Laterality
Asymmetries of Brain, Behaviour, and Cognition

ISSN: 1357-650X (Print) 1464-0678 (Online) Journal homepage: www.tandfonline.com/journals/plat20

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**To cite this article:** Karol Dillon, Philip Edward Kearney & Ian Sherwin (2024) Profiling the different types of laterality in high-performance male and female Gaelic footballers, Laterality, 29:5-6, 574-595, DOI: 10.1080/1357650X.2025.2493723

**To link to this article:** https://doi.org/10.1080/1357650X.2025.2493723



Published online: 29 Apr 2025.

LATERALITY: ASYMMETRIES OF BRAIN, BEHAVIOUR, AND COGNITION
2024, VOL. 29, NOS. 5–6, 574–595
https://doi.org/10.1080/1357650X.2025.2493723



# Profiling the different types of laterality in high-performance male and female Gaelic footballers

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**ABSTRACT**

When performing sporting tasks, individuals may use a single side for all tasks (consistently unilateral), both sides equally on each task (consistent bilateral), different sides for different tasks (mixed laterality) or opposing sides when performing tasks with hands versus feet (crossed laterality). Previous research has largely focused on analysing laterality within a single skill. This study used notational analysis to investigate laterality profiles across four skills (two with the hands: hand pass and hop; and two with the feet: kick pass and solo) within high-performance Gaelic Football players. Fifty females and 83 males completed sufficient trials on all four skills to be included. While the majority of players were unilateral, some players displayed a different laterality profile. No player was consistently bilateral for all four skills. Chi-squared tests of independence revealed minimal differences between males and females in levels of partial bilaterality, crossed laterality or mixed laterality. Left-sided male and female players were significantly less lateralized than their right-sided counterparts for all assessed skills. Overall, findings show that laterality is complex, idiosyncratic and non-binary. Recognizing the idiosyncratic nature of limb dominance has numerous applications for coaches involved in player development, opposition analysis and sport scientists involved in talent development.

**ARTICLE HISTORY** Received 18 June 2024; Accepted 10 April 2025

**KEYWORDS** Unilateral; bilateral; crossed lateral; mixed-handed; mixed-footed

## Introduction

Several studies have sought to quantify the extent to which soccer (Carey et al., 2001; Carey et al., 2009; Marcori et al., 2022), basketball (Giovanini et al., 2020; Stöckel & Vater, 2014; Stöckel & Weigelt, 2012) and Gaelic football players

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Supplemental data for this article can be accessed online at https://doi.org/10.1080/1357650X.2025.2493723.

(Dillon et al., 2024; Murray et al., 2023) are equally adept at using both sides of the body; the ability to use both sides is termed bilateral skill. However, the expression of laterality in sport is more complex than often perceived (Castañer et al., 2018; Stöckel & Carey, 2016; Tran & Voracek, 2016). For instance, a player may have a clear dominant side for one particular skill, but the opposite side may be dominant for another skill, while the player can use both limbs with equal dexterity for a third. As such, researchers need to be aware of how sport-specific foot and hand preferences may vary according to the task (Díaz-Pereira et al., 2023). For example, some players may exhibit a clear unilateral preference but still demonstrate high proficiency on the rare occasions they use their non-dominant side (Carey et al., 2001; 2009). Documenting the "rich tapestry" (Castañer et al., 2018) of motor laterality profiles demonstrated within competitive sport may have implications for research and applied sport science.

There is inconsistency around definitions relating to laterality within the sporting context, with Loffing et al. (2014) calling for a more careful use of the term "handedness"; a point which also applies when describing footedness. Most people predominantly or exclusively use one side of the body for tasks of daily life (Cuellar-Partida et al., 2021); this is known as being consistently unilateral (Papadatou-Pastou et al., 2020). Some individuals are bilateral (also termed ambidextrous) in that they are equally likely to use either side of the body to perform a task. Thus, for any one task or sport skill, an individual may be considered consistently right sided, consistently left sided or consistently bilateral. When multiple tasks are considered concurrently, as is the case within many sports (e.g., passing, dribbling and shooting skills in soccer), a simple classification of right-sided, left-sided and bilateral is insufficient to describe the diversity of motor laterality profiles a player might display (Castañer et al., 2018). As Díaz-Pereira et al. (2023) have highlighted, laterality preferences may be task-specific. Thus, an individual may perform one task with the right hand consistently, but consistently perform another task with the left hand. Such an individual is unilateral for any one task, but when considered across a range of tasks would be described as "mixed lateral". While both bilaterality and mixed laterality are "middle" categories between consistently right- and consistently left-sided (Papadatou-Pastou et al., 2008), it is incorrect to use these terms interchangeably; when considering any one skill, a bilateral individual may use either side whereas someone who demonstrated mixed laterality would have a clear preference for one side. Crucially, several sports-related studies (Grouios et al., 2002; Gualdi-Russo et al., 2019; Stöckel & Vater, 2014; Stöckel & Weigelt, 2012) have failed to differentiate between mixed-handedness and bilaterality.

