

Analysis of Spatially Referenced Headers in Grassroots Football: A Proof-of-Concept GIS Approach

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Abstract: Sports Geography, and specifically spatially referenced locations of events during games and training are increasingly being used to support sports analytics. Here, we develop a proof-of-concept to identify heading locations in amateur football in Ireland, combining video analytics, geographic information systems and science (GIS), cartography, and sports-geography to support this pressing issue. This is to our knowledge the first time such research has been undertaken on Irish sport and subsequently in Irish geography. Video recordings from six amateur premier teams were used to gather and digitise location information on headers. These headers were classified into a typology and visualised to support spatial cognition. Ripley's K spatial point pattern analysis was then applied to statistically test whether header distributions exhibited clustering, dispersion, or randomness across multiple distance scales. In total, we identified 534 headers across five games, varying in location and typology. We found that defensive headers were the most common type, accounting for over half of all recorded headers. Goal kicks and throw-ins also contributed significantly to the total number of headers. Statistical analysis revealed that while overall headers approximated spatial randomness, specific tactical contexts produced distinct patterns: headers from opponent corners exhibited significant clustering in defensive zones, headers from own corners displayed strong dispersion reflecting clearance tactics, and throw-in headers demonstrated distance-specific clustering. We highlight the important positional aspect of the wings in heading, which is a novel result, while the condition of the pitch affected the styles of play of the teams involved, with wet conditions and poorly maintained playing surfaces leading to more headers. The need to deconstruct spatially referenced heading locations by typology, league, and level will be important considerations for policy makers, coaches, and players and may support decisions to reduce long-term brain injuries in players.

Keywords: *Football; GIS; Heading; Football; Video Analysis*

Introduction

Sports geography has a long history in Ireland. In football, Holmes and Storey (2011) argued that Ireland was one of the first nations to push the boundaries of player eligibility in the national team, with the Irish diaspora being used to widen the pool of available talent (Storey, 2023). Ireland is also at the forefront of research exploring the role of the women's national team in growing communal family engagement and national affiliations (Kitching 2025). Similarly, Foley (2015, 2017) and Britton and Foley (2021) have explored the role of geography and place making (particularly blue spaces) in the role of emotions and wellbeing. Griffin and Strachan (2019) hosted a special issue on the history of Irish sport, with several articles pointing to the role that sport played in the Irish cultural revival and revolutionary periods (Rouse, 2019; Raftery & Delaney, 2019; McElligott, 2019). This theme will be further developed in the upcoming Atlas of Irish Sport (Crowley *et al.* Forthcoming) that combines a multidisciplinary and cartographic approach to exploring the subject.

Geographic Information Systems-Science (GIS) has a longstanding history within sports geography. Studies have investigated the impact of variations in sporting opportunities on people's involvement with sport, exploring the nexus of socio-economic variations and underlying geography in provision of facilities (Hillsdon *et al.* 2007; Higgs *et al.* 2015). Similarly, the use of GIS to identify new locations for facilities aligns with one of the more predominant uses of GIS in the wider field, namely site selection (Salami and Khodaparst, 2021; Erturan-Ogut and Kulu 2023). The application of spatial analytical techniques in sports geography is therefore well established; however, despite the popularity of sport in Ireland, studies exploring spatial reasoning alongside spatially referenced game data are lacking.

Analytics across various sports have predominantly focused on goals or points scored (Goldsberry 2012; Shortridge *et al.* 2014). In recent years, there has been a consensus towards achieving a better understanding of players' interactions during the game for both attacking and defensive actions (Gudmundsson and Horton, 2017). Gaining knowledge from sports analytics about a team, whether your own or the opposition, can arguably have a beneficial impact as it allows for patterns of play to be monitored and analysed (Gudmundsson and Horton, 2017). Sports analytics involves the structured collection of data, the application of advanced analytical models that utilise this data, and information technologies to educate decision-makers to support their team in attaining a competitive advantage (Martin, 2016). Due to the spatial nature of the data, geography has a key role in developing such decision-making, both from a bottom-up team perspective, but it also supports top-down policy decisions. However, Goldsberry (2019) argues that it is only recently that sports analytics and geography have become allies, following the advent of spatially referenced game data alongside increased availability of high-powered computing, and a cultural demand for quantification of sports.

Association Football (or 'soccer' and herein 'football') is the world's most popular team sport (Hulteen *et al.* 2017). The game is regulated globally by Fédération Internationale de Football Association (FIFA); however, each nation has their own regulatory body. In

the Republic of Ireland, this is the Football Association of Ireland (FAI). Players specialise in different positions that include goalkeeping, defence, midfield, and attack. The objective is simple, to score more goals than the opponent. Passing, dribbling, shooting, and controlling the ball in various ways are fundamental skills developed from grassroots to professional levels. The game is played with a ball primarily with feet, but players can also use their chest, thighs, or head in an outfield position, while goalkeepers are allowed use their hands within a specific area of the pitch; on a full sized pitch this area is 44 yards (40.2m) wide by 18 yards (16.5m) long.

