Exploratory Application of the Generalized Matching Equation to Penalty Choice Responses in Rugby Union: A Descriptive Analysis

Aplicación exploratoria de la ecuación de igualación generalizada a las respuestas de elección de penaltis en el rugby: un análisis descriptivo

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Abstract:

This exploratory study applied the Generalized Matching Equation (GME) to analyze penalty choice behavior (lineouts vs. goal kicks) in rugby union. Data from eleven matches involving six top and bottom teams from the English Premiership were analyzed using visual pattern analysis across team, opponent, score differential, and field position. Higher-ranked teams showed greater variance accounted for by the GME ($R^2 > 0.70$) than lower-ranked teams ($R^2 < 0.30$). Bias toward lineouts increased with larger score margins and when penalties occurred near the sidelines and the in-goal area. Overall results showed a modest fit ($R^2 = 0.404$), hyposensitivity to reinforcement ($a = 0.363$), and a general lineout bias ($\log b = 0.343$). This demonstrates the GME's feasibility for examining tactical decision-making in rugby, providing a foundation for future research.

Keywords:

Rugby union; choice behavior; generalized matching equation; exploratory analysis.

Resumen:

Este estudio exploratorio aplicó la Ecuación de Igualación Generalizada (GME) para analizar el comportamiento de elección de penales (lineouts vs. saques de meta) en rugby unión. Se analizaron datos de once partidos que involucraron a seis equipos de primera y última línea de la Premiership inglesa mediante análisis de patrones visuales a través del equipo, oponente, diferencial de puntaje y posición en el campo. Los equipos de mayor ranking mostraron una mayor varianza explicada por la GME ($R^2 > 0.70$) que los equipos de menor ranking ($R^2 < 0.30$). El sesgo hacia los lineouts aumentó con mayores márgenes de puntaje y cuando los penales ocurrieron cerca de las líneas laterales y el área de gol. Los resultados generales mostraron un ajuste modesto ($R^2 = 0.404$), hiposensibilidad al refuerzo ($a = 0.363$) y un sesgo general hacia el lineout ($\log b = 0.343$). Esto demuestra la viabilidad de la GME para examinar la toma de decisiones tácticas en rugby, proporcionando una base para futuras investigaciones.

Palabras claves:

Rugby unión; comportamiento de elección; ecuación de igualación generalizada; análisis exploratorio.

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Introduction

Behavioral scientists have developed mathematical frameworks to examine choice behavior by measuring the effects of reinforcement on an organism's decision-making (Herrnstein, 1961). These approaches suggest that organisms faced with multiple alternatives tend to allocate their behavior proportionally to the reinforcement they have previously experienced. Herrnstein's initial formulation (1961), known as the Matching Equation (Equation 1), proposes that behavior frequencies (B1 and B2) across alternatives correspond to the relative frequencies of reinforcement (R1 and R2) delivered for each behavior.

$$\frac{B1}{B1 + B2} = \frac{R1}{R1 + R2} \qquad \text{(equation 1)}$$

Subsequent research (Baum, 1973; Baum & Rachlin, 1969) identified additional variables that may influence choice behavior: sensitivity to reinforcement (a) and bias toward available options (log b). This expanded framework became known as the Generalized Matching Equation (GME) (Baum, 1974):

$$log\left(\frac{B1}{B2}\right) = a\ log\left(\frac{R1}{R2}\right) + log\ b \qquad \text{(equation 2)}$$

Sports performance has emerged as one context for exploring GME applications. Previous research has suggested that quarterbacks may exhibit bias toward running rather than passing plays (Reed et al., 2006; Stilling & Critchfield, 2010), while some studies have observed patterns suggesting successful teams may demonstrate greater sensitivity to reinforcement than less successful ones (Alferink et al., 2009; Reed et al., 2006). However, other investigations indicate that athletes may show reduced sensitivity to reinforcement due to sport-specific developmental variables (Poling et al., 2011). GME frameworks have also been applied to examine how rule changes might influence behavior patterns in sports contexts (Falligant et al., 2016; Romanowich et al., 2007).

Since the initial application of GME to sports contexts (Vollmer & Bourret, 2000), many investigations have focused on traditional North American sports. Recently, researchers have begun exploring applications to other sporting contexts, including volleyball (Falligant et al., 2021) and chess (Cero & Falligant, 2020). The present study aims to examine the potential applicability of GME frameworks to rugby union decision-making.

Rugby union is a contact sport played by approximately 9.6 million participants across 123 countries (World Rugby, 2017). The game involves two teams of 15 players competing to score the most points across two 40-minute halves. Playing fields measure between 94×68 and 100×70 meters, with goalposts spanning 5.6 meters in width and extending at least 3.4 meters in height. Behind each goalpost lies an in-goal area measuring 6×68 to 22×70 meters. Players advance an oval-shaped ball (740-770mm horizontal circumference, 580-620mm vertical circumference, 280-300mm width) through various means. Scoring occurs through tries (placing the ball in the in-goal area for 5 points, with an optional 2-point conversion kick) or penalty/

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drop kicks (3 points for successful kicks between the goalposts). Forward passing by hand is prohibited; however, players may kick the ball forward, provided the receivers are behind the kick line when executed.