Crossed laterality is a particular subset of mixed laterality which refers to people whose limb preference is not ipsilateral (same side) for hands and feet (Díaz-Pereira et al., 2023) or for eye and limb (Moreno et al., 2022). Crossed laterality has also been referred to as "confused laterality" (Sabatino & Becker, 1971), "mixed preference" (Ullman, 1977), or "mixed dominance" (Shaywitz et al., 1984). In response to this inconsistent use of terms, Ferrero et al. (2017), while admitting that there is a lack of consensus on the operational definition of crossed laterality, proposed two definitions by referring to absolute crossed laterality as

> always using the same opposite sides of the body while performing different tasks with any combination of hand, eye, foot, or ear and *relative crossed laterality as* the marked (but not exclusive) preference for using the same opposite sides of the body while performing different tasks (p. 7).

Studies in the general population have shown that 2% to 7% of right-handed adults prefer their left foot, with the prevalence of left handedness and right footedness being between 20% and 50% of left handed individuals (Barut et al., 2007; Elias et al., 1998; Packheiser et al., 2020; Tran & Voracek, 2016). Thus, crossed laterality may be more prevalent amongst left handers. In a systematic review of 14 studies (2759 participants) Moreno et al. (2022) found a higher prevalence of athletes with crossed hand-eye laterality profiles in sports such as soccer 53%), tennis (42%) and team sports (50.7%) than in the general population (10-30%). Castañer et al. (2018) found that 18% of young athletes (n = 95, aged 17-26) with mixed laterality used their left leg for locomotion and stability skills, but performed manipulation tasks, like picking up a ball, with their right upper and lower limbs). However, there is a scarcity of research on the prevalence of crossed laterality within sports which allow the player to manipulate a ball with both hands and feet (e.g., Gaelic football; Australian Rules football; rugby).

It is conceivable, albeit to our knowledge untested, that crossed laterality may offer an advantage to sportspeople looking to execute skills with both sides of the body. For example, Pavely et al. (2010) studied the movement patterns of experienced players when kicking off of both the dominant and non-dominant sides. When kicking with the dominant foot, players routinely dropped the ball from the dominant hand to the dominant foot—an ipsilateral pattern advised by biomechanists (e.g., Ball, 2008). In contrast, when kicking with the non-dominant foot, players who had a consistent dominant side for hand and foot avoided using two non-dominant limbs in concert, instead dropping the ball across the body in what Pavely described as a sub-optimal pattern. As such, one could postulate that crossed lateral players may have a practical advantage when using the non-dominant foot because they are only using one non-dominant limb, versus a consistently unilateral player who is using two non-dominant limbs (the hand for feeding the ball and the foot for striking) when kicking the ball from the hands.

Previous research on bilaterality in sport has almost exclusively focused on male athletes in soccer and basketball (Carey et al., 2001; 2009; Marcori et al., 2022; Starosta, 1988; Stöckel & Vater, 2014; Stöckel & Weigelt, 2012; for an exception, see Dillon et al., 2024). However, non-sport specific handedness studies have highlighted the influence of gender (Papadatou-Pastou et al., 2008; 2020; Papadatou-Pastou, Jones & Munafò, 2010). A meta-analysis by Papadatou-Pastou et al. (2020) revealed that 16% of females were non-right-handed (i.e., left- or mixed-handed) compared to 20%% of males. Extending this to footedness, and drawing primarily from self-report questionnaires, Packheiser et al. (2020) specified that males exhibited higher rates of left-footedness (18%) compared to females (14%). The extent to which these gender differences also apply to other laterality profiles such as bilaterality, mixed laterality or crossed laterality in sporting tasks remains uncertain. Dillon et al. (2024) compared the prevalence of bilaterality within males and females. A video analysis of 121 games (76 male, 45 female) revealed that, irrespective of playing level (top divisions versus lower divisions) or gender, high performance adult Gaelic football players relied upon their dominant side for the majority of skill executions. Male players from the top divisions were generally less reliant on the dominant limb than all female players, albeit still favouring their dominant side. The direct observation of skill performance by Dillon et al. (2024) in comparison to the use of questionnaires by most studies of daily living tasks (Packheiser et al., 2020; Papadatou-Pastou et al., 2020) may explain why gender differences were less pronounced within this analysis of sport performance compared to daily living tasks. There is a clear need for more observational studies on laterality in sports that include female athletes, and ideally, future research should extend to explore mixed and crossed laterality profiles in both male and female sportspeople.

While fully bilateral individuals who can use each limb with equal dexterity are rare, there is an increasing body of research, beyond sport, demonstrating that left-handed individuals are less reliant on their dominant hand than their right-handed counterparts (Fagard & Corroyer, 2003; Johnstone et al., 2021; McGrath & Kantak, 2016; Przybyla et al., 2013). In real life terms, this means that left-handed individuals use their dominant hand less often in daily tasks than their right-handed counterparts. Indeed, Johnstone et al. (2021) stated that "reduced asymmetry in left-handers is found so routinely that most people no longer bother to look." (p. 3781). Extrapolating to a sporting context, these findings suggest that individuals with a preference for using their left side may find it easier to develop bilaterality than their right sided peers as they are already making greater use of the non-dominant limb. A person who may be predisposed to being more bilateral is at a clear advantage in a sport where bilaterality is so valued (Dillon et al., 2024). This pattern of weaker dominant side preference for left-lateralized individuals has not always been observed in sport however. For example, Carey et al. (2001) categorized soccer players into right and left-footed groups based on the analysed skill (1st touch, clearance, dribble, pass, set piece, shot on goal, tackle) and reported very similar values of dominant side use for right and left footed players. Other sporting studies investigating laterality (Giovanini et al., 2020; Stöckel & Vater, 2014; Stöckel & Weigelt, 2012) did not investigate whether left-handed players are equally, more, or less, asymmetrical than their right-handed counterparts. The discrepancy between the asymmetry levels observed in left-lateralized individuals during daily tasks and the paucity of research in sport warrants further investigation.