Striking the ball with the head (heading) is an integral football skill, required by both defensive and attacking players in set-piece moments, and in open play phases of the game (Peek *et al.* 2023). The act of heading can include passing the ball, defensively clearing the ball, shooting towards goal or controlling the ball to either create or deny an attacking opportunity. The increase in the value of set-pieces has coincided greatly with a rise in the value of heading, with nearly half of all heading game actions occurring within set-pieces (Sarajärvi *et al.* 2020). An increase in the number of goals scored from set-pieces (i.e. penalties, free-kicks, corner kicks, goal kicks, and throw-ins) has become an emerging trend within the professional club game over the last few decades (Sarmiento *et al.* 2025). This is reflected within the international stage, where the frequency of goals scored from set pieces increased by 0.27% across every rendition of the FIFA World Cup from 1966 to 2018 (Mićović, *et al.*, 2023). Goals, and goal contributions directly from set-pieces, or following on from set-pieces are an ever-increasing factor contributing to game outcomes (i.e. winning and losing), highlighting their essential value from both an attacking and defensive perspective (Sarmiento *et al.*, 2025; Strafford *et al.*, 2019).

Across the “big 5” European top-flight professional leagues (in France, Spain, Germany, England, and Italy), a minimum of 90 headers per game is commonly observed, with evidence of a higher number of headers in lower tiers of competition (Tierney & Higgins, 2021). Over the past 5 completed seasons (2020-21 through 2024-25) within the English Premier League, a total of 847 headed goals were scored, headed goals accounting for 15.3% of all goals scored across the competition within that time span (Transfermarkt, 2026). Players in the English Premier League perform and contest more aerial duels than those in La Liga (Dellal *et al.*, 2011), while Italian football clubs had a higher percentage of goals scored from headers than those in Spain (Papadopoulos 2021), indicating that playing style and culture can contribute to heading incidents (headers) within a game. Liu *et al.*, (2015) have all previously highlighted that headed scoring opportunities are an important tactic for weaker teams that typically have fewer chances to score from open play. Headers are a vital component to offensive and defensive play, with cultural differences in their prevalence across countries reflecting varying playing styles, endemic to different places.

Here we present a proof-of-concept study that uses low-cost technology to identify header locations, incorporate them into a GIS framework, and use the resulting information to support spatial analytics, focusing on adult grassroots teams. Beyond descriptive mapping and visualization, we employ spatial point pattern analysis to

statistically test for clustering or dispersion in header distributions. Moreover, this research also provides the opportunity to explore the spatial dimension of potential health consequences of heading the ball. Head injuries in football are a longstanding consideration, with research needed to determine the reasons behind such deficits (Kirkendall *et al.*, 2001). Through spatial analysis of heading locations, we may be able to identify novel geographic patterns that could support insight into this pressing issue. The remainder of the introduction is structured into i) tactics and ii) health.

Tactics

Information on the location of headers on a pitch is used predominantly to better understand a team's playing style, so that coaches can develop baseline information, or a playing philosophy that enables them to anticipate an opponent's movement patterns and effectively counteract them, or to increase their own team's goal-scoring opportunities (Beernaerts *et al.*, 2020). The information generated is used in sports analytics studies which focuses on improving sports performance through the application of scientific methodologies (Morgulev *et al.*, 2018).

Research has typically focused on gathering macro-level statistics such as headers per game (Dellal *et al.*, 2011; Rampinini *et al.*, 2009) and/or jumping techniques utilised when heading the ball (Kristensen *et al.*, 2004; Paoli *et al.*, 2012). Sarajärvi *et al.*, (2020) conducted research which examined the frequency and locations of headers in the English Premier League during the 2017-18 season, concluding that most headers occurred during a defensive action where a player headed the ball to prevent an attacking team from making progress. Identifying areas of the pitch where headers most commonly occur can therefore provide a competitive advantage for those involved in sports analytics, by helping organise either defensive or attacking structures to improve attacking chances or reduce attacking opportunities. (Sarajärvi *et al.*, 2020).

Health

Knowledge of heading location may also prove to be important in reducing brain injuries. In 2021, the English Football Association (FA) introduced guidelines for professional footballers to reduce the frequency of heading the football in training. They recommend that no player should complete more than ten high-force headers, such as headers from long passes/goal kicks or from crosses, free kicks, or corners, per week. This was in response to the increasing concerns that repeated heading of the ball may lead to long-term neurodegenerative diseases (Evans *et al.*, 2022). For the 2022-23 season the English FA trialled a heading ban in football for players aged U-12, mirroring a ban introduced in the United States in 2015 which targeted the same age cohort. These bans and guidelines were introduced because of recent studies identifying a link between heading and brain injuries (Rodrigues *et al.*, 2016). These include early onset dementia, motor neuron disease, and Parkinson's disease with a higher frequency of these injuries reported amongst retired professional players relative to the general population (Mackay *et al.*,

2019; Neal *et al.*, 2022; Russell *et al.*, 2019; Ueda *et al.*, 2023). Due to scientific and public concerns, such proactive guidelines were widely supported (Peek *et al.*, 2023).

Heading locations can therefore inform the development of a typology of the headers that are utilised within a game. For example, Sarajärvi *et al.*, (2020) suggest that a considerable number of headers (~50%) in the Premier League occur because of goal kicks, with Tierney and Higgins (2021) suggesting that rule changes relating to goal kicks are needed due to the higher velocity of the football. However, it is unclear where precisely the headers that result from goal kicks (or other plays) occur on the pitch and whether there is a bias in where the football lands after such plays. If there is a pattern it may be important information to inform and support any rule change. Therefore, there is a need to investigate how and where headers at all levels of the game are occurring, and whether statistics from the professional leagues can be accepted and applied to those playing at non-elite levels. This builds on successful rule changes that have been implemented due to head injuries in football (Peek *et al.*, 2023). For example, in 2006 the deliberate elbowing of the head by a player resulted in the red card¹ for the offending player, supporting a 29% reduction in head injuries in the German Bundesliga from 2000-01 to 2012-13 (Beaudouin *et al.*, 2019).