When teams receive penalties, they typically face two primary options: (1) kick toward the sideline to initiate a lineout at the location where the ball exits play, potentially earning 5 points if a try results, or (2) attempt a direct goal kick from the penalty location for 3 points if successful (World Rugby Laws, 2021). The present study explores whether GME frameworks might describe team choice patterns between these alternatives following penalties in attacking half of the field.

Rugby union has been the subject of numerous investigations examining tactical behaviors associated with team success. Performance Indicator (PI) research has attempted to identify, through statistical regression approaches, which game actions may predict victory outcomes. These studies have examined whether frequencies of specific behaviors, such as lineouts and kicks, correlate with winning performance (Colomer et al., 2020; Gaviglio et al., 2013; Vaz et al., 2011). Additionally, performance metrics research has provided technical- tactical data to coaching staff, including tackle counts, defenders beaten, and offload statistics (Francis & Jones, 2014; Kraak et al., 2018; Painczyk et al., 2017). Applying GME to rugby union choice behavior may contribute a behavioral analysis perspective to this field, offering insights into psychological dimensions that have received limited attention in existing rugby research.

Previous studies have examined factors influencing rugby kick success, identifying distance and angle to goal as primary variables affecting kicker effectiveness through both quantitative (Nel, 2023; Pocock et al., 2018; Quarrie & Hopkins, 2015) and qualitative approaches (Pocock et al., 2020). The present investigation examines whether field position variables might relate to team choice patterns. We investigate whether bias values for goal kick options may vary depending on the distance and angle at which penalties occur from the goal, potentially providing behavioral evidence for how field position influences rugby union decision-making.

For GME application to penalty choice behavior, we designated lineout selection as B1 and goal kick selection as B2. Points obtained immediately following each choice served as reinforcing stimuli (R1 and R2, respectively), yielding:

$$log\left(\frac{lineout\ option}{goal\ kick\ option}\right) = a\ log\left(\frac{points\ earned\ from\ lineout\ options}{points\ earned\ from\ goal\ kick\ options}\right) + log\ b \quad \text{(equation 3)}$$

Choice behaviors were examined across four contextual conditions: the team making the decision, the opposing team, the score differential when penalties occurred, and field position where penalties were awarded. This investigation aimed to explore whether applying

GME to rugby union penalty choices might demonstrate the descriptive flexibility observed in previous behavioral analysis applications to sports contexts (Critchfield & Stilling, 2015; Stilling & Critchfield, 2010). Specifically, we sought to examine whether reinforcement sensitivity (a) and bias (log b) indices might vary according to team identity, opposition, score differential, and field position conditions.

This exploratory analysis represents an initial examination of GME applicability in rugby union contexts, aimed at establishing methodological foundations and identifying patterns that

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warrant further investigation through more comprehensive data collection and statistical validation.

Method

Sample Characteristics

This exploratory investigation examined 11 matches involving 6 teams from the 2019- 2020 Gallagher Premiership Rugby season (the top tier of English rugby competitions). Teams were selected based on their standings through round 12, comprising the three highest-ranked teams and the three lowest-ranked teams, to facilitate a preliminary comparison of choice patterns across performance levels. All matches were accessed through the league website (Premiership Rugby, 2021) during 2020.

Data was recorded using standardized observation sheets for each match, resulting in 66 completed forms. For each penalty occurring in the attacking half during observed matches, the following variables were documented: the alternative selected (lineout or goal kick); the field location where the penalty was awarded (according to the field diagram provided on observation sheets); match time when the penalty was signaled (minutes and seconds); score differential at the time of penalty; and points obtained following the penalty decision.

Analytical Framework

This study employed visual pattern analysis consistent with behavioral analysis traditions for examining choice behavior in applied settings. The approach follows established practices in GME literature where descriptive patterns are identified through graphical analysis before hypothesis-testing studies are conducted.

Analysis Parameters

Teams

The three highest-placed teams (Bristol Bears, Exeter Chiefs, and Sale Sharks) and three lowest-placed teams (Gloucester, Leicester, and London Irish) were selected based on standings through round 12 of the championship. This selection enabled an exploratory comparison of choice patterns between teams competing at different competitive levels. Previous studies in basketball (Alferink et al., 2009) and soccer (Reed et al., 2006) have suggested that higher-ranked teams may exhibit different sensitivity patterns to reinforcement compared to lower-ranked teams. In contrast, investigations in ice hockey have found fewer clear patterns (Seniuk et al., 2015). In baseball, established athletes appeared to show reduced behavioral sensitivity, possibly operating more under rule control than environmental contingencies (Poling et al., 2011). As an initial GME application to rugby union, examining whether successful teams might show different choice patterns compared to less successful teams appeared warranted for exploratory purposes.