Gaelic football is a national sport of Ireland. It is a high-intensity contact field game involving two teams of 15 players on a pitch measuring between 130- and 145-m long and 80- to 90-m wide. The duration of a senior male match is 70 minutes while the duration of a female match is 60 minutes. Gaelic football is an ideal natural laboratory for investigating the extent to which different patterns of laterality (i.e., unilaterality, bilaterality, mixed-handedness, mixed-footedness and crossed laterality) may be prevalent in the playing populations, because it is one of very few sports where hands and feet on both sides of the body may be used to complete the multiple ball skills involved in gaining, carrying, distributing possession and attempting to score (see Supplementary File A for an illustration of these differing skills). More specifically, in a Gaelic football game, when carrying the ball and maintaining possession, a player can either hop or solo the ball. A hop involves striking the ball against the ground and catching it using their hand, similar to a basketball dribble. A solo involves dropping the ball and kicking it upward with their foot, allowing them to regain possession. When passing the ball to a teammate, players have two options: hand passing or kick passing. Hand passing involves striking the ball with one hand (open hand or fist) while holding it in the other hand. The kick pass involves dropping the ball from the hand to the foot (similar to a goalkeeper in soccer) and kicking the ball to a teammate. When attempting to score, points are scored by kicking the ball over the crossbar between the goalposts, similar to a rugby conversion. Goals, on the other hand, are scored by kicking the ball into the net below the crossbar, akin to soccer goals. Notably, while goals must be scored with the foot, points may be scored with either the hand (via a punch or fisted pass) or the foot.

Gaelic football offers the opportunity to observe a wide range of well-practiced limb combinations (foot and hands working in tandem with a ball) in a performance environment. For example, a study of 33 male intercounty games in 2023 documented an average of 421 handpasses, 130 kick passes and 54 shots executed per game (Carroll, 2023). To date, examination of laterality profiles within Gaelic football has largely focused on individual skills and thus been restricted to considering right-sided, left-sided and bilateral individuals (Dillon et al., 2024; Murray et al., 2023). Despite their potential relevance to player assessment and development, the prevalence of mixed- and crossed laterality has not been explored within sports using multiple sets of limbs such as Gaelic football. Understanding laterality profiles when executing these diverse skills may be of value to coaches when evaluating and developing players, and valuable to analysts when evaluating opposition players.

Gaelic football, and similar games where the ball is manipulated with both hands and feet, may also provide an opportunity to develop understanding of laterality more generally. Both coaches and the demands of the game encourage players to develop both sides of the body for multiple sets of limbs. It is not known how this encouragement influences the development of laterality profiles. For example, does the emphasis on laterality for both hands and feet lead to fewer consistently unilateral players as players might have success developing one limb (e.g., hand) which provides confidence to keep practicing with another, potentially more difficult limb (e.g., foot)? Alternatively, do players develop a high degree of mixed laterality because they concentrate on performing different skills with different limbs? The first step towards answering such questions is to document the "rich tapestry" (Castañer et al., 2018) of motor laterality profiles demonstrated within a competitive sport such as Gaelic football.

This study is a re-analysis of the dataset of Dillon et al. (2024), with a particular focus on patterns across skills, to explore the extent to which mixed and crossed laterality were present within the dataset. Specifically, the aims of this exploratory study were: (1) to identify the laterality profiles (i.e., consistent unilaterality, consistent bilaterality, partial bilaterality, mixed-laterality, crossed laterality) present within high-performance male and female Gaelic football players; (2) to test for an association between gender and the prevalence of these laterality profiles; and (3) to ascertain if right-sided players are more unilateral than left-sided players.

## Method

### *Participants*

The data set (number of games, gender and teams) was the same one used by Dillon et al. (2024) in their profiling of bilaterality within the performance of individual skills in male and female high performance Gaelic footballers. In brief, video recordings of 121 games were coded by the first author; for this study, a subset of the analysed data involving 133 participants (83 male, 50 female) met the inclusion criteria. Specifically, participants were required to have performed a minimum number of skill executions on each of the four analysed skills (see section 2.3) across the recorded matches to be included. The minimum number of skill executions required was determined using the limits of agreement method (Hughes et al., 2001) and is described in detail in Dillon et al. (2024).

### *Design and procedures*

A cross-sectional design was chosen to objectively identify players' laterality profiles when executing multiple ball skills. Footage had originally been coded using Nacsport performance analysis software (Nacsport Scout Plus). As referenced in Supplementary File A, a player in possession of the ball in Gaelic football can distribute the ball using either a hand pass (which involves striking the ball with one hand) or a kick pass, carry the ball forward using either a hop (a one handed bounce) or a solo (kick the ball to oneself), or attempt to score by kicking or hand passing the ball over the cross bar of the goals (a point) or by kicking the ball into the net (a goal). A definition for the successful performance of each skill (akin to Carey et al., 2001) was developed through conversations amongst the research team (see Dillon et al., 2024). Dominant leg and hand were denoted via the limb used in the majority of skill executions (≥60%, Oldfield, 1971). A coding template was created in Nacsport which was used to register each player's actions in a match including the skill and associated descriptors. Once the data was exported for each match, it was transferred into a Master MS Excel 365 workbook containing all actions for the players. Each player was given a universal ID and each game was given a code to denote the teams playing and the date of the match. The combination of player ID and game codes enabled all of the data to be collated in an Excel file to allow for comparison across multiple games for the same player.