To-date, there is no published analysis undertaken of Irish amateur football teams to the best of the authors' knowledge, exploring either tactical or health consequences. This is pertinent as according to Sport Ireland's (2022) Irish Sports Monitor (ISM) Annual Report, 25% of all adults reported playing some level of competitive football over the age of 16, with football the most popular team sport exercise when considered across socio-economic statuses, ethnicities, and ages across the years 2022-24. Coupled with the lack of spatial reasoning alongside spatially referenced game data in Irish football, at any level of the game, the need for research into the geography of heading locations to support ongoing discourse related to football, geography, health, and sports analytics is evident.

Methodology

This study collected and analysed data for six different adult amateur premier teams in the 2022-2023 season of The Waterford and District Junior League (Ireland). One team was followed as they played five opposing teams, home and away. Adopting a similar approach to Sarajärvi *et al.*, (2020), players who intentionally headed the ball were considered for this research, and accidental touches of the ball on a player's head were not included. Multiple situational variables were used for the data collection, similar to those in Sarajärvi *et al.*, (2020).

Video data were acquired using a Veo video recorder. Veo is an intelligent double-sided camera that covers a 180 degree view of the full pitch. The camera automatically follows the ball's position on the pitch, capturing the full game. It has been widely used for game analysis (Minkesh *et al.*, 2019). Video recording analysis was used to subsequently create

¹ A red card in football is the most serious punishment a referee can give to a player during a match, with the player immediately sent off the pitch. This player cannot return or be replaced.

the primary data. A preliminary inspection of the video data was used to identify the main types of headers (Table 1). The recordings were then replayed and manually inspected to identify: a) the location of each header and; b) which type of header was executed based on those identified in the preliminary inspection (Table 1). The pitch was divided into a reference grid (Figure 1) and headers were plotted to this grid (following Brooks *et al.*, (2016)). The pitch grid location and type of header was recorded in Microsoft Excel and georeferenced within GIS (QGIS v3.22.9.)

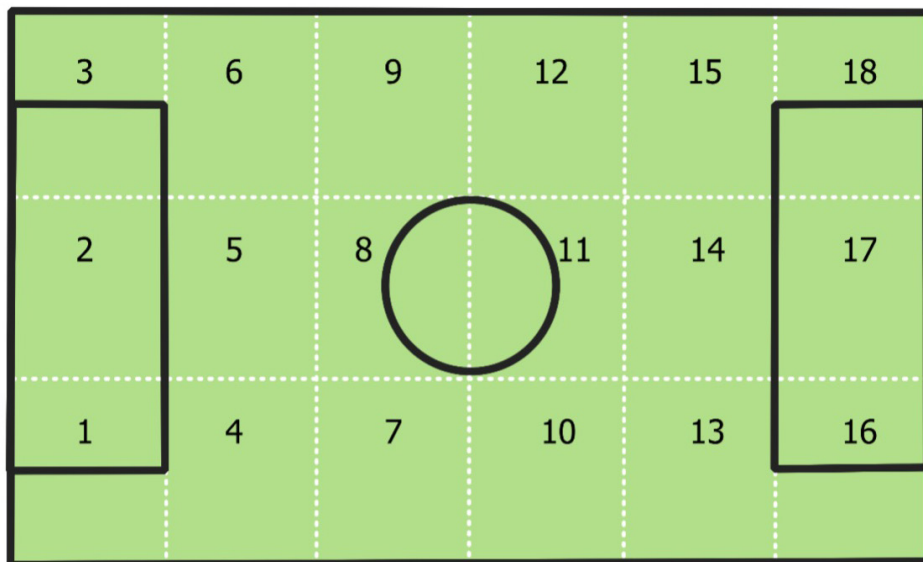


Figure 1: Football pitch split into 18 zones. Zones 1-3 are defensive areas, and 16-18 are the attacking areas (method adapted from Brooks *et al.*, 2016)

For each of the 16 zones, the total number of attacking, defensive, and other headers were reported as frequency and visualised using a graduated proportional symbology. The explicit coordinates of the header locations were then used to generate heatmaps, which represent the density of headers in a location. These maps support spatial cognition of patterns (Holloway, 2023).

Table 1: The typology of headers used in the research and their codes and colours used to display the data

Legend	Code
Attacking header 1 = Header in opposition half	1
Attacking header 2 = Header in own half	2
Attacking header 3 = Attacking team header from free kick	3
Attacking header 4 = Attacking team header from corner	4
Defensive header 1 = Defensive header in own half	5
Defensive header 2 = Defensive header from a free kick in own half	6
Defensive header 3 = Defensive header from a corner	7
Header resulting from a goal-kick	8
Header resulting from a throw-in	9
Header resulting in a goal	10
Attempted header resulting in a head injury	11

Spatial Point Pattern Analysis

While descriptive statistics and visual inspection of spatial patterns provide valuable insights, they cannot definitively determine whether observed patterns represent statistically significant clustering, dispersion, or randomness. To address this, point pattern analysis using Ripley's K was used (Ripley, 1976). Unlike nearest-neighbor approaches that focus on a single scale, Ripley's K provides a cumulative measure of spatial dependence by comparing observed point distributions against those expected under a homogeneous Poisson process, or complete spatial randomness (CSR). Confidence envelopes generated through Monte Carlo simulations are then used to test whether deviations from CSR are statistically significant. Applications of Ripley's K are widespread in geography, ecology, epidemiology, and criminology, where it has been used to evaluate the clustering of trees, disease cases, and crime incidents (Dixon, 2002; Bailey & Gatrell, 1995). More recently, methods like Ripley's K have entered the domain of sports geography and sports analytics (basketball; Miller *et al.*, 2014; Franks *et al.*, 2015).

