriers based on clustering around different themes of barrier statements (21). Overall, five clusters were identified based on the statement grouping by the SME including general barriers termed: (1) '*Budget and Equipment*', (2) '*Data and Testing Considerations*', (3) '*Player and Coach Perceptions*', (4) '*Test Appropriateness*', and (5) '*Time and Space*'. For specific barriers (i.e., the statements), 12 of the 35 statements were rated highly for both importance to overcome and feasibility to overcome (i.e., Go-Zone quadrant 1 [Figure 2]). The statements which were rated highly were distributed across the cardio-autonomic (n = 6 statements), tissue biomarker (n = 3 statements), neuromuscular performance (n = 2 statements), and self-reported (n = 1 statement) domains. Each of the highly rated statements were located in the clusters of '*Budget and Equipment*', '*Data and Testing Considerations*', or '*Player and Coach Perceptions*'.

The '*Data and Testing Considerations*' cluster had the highest rating for importance to overcome and feasibility to overcome and contained the largest number of statements which were rated highly for both importance to overcome and feasibility to overcome. Within '*Data and Testing Considerations*', for the cardio-autonomic and tissue biomarker domains the quantity of data, skill limitations of support staff, and the lack of clarity on how the data will influence training were consistently rated highly for importance to overcome and feasibility to overcome. Research in professional rugby union which examined barriers to the use of GPS technology has identified data and technology related barriers such as the validity and reliability of the technology, and lack of staff to manage the quantity of data (52). Collectively, these findings indicate that SME working in rugby identified that there are potential skills or knowledge deficits worth overcoming in the workflow from data collection through to presentation as it relates particularly to objective measures and metrics. Lack of knowledge has been identified previously as a barrier to mental fatigue monitoring in sport by coaches and support staff, and our results therefore corroborate those of Russell et al. (2023) (39). Other specific barriers within the '*Data and Testing Considerations*' cluster related to the sensitivity of subjective tests for self-reported fatigue, and a lack of research on the effectiveness of the tests in quantifying cardio-autonomic fatigue. Within the present study, the identified skills or knowledge deficit relates to how to collect, analyse, and present valid and reliable data on post-match fatigue, and how this data may effect subsequent decisions regarding training content. Therefore, for rugby there is a need for staff training and professional development specifically for improving understanding and application on how to collect, handle, analyse, visualise, and present data from monitoring systems, which aligns with prior research (37, 44).

The '*Test Appropriateness*' and '*Time and Space*' clusters had the lowest importance to overcome, whilst the '*Budget and Equipment*' and '*Time and Space*' clusters had the lowest mean feasibility to overcome. The SME indicated that to implement post-match fatigue monitoring through neuromuscular, cardio-autonomic, and tissue biomarker measures and metrics, constraints such as the time spent with the players, the time and space needed to conduct the test, and having available financial resources to procure the testing equipment, are not feasible to overcome and/or not important to overcome. Within these lower-rating clusters, the only specific barrier that was considered both highly important to overcome and highly feasible to overcome was for access to equipment for cardio-autonomic testing. This is to be expected as validated cardio-autonomic testing can be undertaken through relatively inexpensive methods such as mobile phone applications (36). Cardio-autonomic fatigue monitoring is therefore an objective monitoring tool which can be recommended to quantify post-match and ongoing fatigue monitoring in the rugby football codes (12, 42). For support staff implementing such measures and metrics, the use of heart-rate variability measures and metrics collected daily has been proposed as effective in quantifying short-term cardio-autonomic fatigue in rugby (12, 46). Other measures and metrics such as heart-rate during submaximal exercise, and heart-rate recovery post submaximal exercise are also indicators of cardio-autonomic fatigue in rugby (42). Cardio-autonomic measures and metrics also meet the criteria of coaches as set out by Starling & Lambert (43) in that they are time efficient, give immediate feedback, are relatively easy to administer, inexpensive, and non-fatiguing. These results could be considered in conjunction with a recent study by Naughton et al., (2023) which identified the importance and feasibility of a range of fatigue monitoring methods and metrics in the rugby football codes (32). Highly rated monitoring methods and metrics included countermovement jump force and power for neuromuscular fatigue, heart rate variability for cardio-autonomic fatigue, and subjective fatigue measures of self-reported fatigue and muscle soreness (32). From a practical perspective, the results of the present study and those of Naughton et al., (2023) allow a practitioner in rugby to firstly identify what measures and metrics are important to implement and are feasible, the barriers they may face when choosing to implement those measures and metrics, and the importance of and feasibility to overcome such barriers (32). This would be necessary to consider alongside information in each practitioner situation (e.g., level of resourcing, time and staff availability, etc.).