### *Measures*

The limits of error method of Hughes et al. (2001) was used to establish the number of trials necessary to provide a representative profile for each skill. For each skill, the method graphs the cumulative use of the dominant side as a percentage against time. A zone defined by the final percentage mean use of the dominant side ±5% is overlayed upon the cumulative mean graph. The variable of interest is deemed to have stabilized when the cumulative mean enters the zone for the last time. To optimize the sample size, the average number of trials required for performance to have stabilized was chosen as the minimum number of skill executions required for inclusion in the study. This method was applied to a subset of 30 players who had completed a minimum of 50 skill executions for the hop, solo and handpass, and a minimum of 20 skill executions for the kick pass. It was not possible to apply the 50 skill executions as the requirement for the kick pass due to the relative infrequency that skill was carried out in games. Consequently, the 30 players who had executed the most kick passes were chosen instead. Applying this process indicated that only players who had executed at least 10 kick passes, 13 solos, 22 hops and 26 handpasses should be included (Dillon et al., 2024).

Four skills were included for analysis: kick pass, solo, hand pass and hop. Shooting for scores was not included due to the small number of players who had executed sufficient shots from play to form an accurate representation of laterality in that particular skill. Each player was initially classified as unilateral right-sided, unilateral left-sided, or bilateral within each skill. The parameter for classifying a player as bilateral on a particular skill was 40-60% limb dominance based on criteria used when analysing the Edinburgh Handedness Inventory (Oldfield, 1971). Right side use above 60% was deemed Right-sided (<40% Left-sided) for that particular skill.

With four skills analysed (hop, hand pass, solo, kick pass), and three options for each skill (right, left and bilateral), there were 81 possible combinations for each player. These combinations were used to assign a player to one of six laterality profiles: consistent unilateral (consistent right-unilateral or consistent left-unilateral), consistent bilateral, partial bilateral, mixed lateral, crossed lateral or partial crossed lateral.. A player exhibiting the same dominant side for each skill within one limb (hand: hop and hand pass; foot: solo and kick pass) was deemed consistently unilateral for that limb (e.g., RhopRhandpassRsoloRkickpass; LhopLhandpassLsoloLkickpass). If a player was bilateral for 1–3 skills (e.g., RhopBhandpassRsoloRkickpass; LhopBhandpassLsoloRkickpass) they were classified as being partially bilateral. Mixed laterality was defined separately for skills involving the feet (solo and kick pass) and hands (hop and hand pass). If a player was left footed for one skill, and right footed for another skill (e.g., RhopRhandpassRsoloLkickpass), they were identified as mixed-footed; mixed-handedness was identified in a similar manner (e.g., LhopRhandpassLsoloLkickpass). Crossed laterality was defined in those cases where the dominant limb for both foot skills was opposite to the dominant limb for both hand skills (i.e., RhopRhandpassLsoloLkickpass; LhopLhandpassRsoloRkickpass). Finally, partial crossed laterality (Ferrero et al., 2017) was defined in those cases where the dominant limb for both foot skills was opposite to the dominant limb for one hand skill (e.g., RhopLhandpassLsoloLkickpass; LhopRhandpassLsoloLkickpass) or the dominant limb for one foot skill was opposite to the dominant limb for at least one hand skill (e.g., RhopRhandpassLsoloRkickpass; RhopRhandpassRsoloLkickpass)..

## Reliability of Coding

Data credibility was ensured through an initial training protocol and objectivity checks (McKenzie & van der Mars, 2015). For training, two members of the research team collaborated on coding the same game, discussing coding definitions, the reasons for decisions, and what would be necessary for different decisions to be reached. The training was an iterative approach which continued until both researchers were confident in the coding process. To assess objectivity of the coding system and the researcher, agreement was calculated between the researcher and another coder who was not a member of the research team but who had experience using the same coding system and dataset. The same set of definitions and coding window were used to tag a randomly selected full match. The agreement was calculated for each category by totalling the number of agreed tags for each category, dividing by the total number of tags from each coder and multiplying by 100 to generate a percentage. The researcher and coder independently provided their ratings, which were then submitted to a third researcher for calculating agreement. An agreement of 80% was deemed acceptable (McKenzie & van der Mars, 2015; van der Mars, 1989); objectivity ranged from 81.1% to 86.7% for the skill executed and limb choice (Dillon et al., 2024).

## Data analysis

Unless otherwise stated, statistical analysis was carried out using SPSS for Windows (IBM SPSS Statistics 28). A chi-squared test of independence was run to test if laterality profiles were significantly different between males and females. Where significant chi-square results were found, standardized adjusted residuals (SR) provided a post-hoc test to identify in which measures there were significant deviations from the expected frequencies (Hancock et al., 2013). Adjusted residuals were chosen because they adjust for differences in the marginal totals of the contingency table. A positive SR indicated a higher-than-expected number of individuals in that category. A negative SR indicated a lower-than-expected number of individuals in that category. SRs $\geq \pm 1.96$ were deemed noteworthy.