A Multi-Distance Spatial Cluster Analysis (Ripley's K Function) was conducted in ArcGIS Pro on all headers and their typologies to assess whether header locations exhibit spatial clustering or dispersion across multiple distance scales. The analysis measures the spatial distribution of point features relative to a pattern expected under CSR. For each point in the dataset, the tool counts the number of other points within increasing distance bands and compares it to what would be expected under CSR. The theoretical K function is:

$$K(d) = \frac{A}{n^2} \sum_{i=1}^n \sum_{j=1}^n I(d_{ij} \leq d)$$

where $K(d)$ is the Ripley's K value at a radius d around each point, A is the area of the study region, n the number of points, and d_{ij} is the distance between points i and j . $I(d_{ij} \leq d)$ is the indicator function that equals 1 if $d_{ij} \leq d$, and 0 otherwise.

The original Ripley's K function, $K(d)$, is in units of area (e.g., square meters), which can be hard to interpret directly. To make the results easier to understand, especially when comparing observed patterns to random expectations, analysts often transform the results using the L-function, which is a standardised version of K :

$$L(d) = \sqrt{\frac{K(d)}{\pi}} - d$$

This equation removes unit scaling so there can be a direct comparison of the observed value to the distance.

The conditions for the Ripley's K function in ArcGIS Pro were as follows: 10 distance bands with 10-meter increments (up to 10 meters or length of football pitch), 99 permutations to compute confidence envelopes under the assumption of CSR, Ripley's edge correction formula for the boundary correction method, and a minimum enclosing rectangle as the study area method. The Expected K line represents a homogeneous Poisson process, or CSR, where the number of neighbours increases smoothly with distance. The confidence envelopes, generated through Monte Carlo simulations, indicate the range of variation expected under CSR. When the Observed K curve falls above the upper confidence envelope, this suggests significant clustering (more neighbors than expected). Conversely, when the curve falls below the lower envelope, it indicates significant dispersion or regular spacing (fewer neighbours than expected). If the observed curve remains within the envelopes, the pattern is statistically indistinguishable from randomness at that distance.

Results

Descriptive Statistics

A total of 534 headers were recorded across the five matches. These were recorded across various zones on the pitch (Figure 2). The highest frequency of headers occurred in zones 12 ($n=70$), 17 ($n=56$), and 2, 13, 14 ($n=43$). Headers were recorded in all zones, but the lowest frequency of headers occurred in zones 1 ($n=2$), 16, ($n=5$), 3, and 8 ($n=9$). Attacking headers ($n=128$) accounted for 23.97% of all headers, resulting from open play and set pieces such as corners and free kicks. Defensive headers ($n=282$), which again included headers from open play and set pieces accounted for 52.81% of all headers. Finally, headers from other plays ($n=124$), including goal kicks and throw-ins, and those that resulted in a goal or injury accounted for 23.22% of headers. Interestingly, there were substantial differences in the number of headers recorded across the five matches. While the mean number of headers per game was 107, this masked a substantial range. The match with the highest number of headers ($n=142$) had almost twice as many incidences of heading as the match with the least ($n=73$).

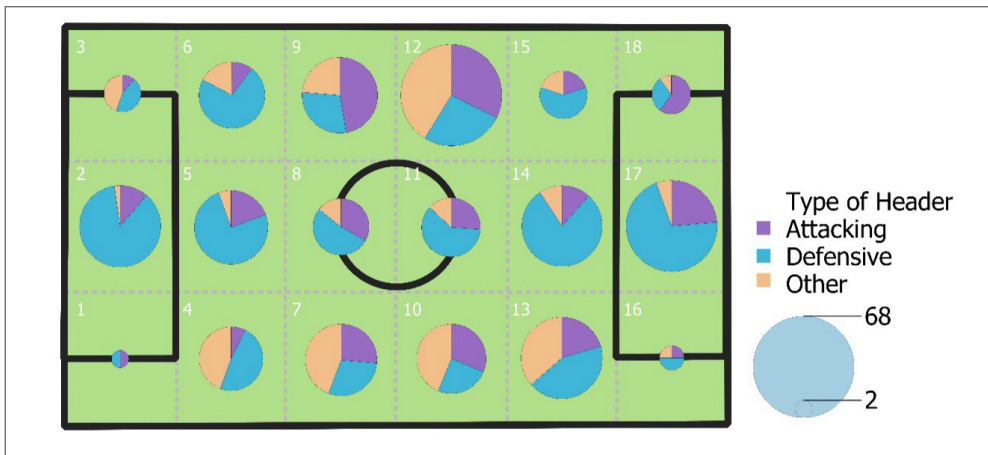


Figure 2: Graduated symbology of the frequency of the headers and the categories of 'attacking', 'defensive', and 'set piece' divided into the 18 pitch zones

Of the 128 attacking headers, the most frequent were those undertaken in the opposition's half, occurring 101 times (78.91%), followed by those undertaken in a player's own half ($n=13$, 10.16%), those won from a team's own free kick ($n=11$, 8.59%), and those from a corner ($n=3$, 2.34%). Visual inspection of the data shows concentrated areas of headers across all five games (Figure 3), with the frequency of attacking headers consistent across games as well. Figures 2 and 3 indicate that zones 9 and 12 were the locations where most attacking headers occurred during the games, largely on the wing. In these two zones nearly one third of all attacking headers occurred. The corner zones of 1, 3, and 16 had, unsurprisingly, the least attacking headers, with only one in each.