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Opponent

The English Rugby Union Championship comprises 12 teams. The eleven analyzed matches from each focal team included encounters with all competing teams, allowing data separation by opposing team rather than solely by the teams under primary analysis. Six teams not included in the primary analysis (Bath, Harlequins, London Wasps, Northampton Saints, Saracens, and Worcester Warriors) contributed six games each (facing each of the six focal teams). The six focal teams contributed five games each (facing each other's focal team except themselves).

This analytical approach was designed to explore whether opposing teams might function as discriminative stimuli influencing choice responses. Research in American college football has suggested that defensive characteristics may influence opponents' tactical choices (Reed et al., 2011). This framework may reveal how different opponents can influence choice behavior patterns across various teams, potentially highlighting environmental factors that affect penalty decisions in rugby union contexts.

Score Differential

The third analytical parameter examined potential relationships between score differential and choice patterns. Matches were pooled and separated according to the score when penalties occurred. Score conditions were divided into five categories: losing by more than 7 points, losing by 1-7 points, tied (0 points), winning by 1-7 points, and winning by more than 7 points. The 7-point threshold was selected because it represents the maximum advantage achievable through a single scoring sequence (try plus conversion: 5 + 2 points).

Previous GME applications to American football have suggested that significant score disadvantages may direct teams toward riskier alternatives, while slight advantages may promote more conservative choices (Critchfield et al., 2014; Stilling & Critchfield, 2010). In rugby union, goal kicks might represent safer, more predictable choices in close matches compared to lineouts, which may offer higher point potential but with greater variability in outcomes.

Field Position

The final analysis examined potential relationships between penalty location and choice patterns. Similar to score analysis, matches were grouped by penalty location, treating field position as a possible environmental factor influencing team choices. The rugby union field was divided into zones based on visible field markings to facilitate data collection.

Figure 1 illustrates the four field position categories: flanks away from the in-goal area (M and P zones); center away from the in-goal area (N and O zones); flanks near the in-goal area (Q and T zones); and center near the in-goal area (R and S zones). These divisions were determined by two practical considerations for manual data collection: (a) reliance on visible field markings for zone identification, and (b) creating zones of similar dimensions (M and P zones: 15m×28m each; N and O zones: 19m×28m each; Q and T zones: 15m×22m each; R and S zones: 19m×22m each).

Previous research has indicated that kicks from sideline positions and greater distances from goal posts may be perceived as more challenging by rugby kickers. Additionally, penalty proxi-

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mity to the in-goal area might influence choice patterns toward lineout options due to reduced field distance required to reach scoring areas. Examining GME patterns by location may help identify whether specific spatial characteristics of rugby union fields relate to team choice preferences.

Data Analysis

Least-squares linear regression was applied to fit collected data to Equation 2 using Microsoft Office Excel® 2016 software, following established procedures for GME analysis (Reed & Dixon, 2009). Data were grouped by observed match, with each match representing one observation point for graphical analysis.

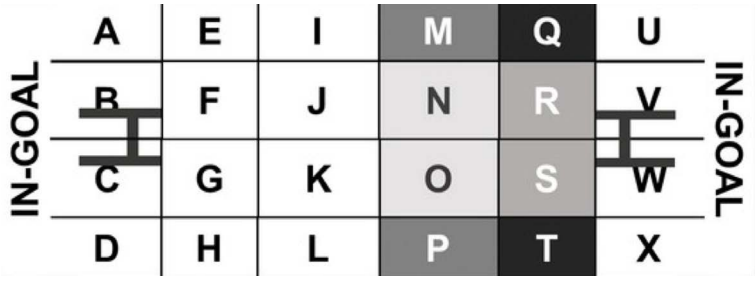
This analytical approach yields three descriptive indices characterizing choice patterns. The variance explained (R^2) indicates the proportion of choice response variability that corresponds to point differentials obtained through these choices, essentially describing how much reinforcement magnitude relates to observed choice patterns. The sensitivity parameter (a) determines how choice patterns vary in response to different reinforcement rates. Values of $a > 1$ suggest overmatching (more pronounced sensitivity than reinforcement magnitude would predict), while $a < 1$ indicates undermatching (less apparent sensitivity than expected). The bias parameter (log b) indicates preference for one alternative that is not accounted for by reinforcement levels. Values of $\log b > 0$ suggest bias toward lineout choices (numerator in Equation 3), while $\log b < 0$ indicates preference for goal kicks (Reed & Kaplan, 2011).

Methodological Considerations

This exploratory analysis employs visual pattern inspection, consistent with behavioral analysis traditions, for the initial examination of choice phenomena in applied settings. The approach prioritizes identifying descriptive patterns that may warrant further investigation through larger-scale data collection and statistical hypothesis testing. Data interpretation focuses on pattern description rather than statistical inference, acknowledging the exploratory nature of this initial application of GME to rugby union contexts.