When all four skills are considered together, mixed laterality in any one limb could be classified within partial bilaterality or partial crossed laterality. Thus, to provide a more accurate picture of the prevalence of mixed laterality, additional Fisher's Exact tests were carried out using R-Studio to test for any association between gender and (a) mixed and (b) crossed laterality. Separate Fisher's Exact tests examined handedness (hand pass and hop) and footedness (kick pass and solo) using a 2 (gender (male, female) x 5 (laterality profile (unilateral left, unilateral right, mixed-handedness/mixed-footedness, consistent bilaterality and partial bilaterality)) contingency table. To assess crossed laterality, 2 (gender) x 5 (laterality profile: unilateral left, unilateral right, crossed laterality, bilaterality and partial bilaterality) Fisher's Exact tests were also carried out for passing (hand and foot pass) and carrying (hop and solo) skills. A value of $p \leq 0.05$ indicated a significant result for all tests. To assess whether right-sided individuals used their dominant side more than left-sided individuals, the distribution of data was assessed using visual analysis of the histograms and Shapiro–Wilk tests (Field, 2009). The data were clearly skewed, so nonparametric Mann Whitney U tests were used to compare the percentage of dominant side use between right- (>60% right side use) and left-sided (<40% right side use) individuals for each of the four skills (hop, solo, hand pass, kick pass).

## Results

For the four skills analysed (hop, solo, hand pass and kick pass), in both the male and female sample, the majority of players were consistently unilateral (Figure 1). Unilateral male and female players were predominantly right-sided and so were grouped within one category. No players were bilateral for all four skills. A chi-squared test of independence showed no significant difference in the laterality profiles of male and female players ($\chi^2 = 3.725$; df = 2; $p = .155$).

Figures 2 and 3 display the prevalence of laterality profiles in hand skills (hop and hand pass), foot skills (kick pass and solo), carrying (solo and hop) and passing (kick pass and hand pass) for male and female players. Each axis signifies a skill (i.e., hand pass, hop, solo, kick pass), with each dot representing a player, and the dot's position in relation to the x and y axis indicating whether the player was unilateral left, partially bilateral, consistently bilateral, unilateral right, mixed-handed, mixed-footed, or crossed-lateral.

### *Hand skills (hand pass and hop)*

Figure 2a,b demonstrates the relative frequency of laterality profiles for hand skills for male and female players (hand pass and hop). Fisher's Exact Test did not show a significant difference ($p = .254$) in hand skills between males and females in passing skills with respect to mixed handedness, consistent bilaterality, partial bilaterality and unilaterality (fully left or fully right). Focusing on the top right and bottom left boxes and skills involving just the hands (hand pass and hop), 73.5% of males were unilateral for these skills (69.9% right; 3.6% left), while 80% of females were unilateral (all right). The central box

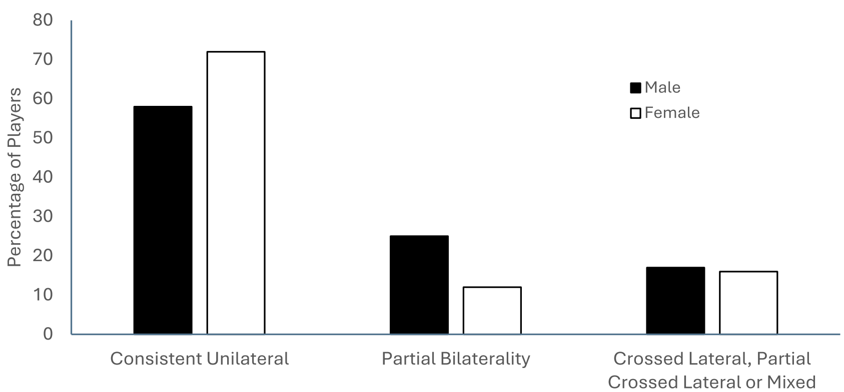


**Figure 1.** Percentage of Male and Female Players who were Consistently Unilateral, Partial Bilateral, Crossed Lateral, Partial Crossed Lateral and Consistently Mixed Lateral.

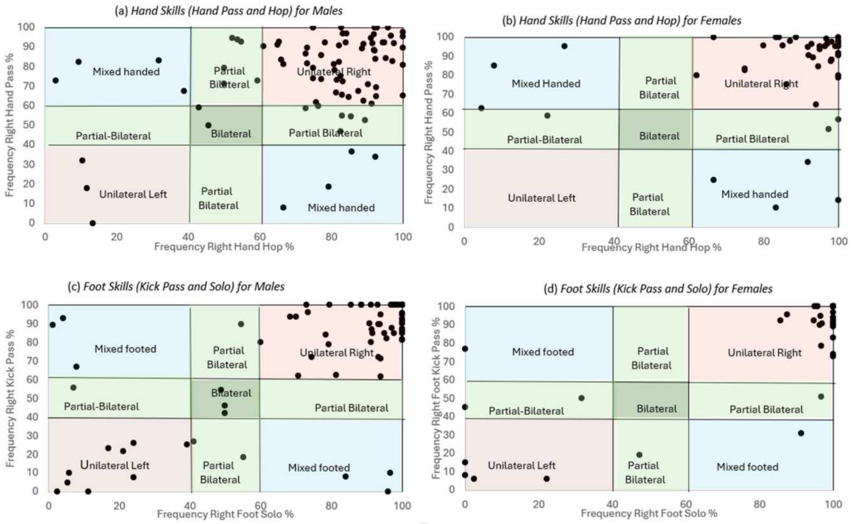


**Figure 2.** Laterality profiles for (a) hand skills for male, (b) hand skills for female, (c) foot skills for male and (d) foot skills for female players.