Defensive headers were the most common type of header across all five games. Of the 282 defensive headers, the most frequent were those in their own half, occurring 220 times (78.01%), followed by those from free kicks ($n=36$ 12.77%) and then corners ($n=26$ 9.22%). Defensive headers again appeared concentrated in areas, primarily in a U-shape around the penalty area. Zones 5 and 14 had the highest density of defensive headers, while zones 6 and 12 on the wings also had a surprisingly high density, mirroring the attacking headers in those zones (Figure 3). Perhaps the most interesting finding is that 27% of all defensive headers occurred in the central penalty area but this rises to almost 70% when the areas immediately in front of the penalty area (zones 4-6 and 13-16) are included. This finding reveals that players in the centre back position headed the ball most during the games; this finding agrees with findings in Roman *et al.*, (2023) who analysed the 2022 FIFA World Cup and youth football in India and Australia, and echoes findings of Tierney & Higgins (2021) who analysed headers across three seasons in the five highest ranked European leagues.

There were 124 headers in total from goal kicks, throw-ins, goals, and head injuries. Five zones on the pitch were dominant for these header locations. Zone 12 was the most common area for headers from this category, with 28 headers, while zone 1 had zero. Goal kicks ($n=61$, 49.19%), and throw-ins ($n=58$, 46.78%) made up 22.29% of the

total headers (n=534) in the dataset. The patterns of play, as seen in Figure 3, suggest that most goal kicks and throw-ins result in headers occurring on the flanks of the pitch. Goalkeepers tended to aim for their wingers when kicking the ball out of their hands and off the ground. Only 3 headed goals occurred in the 5 games. There were 2 head injuries due to an attacking player colliding with a defender to head the ball. Long balls from a defender and a goalkeeper led to the coming together of two players in the air resulting in minor head injuries.

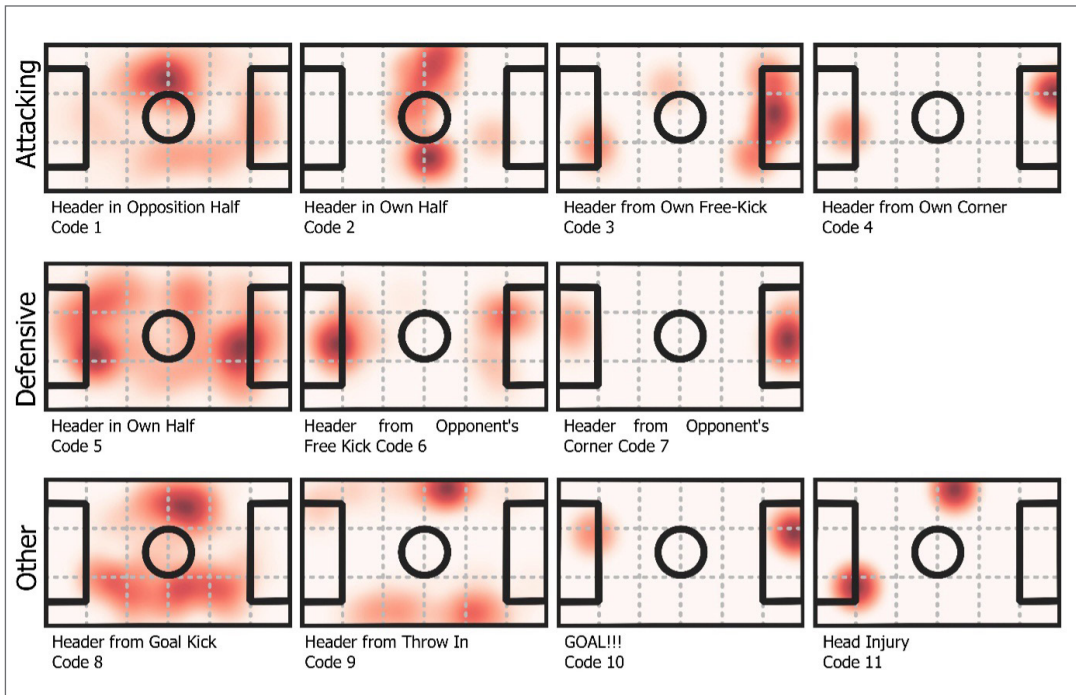


Figure 3: Heatmaps of the typology of headers

Spatial Point Pattern Analysis Results

The Observed $L(d)$ curve closely follows the Expected $L(d)$ curve across all distances when considering all headers collectively (n=534). At larger distances (beyond ~50 meters), the observed values flatten slightly and fall below the expected values, suggesting a trend toward dispersion. However, the Observed $L(d)$ values remain entirely within the 99% confidence envelope (yellow), indicating that the spatial pattern does not significantly differ from randomness.