Figure 1

Illustration of the rugby union field divided into zones based on field markings visible during data collection. Zones A-D and U-X represent in-goal areas. Zones E-L represent the defensive half. Zones M-T represent the attacking half examined in this study.



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Results

Overall Descriptive Patterns

Aggregate analysis of penalty choice patterns across all matches yielded a descriptive fit of $R^2 = 0.404$, indicating that approximately 40% of choice response variability corresponded to point differentials obtained through these choices. This value appears lower than those typically observed in GME applications to other sport contexts. Visual analysis suggested that teams exhibited apparent undermatching to reinforcement (a = 0.363), a pattern that has been observed in previous sports applications of GME (Reed et al., 2006; Seniuk et al., 2015). Overall choice patterns appeared to favor lineout options (log b = 0.343).

These preliminary patterns suggest potential relationships between penalty choices and contextual variables, with apparent variations across team characteristics and situational conditions. Visual inspection revealed that choice behaviors appeared to differ according to team rankings, match conditions, and field positions when penalties occurred.

Team Analysis

Figure 2 presents descriptive patterns across the six teams examined. Each graph represents one team's choice patterns, with individual points representing the eleven matches analyzed for each team. This approach follows established models in previous GME team applications (Reed et al., 2006; Seniuk et al., 2015; Stilling & Critchfield, 2010). Sensitivity to reinforcement values (a) ranged from 0.17 to 0.43 across teams, appearing comparable to findings reported for American football (Stilling & Critchfield, 2010) and ice hockey applications (Seniuk et al., 2015). These patterns suggest that rugby union penalty choices may reflect relatively low sensitivity to immediate reinforcement, possibly indicating greater rule control over contingency control in these decision contexts. Bias patterns (log b) appeared to favor lineout selection across all teams, with values ranging from 0.12 to 0.57. Visual inspection suggested that higher-ranked teams might exhibit somewhat more substantial lineout bias compared to lower-ranked teams.

Variance patterns (R^2) showed considerable variation across teams. Two teams displayed R^2 values above 70% (Sale Sharks and Bristol Bears), while four teams showed values below 30% (Exeter Chiefs, Gloucester, Worcester Warriors, and Leicester Tigers). The teams showing higher variance patterns were among the three highest-ranked teams in the league, while most teams displaying lower variance patterns ranked among the lowest- placed teams. These preliminary observations suggest that choice patterns among higher- performing rugby union teams may exhibit greater correspondence with reinforcement patterns compared to those of lower-performing teams. This descriptive difference may warrant further investigation in studies with larger samples to examine whether variance explained by reinforcement-based models might serve as a behavioral indicator of team performance in rugby union contexts.

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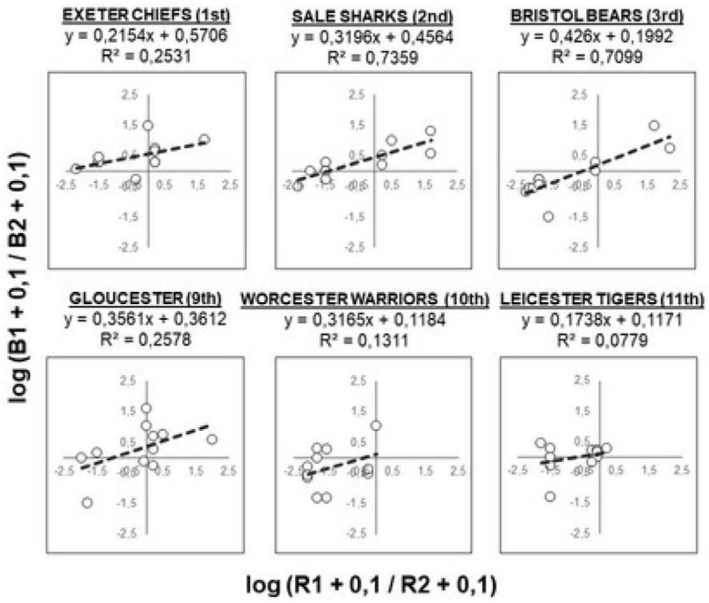
Figure 2

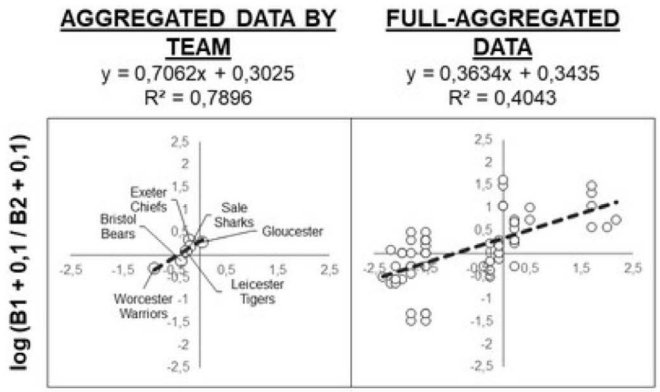
Descriptive GME patterns organized by team. Each point represents choice and scoring data from one observed match (11 points per team). Numbers in parentheses indicate team rankings through round 12.