Note: Each dot represents at least one participant (dots may overlap).

shows that 2.4% of males were bilateral for these two skills, while no females were consistently bilateral. The four boxes on each side of the central bilateral square showed that 15% of males were partially bilateral for these two skills, with 6% of females being partially bilateral. Finally, from the top left and

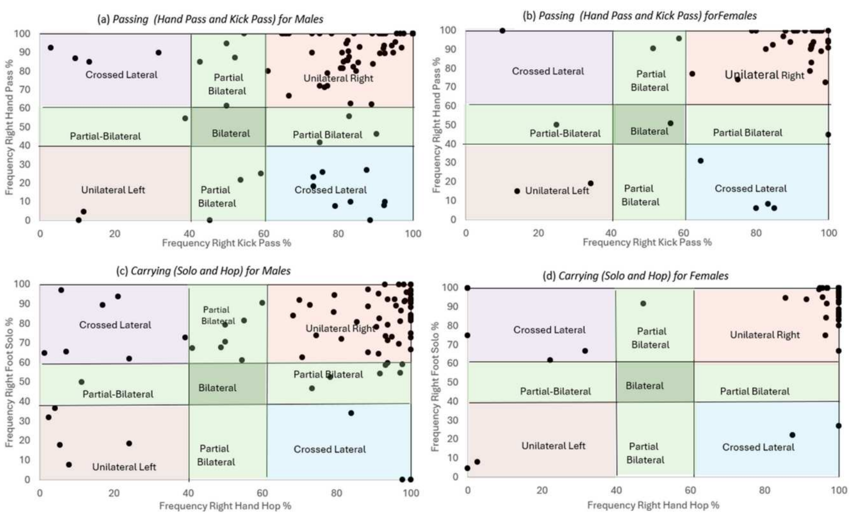


**Figure 3.** Laterality profiles for (a) passing skills for male, (b) passing skills for female, (c) carrying skills for male and (d) carrying skills for female players.

Note: Each dot represents at least one participant (dots may overlap).

bottom right boxes, we see that 10% of males were mixed-handed, while 14% of females were mixed-handed.

### *Foot skills (kick pass and solo)*

Figure 2c,d illustrate the relative frequency of laterality profiles for foot skills (Kick Pass and Solo). Fisher's Exact Test ($p = .395$) indicated no significant difference between males and females in foot skills with respect to mixed footedness, bilaterality, partial bilaterality and unilaterality. The top right and bottom left boxes show that 84.3% of males were Unilateral (73.5 right, 10.8% left), while 88% of females were unilateral (80% right; 8% left). The central bilateral box shows that 3.6% of males were bilateral for these two skills, while no female was bilateral for the same skills. The surrounding four boxes showed that 4.8% of males and 8% of females were partially bilateral. Finally, the top left and bottom right boxes showed that 7.2% of males had mixed foot dominance for these two skills, with the female equivalent being 4%.

### *Passing skills (hand pass and kick pass)*

Figure 3a,b demonstrates the relative frequency of laterality profiles for passing skills (hand pass and kick pass). Fisher's Exact Test ($p = .396$) indicated no significant difference between males and females in passing skills with respect to crossed laterality, bilaterality, partial bilaterality and unilaterality. The majority of both samples were shown to be unilateral; 70% of the males were unilateral (67.5% right; 2.4% left), while 80% (76% right; 4% left) of the female sample was unilateral (bottom left and top right boxes). No male and only one female (2%) player was bilateral for both passing skills (centre box). The four surrounding boxes denoting partial bilaterality showed that 14.5% of males were partially bilateral versus 8% of females being partially bilateral. Sixteen per cent of male players and 10% of female players were crossed lateral (Male: 11% right foot left hand, 5% left foot right hand; female: 8% right foot left hand, 2% left foot right hand).

### *Carrying (solo and hop)*

Figure 3c,d demonstrates the relative frequency of laterality profiles for carrying skills (hop and solo). Fisher's Exact Test ($p = .039$) indicated a significant difference between males and females in carrying skills with respect to crossed laterality, bilaterality, partial bilaterality and unilaterality. The majority of both samples were shown to be unilateral; 72% of the males were unilateral (66% right; 6% left), while 84% (80% right; 4% left) of the female sample was unilateral. No male or female was bilateral for a carrying skill (centre box).

The four surrounding boxes denoting partial bilaterality showed that 17% of males were partially bilateral versus 2% of females. The top left and bottom right boxes show that males had 10% crossed laterality in carrying; (2.4% right hand left foot, 8.4% left-hand right foot) and females had 12% crossed laterality in carrying (4% right hand left foot, 8% left hand right foot). Thus the observed gender differences appears to be due to a higher proportion of males demonstrating partial bilaterality, while a higher proportion of females were unilateral right.