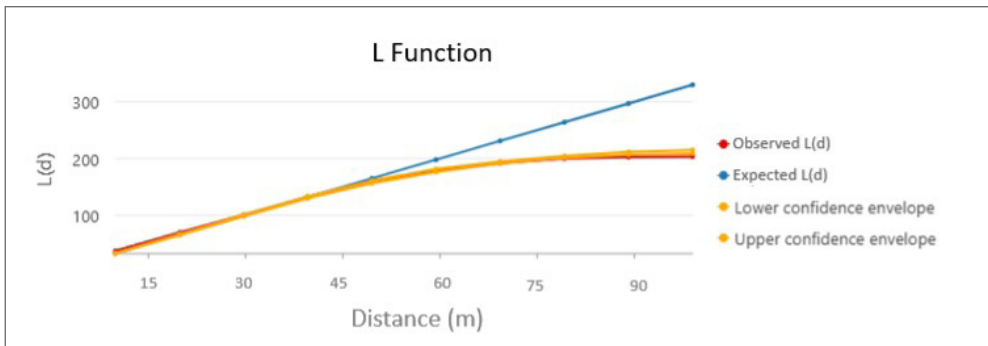


Figure 4: Ripley's K analysis results for all headers (n=534). The observed $L(d)$ values remain within the 99% confidence envelope, indicating spatial randomness.

The Ripley's K analysis was then performed for the typologies of headers (Table 1). The Ripley's K Function analysis across header types reveals mostly random spatial distributions with some mild clustering in specific contexts. Headers in the opposition half (Code 1), own half (Code 2), and from own free-kick (Code 3) display observed K values within the confidence envelopes, indicating spatial randomness. Headers from own corners (Code 4) show strong dispersion, with observed values far below the expected K, likely reflecting wide clearances rather than localised play, which was an unexpected result. Defensive headers in own half (Code 5) also show strong dispersion, with observed values remaining flat and far below expected, suggesting these headers are more spread out across defensive zones than would occur under random spatial distribution. Headers from defensive free-kicks (Code 6) show observed values within confidence envelopes, indicating spatial randomness, while headers from opponent corners (Code 7) display stronger clustering, suggesting repeated defensive actions in concentrated zones. Headers from goal kicks (Code 8) appear spatially random, while throw-in headers (Code 9) show clustering at certain distances, potentially reflecting common tactical routines. Headed goals (Code 10) show a dispersed pattern, with observed K values staying low and within confidence bounds-likely due to their rare and spatially varied nature. Code 11 (head injuries) was excluded due to an insufficient number of data points for analysis. These patterns highlight how set pieces and throw-ins often produce more localised clustering, while open play and goal-scoring headers are more spatially dispersed across the pitch.

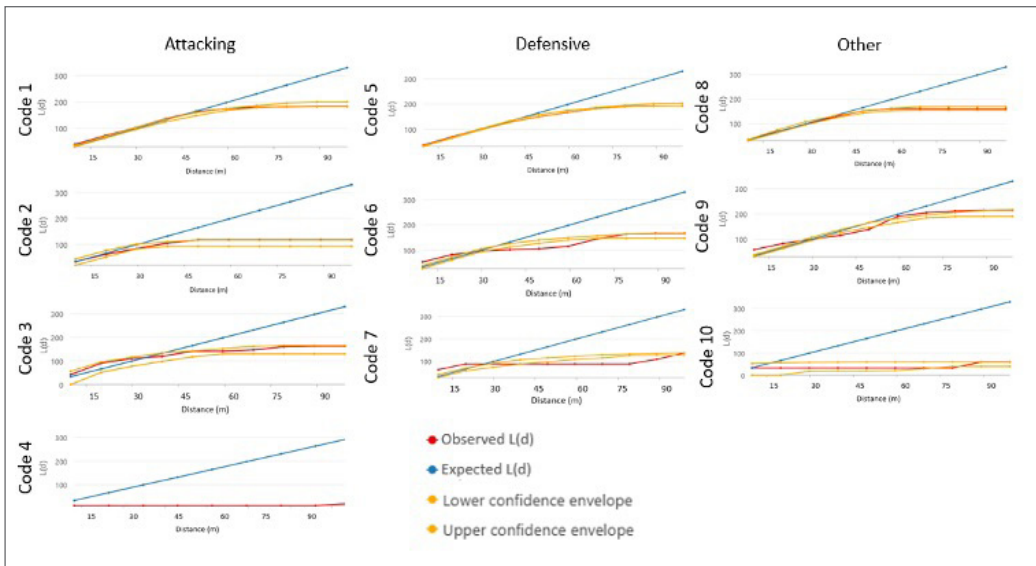


Figure 5: Ripley's K analysis results for header subcategories (Codes 1-10). Observed K (red), Expected K (blue), with lower and upper 99% confidence envelopes (orange/yellow). Different header types show varying degrees of clustering, dispersion, or randomness.