When data were aggregated across all matches for each team, creating six summary points that represented the total choices and scores for each team's season segment, different patterns emerged (Figure 3). This aggregated analysis yielded higher sensitivity values (a) compared to individual match analyses, approaching more closely the theoretical matching value of 1.0. Lineout bias remained apparent in this aggregated view, and variance explained (R^2) increased compared to individual team analyses. The magnitude of the difference between individual-match and aggregated-season analyses appeared greater than the differences observed in comparable studies (Seniuk et al., 2015; Stilling & Critchfield, 2010), suggesting that this pattern may warrant attention in future rugby union applications of GME.

Figure 3

Aggregated seasonal patterns. Left panel: each point represents one team's total choices and scores across 11 matches (6 points total). Right panel: each point represents one match without team separation (66 points total).



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Opposition Analysis

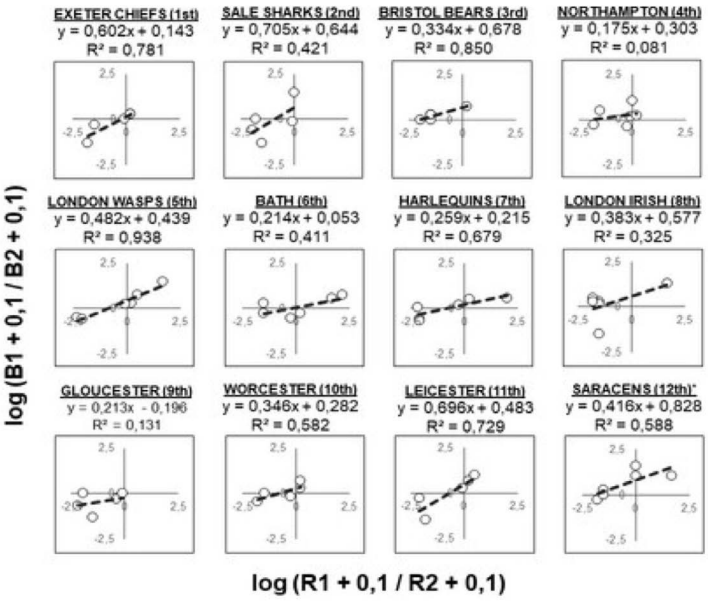
Choice patterns were examined relative to opposing teams encountered across matches (Figure 4). Each plotted point represents a match in which one of the six focal teams faced a specific opponent. This analysis investigates whether opposing teams can function as discriminative stimuli that influence penalty choice patterns.

GME descriptive indices varied considerably across opponents. Opponents appeared to be associated with reinforcement sensitivity values ranging from a = 0.175 (opponents facing Northampton Saints) to a = 0.705 (opponents facing Sale Sharks). Regarding bias patterns, most opponents appeared associated with lineout-favoring choices, with one exception (opponents facing Gloucester showed log b = -0.195, suggesting goal kick preference). The range of bias values spanned from near-neutral choices (opponents facing Bath, log b = 0.05) to strong lineout bias (opponents facing Saracens, log b = 0.83).

These descriptive variations suggest that opposing team characteristics might influence penalty choice patterns, though the mechanisms underlying such relationships remain unclear and would require further investigation to clarify.

Figure 4

Descriptive patterns organized by opposing team. Each point represents choice and scoring data from one observed match. Numbers in parentheses indicate opponent team rankings.



Score Differential Analysis

Figure 5 presents choice patterns organized by score differential when penalties occurred. This analysis treats score conditions as potential environmental stimuli that might influence choice responses (Stilling & Critchfield, 2010). Visual analysis suggested that GME patterns might vary according to the competitive situation. The tied condition appeared to show the highest descriptive fit (R^2 = 0.60), while situations where teams led by small margins showed the lowest

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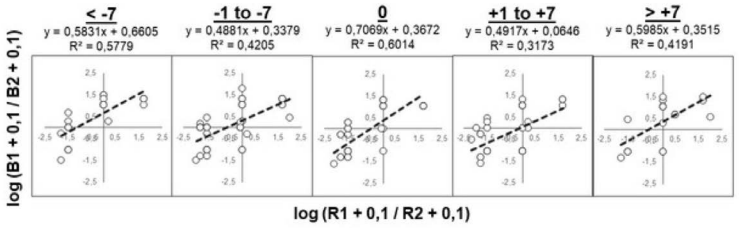
fit (R^2 = 0.32). Sensitivity patterns appeared highest during tied matches (a = 0.71) and lowest when teams were either trailing or leading by small margins (a = 0.49 in both cases).

Bias patterns suggested a potential relationship between score differential and lineout preference (Figure 6). Visual inspection indicated that bias toward lineout choices appeared strongest when teams trailed by more than 7 points (log b = 0.66) and weakest when teams led by 1-7 points (log b = 0.06). This pattern suggests that disadvantageous score situations might be associated with choices favoring higher-risk, higher-reward alternatives (lineouts). At the same time, slight competitive advantages might be related to more conservative decisions (goal kicks).