## Degree of dominance

The analysis in Figure 4 shows median dominant limb use and interquartile range (IQR) by left (< 40% right side use) and right-sided (>60% right side use) players for the four skills examined. For the kick pass, Mann Whitney U tests indicated that left-sided male players (*Mdn* = 85.0%; IQR = 21.15%) used their dominant foot less often than right-sided players (*Mdn* = 94.1%, IQR = 14.3%; z = −2.312; *r* = .−0.254; *p* = .021). Similarly, left-sided female players (*Mdn* = 85.7%. IQR = 16.7%) used their dominant foot less often than right-sided players (*Mdn* = 95.8%, IQR = 9.1%) for the same skill (z = −2.854; r = −.404; *p* = .004). For the solo, Mann Whitney U tests indicated that left-sided male players (*Mdn* = 83.0%; IQR = 36) used their dominant foot less often than right-sided players (*Mdn* = 96.0%; IQR = 11.0%; z = −3.144; *r* = .0.345; *p* < .001) and left-sided female players (*Mdn* = 97.5%; IQR = 13.6%) used their dominant foot less often than right-sided players (*Mdn* = 100%; IQR = .00) for the same skill (z = −2.330; r = −.33; *p* = .020). For the

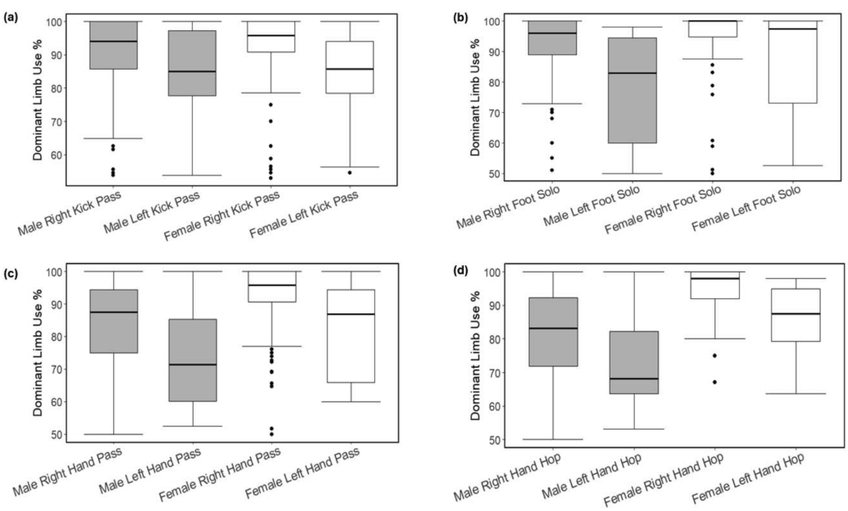


**Figure 4.** Box Plots illustrating medians and IQR ranges for (a) kick pass, (b) solo, (c) hand pass and (d) hop for players who are Left and Right dominant for each skill.

hand pass, Mann Whitney U tests indicated that left-sided male players (*Mdn* = 71.4%; IQR = 28%) used their dominant hand less often than right-sided players (*Mdn* = 88.8%, IQR = 16.4%) for the hand pass (z = −5.605; *r* = −0.615; *p* < .001) and left-sided female players (*Mdn* = 86.9; IQR = 30.9%) used their dominant hand less often than right-sided players (*Mdn* = 95.8%; IQR = 9.5%) for the same skill (z = −3.525; r = −0.499; *p* < .001). For the hop, Mann Whitney U tests indicated that left-sided male players (*Mdn* = 74.1%; IQR = 17.8) used their dominant hand less often than right-sided players (*Mdn* = 83.65%, IQR = 17.8; z = −2.008; *r* = −0.22; *p* = .045) and left-sided female players (*Mdn* = 91.9; IQR = 12.9) used their dominant hand less often than right-sided players (*Mdn* = 96.65; IQR = 11.7) for the same skill (z = −2.496; r = −0.353; *p* = .013).

## Discussion

The primary purpose of the study was to map the laterality profiles demonstrated by high performance Gaelic football players, to compare these profiles between male and female players and to ascertain if right-sided players are more unilateral than left sided players. While the majority of players were unilateral, other laterality profiles were also present (i.e., partial bilaterality, mixed laterality or crossed laterality). No player (male or female) was consistently bilateral for all four skills. Only one comparison (carrying) showed a significant difference in laterality profiles between males and females; males were more likely to use both limbs for one of the skills while females were more likely to strongly rely on their dominant side. Right-sided male and female players were significantly more lateralized than their left-sided counterparts for the kick pass, solo, hand pass and hop. Overall findings show that laterality in Gaelic football is complex, idiosyncratic, and not binary in many cases (i.e., it is more than left- or right-sided).

When analysing a single skill, a player may be classified as unilateral right-sided, unilateral left-sided or bilateral. However, when considering players across multiple skills, additional laterality profiles are possible: mixed laterality, crossed laterality, partial bilaterality and consistently bilaterality. This study documented the prevalence of these alternative laterality profiles within high performance Gaelic football. We do not have comparable percentages from other studies in Gaelic football or other sports to benchmark our results against. However, within the passing and carrying categories, the percentages of partial and crossed laterality observed in the male and female playing population were consistent with previous research on crossed laterality in non-sporting populations (Barut et al., 2007; Elias et al., 1998; Packheiser et al., 2020; Tran & Voracek, 2016). Mixed handedness percentages in skills involving the hands (males 10%, females 14%) were roughly in line with the general population (10%; Papadatou-Pastou et al., 2020) while mixed footedness (7% males, 2% females) was less than the percentages outlined by Packheiser et al. (2020) in the general population (21% for males, 18% for females). The lower percentage of mixed-laterality within Gaelic footballers relative to the general population might be explained by a number of reasons. Firstly, previous research has highlighted discrepancies between data collected using self-report surveys (Grouios et al., 2002) versus direct observation (Carey et al., 2009). Secondly, the advantages of being able to use both limbs within Gaelic football may encourage individuals who demonstrate mixed-laterality in tasks of daily life to develop (at least partial) bilaterality within Gaelic football skills. Future research should compare the levels of mixed-laterality and bilaterality between tasks of daily living and sporting skills.