Discussion

The main aim of this research was to generate spatially referenced game data from a sample of matches in amateur football in Ireland, to undertake exploratory analysis on the geography of heading locations to support ongoing discourse related to football, health, and sports analytics. In doing so, a total of 534 headers were identified, with clusters occurring across different zones of the pitch (Figure 2). When considered across the 11 different typologies of headers (Table 1, Figure 3), we identified several consistent patterns across the games, as well as similarities and differences between attacking and defensive headers that both support and contradict other studies that have investigated the spatial location of headers in professional and youth games. The different types of headers showed significant differences in whether they were considered spatially clustered, dispersed, or random (Figures 4 and 5), demonstrating the need to deconstruct the data into typologies.

The most common area of the pitch that headers took place in was inside both penalty areas (Figures 2-3). In total, there were 117 (21.91%) headers inside the penalty areas across all five games. This aligns with Sarajärvi *et al.*'s, (2020) study of the English Premier League who found 27.6% of headers occurred inside the box. While our results contrasts Sandmo *et al.*, (2020) in their investigation of headers in youth football (ages 11-19) who found that the central midfield area of the pitch was the most common area where heading occurs, our research still identified the central areas of the field to contain a substantial number of header types 1, 2, and 3 (23.03%) (Zones 5,8,11,14 – Figures

2-3). However, our results suggest a difference between adult and youth football. Youth football may possess a less structured, more fluid dynamic, or this may be due to the differences in kicking distance reported by age (Bedoya *et al.*, 2015). The plays that lead to heading the football, such as long-balls and goal kicks may still be the same, but the players that are required to head the ball shift from central midfield to central defence as the age groups increase. If any targeted strategies are introduced in the game to reduce heading, different approaches may be needed for different age cohorts, as well as other axes of differentiation not explored in this study (e.g., gender).

A critical finding from this research was the considerable number of both attacking and defensive headers on the wings (zones 7, 9, 10, and 12 – Figure 1), when compared to other studies (e.g., Sarajärvi *et al.*, 2020). Headers from goal kicks and throw-ins were the most frequent headers in these areas. Multiple reasons may account for both these findings which will be outlined. Ball in-play time (i.e. length of time the ball is in open play during a 90-minute game) across various studies of elite level professional football is typically noted between 54-57 minutes (Jerome *et al.*, 2023; Riboli *et al.*, 2021). A greater number of throw-ins at the amateur level may simply reflect reduced ball in-play time (due to lower standard of player and greater degree of inaccuracy in passing/shooting etc), which culminates in a higher number of both set-piece and heading opportunities. There may also be tactical and player characteristics components that are driving this pattern.

Many of the headers on the wings were the result of long balls played from the defence; there were also many headers that went back and forth from both teams in these areas. Certain strategies employed by football coaches may target the wings for attacks, due to the higher importance in training assigned to central defence. The proliferation of the 4-2-3-1 tactical formation across elite level professional football within the last decade and half has been well documented², and it was the most utilised formation across European football between 2013 and 2025 (Karaman & Özman, 2025). This formation allows the wingers to stretch the play wide and create more chances. These trends can often trickle down to the amateur levels due to their connotations of success and achievement (Wilson, 2023). One of the acknowledged weaknesses of this formation, is a lack of width and cover in defence, which can expose defensive full-backs and wingers to long balls/passes (Păun & Păun, 2021). As such, the concentration of open-play heading along the wings, may be a result of targeted tactical efforts designed to exploit the 4-2-3-1 formation. In a study of the four major football leagues in Europe, Bloomfield *et al.*, (2005) found that on average midfielders were 1-5 cm shorter than defenders, while Parpa and Michaelides (2022) found that wingers were the shortest players on the pitch; such considerations may point to an opportunity that coaches try to exploit.

The Ripley's K analysis provides important statistical context for the visual patterns observed in the heatmaps. While heatmaps (Figure 3) show areas of higher header density that may appear visually concentrated, the Ripley's K analysis reveals that overall

² The 4-2-3-1 formation in football is a tactical setup that balances defense and attack. The numbers describe how players are arranged from back to front: with 4 defenders, 2 defensive midfields, 3 attacking midfielders, and 1 striker.

headers approximate spatial randomness when tested statistically against complete spatial randomness (CSR). This suggests that headers are distributed more evenly across the pitch than visual inspection alone might indicate. However, important exceptions emerged for specific header types: headers from throw-ins exhibited statistical clustering at closer distances with the observed $L(d)$ greater than the expected $L(d)$ at distances up to 20 m (Figure 5, code 9), concurring with the visual patterns in Figure 3 (code 9). Headers from opposition and own corners also exhibited genuine statistical clustering and dispersion, respectively. These likely reflect an immediate defensive tactic in clearing the ball, followed by (dispersed) attacking headers in follow up play. This demonstrates the value of combining visualization methods with rigorous statistical tests-what appears clustered visually may be statistically random, while certain tactical situations produce genuinely non-random spatial patterns that warrant tactical attention.

According to Stelzer-Hiller *et al.*, (2022), the location on the pitch where a header occurs does not affect heading kinematics. Therefore, the site where a head injury occurs may not be important. However, Kirkendall and Garret (2001) suggest that the most common area of the pitch where head injuries occur is inside the penalty box, often from a keeper colliding with a player or from players competing with a ball from a corner or a cross. Conversely, Fuller (2005) found that most head injuries happened outside the box. Our findings tend to agree with Fuller (2005), finding both of our injuries occurring outside the box (although one was just outside). It is worth noting that given our small sample size this requires further research, but with corners exhibiting the most significant spatial clustering (Figure 5), we would expect this pattern to scale.