Figure 5

Descriptive patterns by differential scores at penalty occurrence. Points represent individual matches. Score categories: losing >7 points; losing 1-7 points; tied; winning 1-7 points; winning >7 points.



Field Position Analysis

Choice patterns were examined according to the field position where penalties occurred (Figure 7). The attacking half was divided into four zone groupings, with field position conceptualized as a spatial environmental stimulus potentially influencing choice responses.

Descriptive patterns suggested that penalties in center zones closest to the in-goal area (R and S zones) yielded the highest GME fit (R^2 = 0.64). At the same time, other field positions showed more modest correspondence (R^2 values below 0.40). Sensitivity patterns appeared highest in R and S zones (a = 0.76) and lowest in flank zones near the in-goal area (Q and T zones, a = 0.30).

Bias patterns suggested potential relationships with field position characteristics. Penalties occurring in flank zones near the in-goal area (Q and T zones) appeared associated with strong lineout bias (log b = 0.94). In contrast, penalties in center zones away from the in-goal area (N and O zones) showed much weaker lineout bias (log b = 0.13). This pattern suggests that the location of penalties relative to goal posts and in-goal proximity may influence choice preferences, with difficult kicking angles and positions potentially associated with increased lineout selection.

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Figure 6

Relationship between bias values and score differential. Teams trailing significantly (<-7) appeared to show more substantial lineout bias, while teams with slight leads (+1 to +7) showed weaker lineout bias.

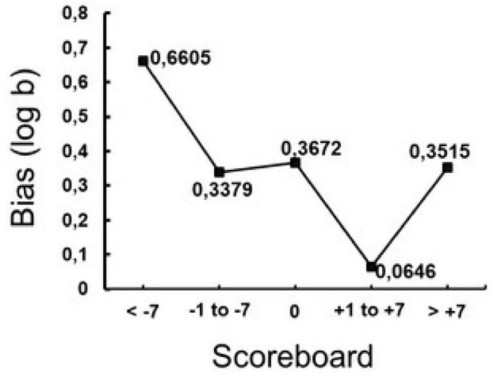
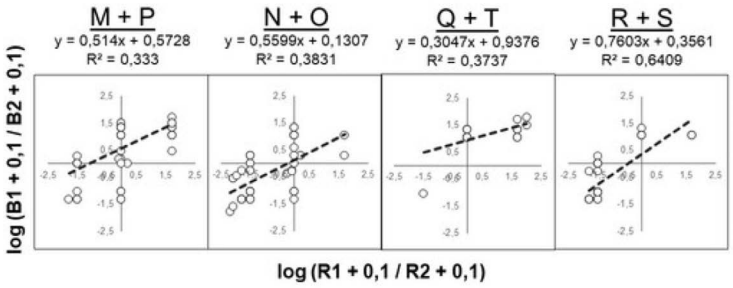


Figure 7

Descriptive patterns by field position. Points represent individual matches. Field divisions: away from in-goal/near flanks (M,P zones); away from in-goal/near center (N,O zones); near in-goal/near flanks (Q,T zones); near in-goal/near center (R,S zones).



Summary of Descriptive Patterns

This exploratory analysis revealed several descriptive patterns suggesting potential relationships between contextual variables and penalty choice behavior in rugby union. Higher-ranked teams appeared to show greater variance explained by GME compared to lower-ranked teams. The score differential seemed to be associated with bias patterns, with disadvantageous situations potentially favoring lineout choices and advantageous situations potentially favoring goal kicks. Field position appeared to influence choice patterns, with difficult kicking positions potentially associated with increased lineout bias. These preliminary observations lay the groundwork for future hypothesis-testing investigations of behavioral choice patterns in rugby union contexts.

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Discussion

Team and Opposition Analysis: Relationship between R^2 and Performance

The descriptive patterns observed across the six teams suggest potential differences in how choice behaviors correspond to reinforcement outcomes. Two of the three highest- ranked teams displayed R^2 values above 0.7, while none of the lowest-ranked teams exceeded 0.3. These preliminary observations suggest that GME might potentially serve as a behavioral indicator of team performance in penalty choice contexts, with point accumulation patterns appearing to correspond more closely with choice behaviors among higher- performing teams. Lower-performing teams appeared to show choice patterns that may be influenced by variables other than immediate point outcomes.

Since these observations are descriptive in nature, this apparent trend warrants investigation through studies with larger datasets and statistical validation. Similar visual patterns have been reported in American football (Reed et al., 2006) and college basketball (Alferink et al., 2009), though not in ice hockey applications (Seniuk et al., 2015). This descriptive finding suggests that rugby union may represent another sports context where performance level appears to be related to behavioral sensitivity patterns, although the mechanisms underlying such relationships remain to be determined.