When averaging over all the statements (i.e., the specific barriers), the SME rated importance to overcome more highly than feasibility to overcome (3.7 vs. 2.6; Figure 2). The SME in the present study therefore consider that barriers to the use of measures and metrics which quantify post-match fatigue as being typically of high importance to overcome, indicating that they consider the methods to have utility and value in their environment. Conversely, the comparatively lower ratings for feasibility to overcome across all the statements in the present study indicates that SME recognise there are limitations in their environments to realistically overcome such barriers. Therefore, for the objective and subjective fatigue monitoring methods assessed by the SME, barriers in their environments may be thought to be relatively 'fixed' and unchangeable. This result may be recognition of the philosophy and culture present in rugby which is often traditional, conservative, and sceptical of the value of new or different approaches (26). Alternatively, the finding may be related to the high proportion of SME working in non-professional rugby teams, particularly in the Round Two of the survey. The SME working in these environments are potentially more resource constrained compared to those working in professional rugby (52). These factors could result in SME considering that they are less able to overcome the barriers which they perceive to be important to overcome. Whilst the present study included SME from non-professional and professional rugby, assessing the heterogeneity in opinions between these cohorts was not our aim. A larger sample of both non-professional and professional SME would be necessary to compare the SME perspectives and determine if differences due to professionalism exist. Likewise, differences between support staff and research academic perspectives could have been present, which were not investigated, as this was not the aim of the present study. Further research to investigate these potential differences it therefore necessary. Finally, decisions taken by people working at higher levels of the system (e.g., the team or organisation), such as deciding if fatigue monitoring systems are not to be implemented can have a direct influence on the potential health and recovery of players (17). Overcoming these barriers to introduce fatigue monitoring systems in rugby therefore requires engaging and educating higher-level actors within the organisation (e.g., managing directors, department leads, and financial decision makers) of the importance and feasibility of post-match fatigue monitoring.

The present study used the Concept Mapping method which has limitations as it includes a component of subjectivity and uses the skills and experience of the researchers involved for making subjective decisions for the wording of the statements, the grouping of the statements involved, and the number of clusters (21). However, reliability of the categorisation of the SME responses by the researchers indicated almost perfect agreement (ICC = 0.962). Other Concept Mapping investigations (9) involve the researchers manually adjusting the clusters in the final output, adding a further layer of subjectivity, which was not conducted in the present study. Another potential limitation is the non-random sampling associated with survey data collection, and with the online survey data collection which was used in the present study, and which may have biased the sample of SME. Further, there were a limited number of fatigue monitoring domains presented to the SME with which they could rate fatigue. This may have limited the potential pool of responses based on the domains of fatigue presented, which could have biased the results. However, these domains were based on previous research and represent domains which a separate study of SMEs considered for importance and feasibility in a recent study of ours (32). Future work could include more open-ended responses in an earlier survey round before refinement through the Concept Mapping approach. There was a decline in respondents from the first round to the second round of data collection, which resulted in a ~21% reduction in respondents working in professional compared to non-professional rugby from the first to the second round. This could have potentially influenced the findings of the present study. Other factors such as the experience level of SME, the rugby codes they were involved with, and current role they held were similar between the two rounds. The findings of the present study are delimited to male rugby football codes and results may differ in the female rugby football codes. The results of the present study should be interpreted in the context of these potential limitations.

Conclusions: Through Concept Mapping, the statements of experienced SME in rugby of the barriers to the use of post-match fatigue monitoring measures and metrics were grouped into five clusters: 1. '*Budget and Equipment*', 2. '*Data and Testing Considerations*', 3. '*Player and Coach Perceptions*', 4. '*Test Appropriateness*', and 5. '*Time and Space*'. The '*Data and Testing Considerations*' cluster contained the largest proportion of specific barriers for cardio-autonomic, tissue biomarker, and self-reported fatigue domains which were highly rated for both importance to overcome and feasibility to overcome. These results, in conjunction with other relevant research, should be considered when identifying which post-match fatigue monitoring methods and metrics to implement.

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