Further research on head injuries in amateur football due to headings is pertinent, as many studies claim that heading in professional football leads to significant brain injuries (Mackay *et al.*, 2019; Neal *et al.*, 2022; Russell *et al.*, 2019). Our study adds to the recent literature (Ueda *et al.*, 2023; Weber *et al.*, 2022) surrounding head injuries in football. Furthermore, it has recently been suggested that changes to rules surrounding goal kicks would be beneficial for players as it would result in less heading (Caccese *et al.*, 2016; Tierney and Higgins, 2021). Although these rule changes would positively impact the player's physical health, they may disrupt the different variations of how football is played. In this study, only 61 headers from goal kicks were recorded in the dataset, accounting for just 17.23% of the headers. This contradicts Sarajärvi *et al.*, (2020) who found that almost 50% of headers occurred from goal kicks in the English Premier League. Rule changes may need to be developed based on the specifics of the leagues they are introduced into, differing across youth, amateur, professional football, and across women's and men's leagues. In summer 2025, the FAI updated their concussion protocol (FAI 2025), highlighting heading as a potential mechanism of injury and/or concussion, and a recommendation that youth players adhere to heading guidelines recommended at a European governing body level. No recommendations or specific guidelines were made for amateur or professional adult players, beyond coaches attempting to "limit the heading burden as much as is practical" (p.8).

Some key similarities were found when compared to studies that have explored spatially referenced heading data in the professional game. Our research found that defensive headers accounted for more than half ($n=282$, 52.81%) of the headers in the dataset. This is a comparable finding to Sarajärvi *et al.*, (2020), who stated that most headers occurred during a defensive action. Similarly, Weber *et al.*, (2022) analysed over 1240 matches in German professional football and found that 64.3% of headers were defensive. Therefore, when considered at the amateur level in Ireland, players undertaking defensive duties are required to head the ball more often than players in other positions. Based on the location of these headers (Figure 3), these players include central defenders, but also those involved in plays near the wings, such as wingers and central midfielders.

The difference in the number of headers across games was an interesting finding. The highest number of headers (103 to 142) was recorded on the poorest of all the pitches (little grass, soft underfoot, lots of divots). The state of the pitch may have contributed to players resorting to play the ball for long periods in the air rather than on the ground. Dragoo & Braun (2010) claim that the condition of a football pitch can significantly impact the game's pace and a team's playing style. Unsurprisingly, the lowest number of headers within this research ($n=73$) was recorded on the best playing surface (grass cut, well-maintained, very few divots, flat). It was interesting to note during the game with the lowest recorded headers that most of the goal kicks were played short. Both teams attempted to play the ball out from the back on the ground throughout the game, resulting in significantly fewer headers.

We suggest further research is needed, particularly at grassroots level (e.g., youth, amateur), to explore the role that pitch condition plays in the frequency of headers during football. If pitch condition is linked to lower financial resources of a club or an area, there is a chance that differences across socio-economic axes may result in a disproportionate number of headers and a higher rate of head injuries for poorer clubs. Moreover, given that climate projections in Ireland are expecting an increase in extreme rainfall events (O'Brien and Nolan, 2023), which will coincide with the football season, we expect pitch conditions to worsen, which may compound issues with already poorly drained pitches. Furthermore, there are proposed league changes by the FAI to transition all competitive leagues (from grassroots to professional) to a calendar-year season; however, exemptions to retain winter schedules are being granted. Therefore, this creates the opportunity to explore whether any dichotomy across playing style, heading patterns, and pitch conditions exist given the impact of playing season. In short, our research has highlighted the need for further research and resources to identify whether such patterns persist across the football playing population and the need to ascertain whether a correlation exists between the quality of the pitch and the number of headers.

Conclusion

The aim of this research was to explore how heading locations in football can be used to support sports analytics and inform decisions to support health related discussions on brain injuries in players. Here, we developed a proof-of-concept to identify heading locations in amateur football in Ireland, combining video analytics, geographic information systems, science (GIS) and cartography. This is to our knowledge the first time this research has been undertaken in Irish sport. While we focused on football (soccer), this proof-of-concept can be transferred to most sports, providing sports geography researchers with a tool to analyse pertinent analytical and cultural considerations. Video recordings from six amateur premier teams were used to gather and digitize location information on headers. These headers were classified into a typology and visualised to support spatial cognition. In total, we identified 534 headers across all games, varying in location and typology. We found that defensive headers were the most common type of header (Figures 2-3), accounting for over half of all recorded headers. Goal kicks and throw-ins also contributed significantly to the total number of headers (Figure 3). This research highlights the important positional aspect of the wings in heading (Figure 3), which is a novel result not reported in other studies, which we posit is derived from spatial clustering from throw-ins (Figure 5). This may suggest a preference for amateur football, or a situational variable that is specific to Ireland. Beyond descriptive mapping, we applied Ripley's K spatial point pattern analysis to test whether header distributions exhibited clustering, dispersion, or randomness. This statistical analysis revealed that overall headers approximate spatial randomness, though specific header types-particularly those from set pieces like corners and throw-ins-exhibited significant clustering at certain distances. This methodological contribution demonstrates the value of applying advanced spatial analytical techniques from geography to sports analytics, combining both visualization and statistical hypothesis testing. This research has identified the need to deconstruct spatially referenced heading locations by typology, league, and level. This will be important considerations for policy makers, coaches, and players, as well as the discourse surrounding the long-term brain injuries in players.

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