This exploratory finding may contribute to Sports Science research in rugby union that examines which game variables relate to match outcomes (Gaviglio et al., 2013; Vaz et al., 2011). GME applications might offer a behavioral analysis perspective for investigating how psychological factors relate to penalty choice behaviors. Including behavioral choice patterns as potential performance indicators would represent a novel approach in rugby union research, complementing existing technical and tactical performance measures.

Using GME as a Psychological Metric of Performance

Performance Analysis in rugby union has expanded considerably, with specialized data collection companies (Opta - https://www.optaprorugby.com; Hudl SportsCode - https://www.hudl.com/sports/rugby) and academic research investigating performance during specific match phases (Croft et al., 2015; Vaz et al., 2019; Watson et al., 2021).

While psychological factors are recognized as essential for sports performance (Dosil, 2005; Luiselli et al., 2011; Luiselli & Reed, 2011), quantitative Performance Analysis tools addressing psychological dimensions appear less common than tools addressing technical and tactical skills (Bransen et al., 2019; Reed et al., 2011). The exploratory application of GME in this investigation suggests a potential approach for quantitatively characterizing behavioral choice patterns in rugby union penalty situations.

The relatively low lineout bias observed for Bristol Bears (log b = 0.19) compared to other teams illustrates how such analyses might provide tactical insights. This pattern suggests Bristol Bears appeared to select goal kicks more frequently than might be predicted based solely on point outcomes from available alternatives. Understanding such tendencies could potentially inform preparation strategies when facing particular opponents. Similarly, teams might benefit from recognizing situations where they tend to commit penalties, given opponents' likely choice patterns.

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The opposition analysis reveals how defensive characteristics might function as discriminative stimuli influencing attacking choice responses. The observation that opponents facing Saracens showed strong lineout bias (log b = 0.82) suggests teams confronting this defense appeared to select lineout options more frequently than point outcomes alone might predict. Such patterns, if confirmed through larger studies, could inform tactical preparation by highlighting how specific opponents might influence penalty choice behaviors.

This exploratory evidence suggests GME might offer a framework for characterizing both attacking choice patterns (team analysis) and defensive influence on opponents' choices (opposition analysis). Future investigations with larger datasets might determine whether such measures could provide reliable tactical intelligence for coaching staff in rugby union contexts.

Scoreboard Analysis

The Influence of Differential Score on Bias Patterns

Rugby union offers three primary scoring mechanisms: tries with conversions (7 points), tries without conversions (5 points), and successful goal kicks (3 points) (World Rugby Laws, 2021). For the penalty choices examined in this study, tries could only result from lineout selections, while goal kicks could only produce three-point outcomes. The observed average points per lineout attempt (0.93) and per goal kick attempt (2.23) suggest lineout choices might represent higher-risk, higher-reward alternatives compared to the more predictable goal kick option.

The descriptive patterns observed across score differentials suggest potential relationships between competitive situations and choice preferences. Teams trailing by more than seven points appeared to show more substantial lineout bias (log b = 0.66), while teams leading by small margins showed weaker lineout bias (log b = 0.06), approaching goal kick preference. These patterns suggest that differential scores may function as a contextual stimulus influencing choices toward riskier alternatives when catch-up scoring becomes necessary, and toward safer alternatives when protecting a narrow lead.

Similar patterns have been observed in other sports contexts. American football applications have suggested that greater score deficits may lead teams to make riskier play selections (Stilling & Critchfield, 2010). The current findings provide another example of how competitive situations might influence choice behaviors across different sports, with the "distance to opponent" stimulus appearing to systematically relate to risk tolerance in tactical decisions.

Field Position Analysis

Relationship between Bias Values and Proximity to Flanks and In-Goal Area

The descriptive patterns observed across field positions suggest potential relationships between spatial factors and choice preferences. Penalties occurring near field flanks appeared associated with stronger lineout bias (M+P zones: log b = 0.57; Q+T zones: log b = 0.94) compared to central positions (N+O zones: log b = 0.13; R+S zones: log b = 0.36). Additionally, penalties closer to the in-goal area appeared to show more substantial lineout bias (Q+T: log b = 0.94; R+S: log b = 0.36) compared to more distant positions (M+P: log b = 0.57; N+O: log b = 0.13).

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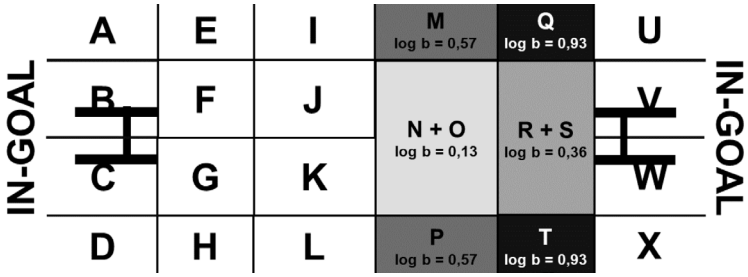
These patterns suggest potential relationships between kicking difficulty and preferences for choice. Previous rugby union research has identified that kicks from flank positions and greater distances present increased difficulty (Nel, 2023; Pocock et al., 2020; Quarrie & Hopkins, 2015). The observed bias patterns align with such findings, suggesting that spatial conditions affecting kick difficulty might correspond with choice preferences favoring lineout alternatives.

The relationship between in-goal proximity and lineout bias presents an interesting pattern that differs somewhat from research on kicking difficulty, which typically identifies distant kicks as more challenging. The more substantial lineout bias observed near the in- goal area might reflect the increased reinforcement value associated with try-scoring opportunities when the field distance to the goal line is reduced. Alternatively, other reinforcing stimuli beyond point accumulation might influence these choice patterns in ways not captured by the current analysis.

Figure 8

GME data by field position where the penalty is marked. There is a relationship between field position and bias (log b) values. The darkest areas show that bias is more pronounced for the lineout option when a penalty is marked near the sideline and in the in- goal area (zones U-X).



These preliminary spatial relationships suggest that field position characteristics might systematically relate to penalty choice behaviors, though the underlying mechanisms warrant further investigation through controlled studies.

Methodological Considerations and Limitations

This exploratory analysis employed visual pattern inspection consistent with behavioral analysis traditions for examining choice phenomena in applied settings. Several significant limitations should be acknowledged when interpreting these findings.

The descriptive nature of the analysis limits conclusions to pattern identification rather than statistical inference. The sample size (11 matches per team, totaling six teams) represents a relatively small dataset for drawing broad generalizations about rugby union choice behavior. The focus on teams from a single league during a single season segment may limit generalizability to other competitive contexts or time periods.

The field position categorization system, while based on practical considerations for data collection, represents a simplified approach to characterizing spatial relationships that might in-

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fluence choice behavior. More sophisticated approaches incorporating continuous distance and angle measurements might reveal different patterns.

The reinforcement measure (points obtained) captures only immediate scoring outcomes. It does not account for other potentially important consequences of penalty choices, such as field position gained, time management, or momentum factors. These additional variables might significantly influence choice behaviors in ways not reflected in the current analysis.

The opponent analysis treats defensive teams as a discriminative stimulus, but does not control specific defensive characteristics that might systematically influence choice behaviors. Future investigations might benefit from incorporating specific defensive performance metrics to better understand the mechanisms underlying opponent effects.

Future Research Directions

This exploratory investigation lays the groundwork for several potential research extensions. Larger-scale studies incorporating multiple seasons and leagues could examine whether the observed patterns replicate across different contexts and provide adequate power for statistical hypothesis testing.

Incorporating additional reinforcing stimuli beyond point accumulation (such as field position gained, possession retention, and momentum indicators) might improve model fitness and provide a more comprehensive understanding of choice determinants. Developing continuous measures for field position characteristics (distance and angle to goal posts) could refine spatial analyses beyond the categorical approach employed here.

Longitudinal analyses could examine whether choice patterns change over seasons or across different competition phases. Individual player analyses might reveal whether penalty choice patterns vary according to specific decision-makers (captains, kickers) rather than team-level factors.

Integration with existing rugby union performance analysis frameworks could explore relationships between behavioral choice patterns and other established performance indicators. Such approaches might determine whether behavioral measures provide independent predictive value for team performance beyond current technical and tactical metrics.

Conclusions

This exploratory analysis examined the potential applicability of GME frameworks to penalty choice behavior in rugby union contexts. Descriptive patterns suggested possible relationships between team performance levels and choice behavior, corresponding with reinforcement outcomes. Higher-ranked teams appeared to show greater variance explained by GME compared to lower-ranked teams.

Contextual variables appeared to relate to choice patterns in theoretically consistent ways. Score differential patterns suggested that disadvantageous competitive situations might favor riskier alternatives (lineouts) while advantageous situations might favor conservative choices

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(goal kicks). Field position patterns suggested that spatial factors affecting kick difficulty might correspond with choice preferences.

While these preliminary observations require confirmation through larger-scale statistical investigations, they demonstrate the feasibility of applying behavioral analysis frameworks to rugby union tactical decisions. The patterns observed align with theoretical expectations from GME applications to other sports contexts, providing a methodological foundation for future hypothesis-testing research.

The application of GME to rugby union choice behavior might offer coaching staff and analysts a behavioral perspective for understanding tactical decision-making patterns. By identifying how different contextual factors appear to influence penalty choices, such approaches could complement existing performance analysis tools in characterizing team behavior across multiple dimensions.

This investigation contributes to the expanding application of behavioral analysis principles in sports contexts and suggests rugby union as a viable domain for future research on choice behavior. The descriptive patterns observed warrant further investigation through comprehensive data collection and statistical validation to determine their reliability and practical significance for rugby union performance analysis.

Declaration of Conflicting Interests

The authors declare that there are no conflicts of interest related to the research, authorship, or publication of this paper. This statement affirms the authors' dedication to maintaining objectivity and integrity throughout the research process.

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