The existence of both mixed and (at least partially) bilateral players highlights the need for future research to distinguish between these two profiles. Grouios et al. (2002) demonstrated that professionals were more likely to report as "mixed footed" compared to non-sporting university students, however their analysis did not distinguish between mixed sided and bilateral. Carey et al. (2009), in a study which surveyed 400 amateur soccer players, found similar percentages to Grouios but also failed to differentiate between mixed footed and bilateral. Stöckel and Vater (2014), after administering a questionnaire to assess player laterality in basketballers, referred to players being "mixed-handed" and making "equal use" of each hand interchangeably. Finally, Gualdi-Russo et al. (2019) did not distinguish between mixed handed and bilateral basketball players, reporting only a combined figure. These examples underline the importance of future researchers should taking greater care to distinguish between mixed-laterality and bilaterality.

For the four skills analysed (hop, solo, hand pass and kick pass), in both the male and female sample, only one comparison (carrying skills) showed a significant difference in the laterality profiles of male and female players. The scarcity of research on laterality among female athletes makes comparisons challenging, with Dillon et al. (2024) being the only study to explore this topic across both male and female athletes. In their study, it was observed that high-performance male Gaelic football players exhibited less dependence on their dominant limb compared to their female counterparts. In the current study, the sample was restricted to players who had demonstrated sufficient skill executions on all four skills. These were therefore the players who were most involved in the play, and likely to have been amongst the top performers on each team. It may be that this inadvertent focus on the best male and female players contributed to the general lack of significant differences. These results suggest that knowledge relating to laterality profiles is relevant to coaches and applied sports scientists working in both the men's and the women's game.

Left-handed and left-footed players were relatively less reliant on the dominant limb, in each of the skills analysed, than right-side dominant players; albeit most players were still markedly biased towards one limb. The increased bilaterality of left footed Gaelic footballers is inconsistent with previous sporting research in soccer (Carey et al., 2009). While the inconsistency in results cannot be definitively explained, the differing skill demands of soccer and Gaelic football may play a role. Kicking in soccer uses only the feet to control the ball; in Gaelic football skills using the feet are performed with both hands and feet because the ball is routinely carried with the hands and must be dropped from the hands to the feet to kick a pass. The increased bilaterality amongst left-side dominant individuals is consistent with a number of non-sporting studies (Bondi et al., 2020; Bryden, 2016; Buckingham et al., 2011; Johnstone et al., 2021; Judge & Stirling, 2003; Peters 1988) who have found that left-handers have smaller asymmetries, or are more inclined to use their non-dominant hand, in skills involving their hands than right-handers. However, within Gaelic football the increased levels of bilaterality seen in left-sided players is not widely known amongst coaches and players (Dillon et al., 2024). The implication of left-handed and left-footed players being more bilateral than their right-sided counterparts centres around expectations from coaches and potential talent identification. These findings suggest that coaches may find it easier to develop bilaterality amongst left sided players, and it may be beneficial to have different expectations for the rate of progress of left and right sided players. However, these suggestions need to be empirically assessed.

Outside of sport, McGrath and Kantak (2016) had ten right-handed and ten left-handed adults practice two distinct motor skills (involving navigating a computer cursor) with their dominant or nondominant arms during separate sessions two–four weeks apart. The right-handed group demonstrated significantly greater skill improvement for their dominant-right hand than their nondominant-left hand. In contrast, for the left-handed group, both dominant and nondominant hands demonstrated comparable improvements. While there have not been equivalent studies done directly with sportspeople, McGrath & Kantak's results reinforce the suggestion that left-side dominant players could potentially develop bilaterality more easily than their right-side dominant counterparts.

Differences in the physical structure of the brain has been postulated as a reason why left sided individuals are less lateralized than their right-sided counterparts. More specifically, the corpus callosum is frequently seen as a key cerebral factor influencing lateralization. The corpus collosum is the main fibre tract connecting the right and the left cerebral hemisphere and has more than 350 million fibres (Westerhausen et al., 2004). More consistent hand preference is associated with smaller corpus callosum size (Habib et al., 1991; Luders et al., 2010; Moffat et al., 1998; Tuncer et al., 2005; Westerhausen et al., 2004; Witelson, 1985). The larger corpus callosum in left-handed and bilateral athletes is thought to accelerate the exchange of sensory-motor information between the cerebral hemispheres and allow for faster and more accurate movements (Cherbuin & Brinkman, 2006; Tran & Voracek, 2016). Collectively, these findings point to a potentially significant interplay between cerebral structural differences and laterality in players, and provide a potential mechanism by which left-side dominant players might develop bilaterality more easily.

## *Application for practice*

The results presented in this paper have implications for coaches, applied sports scientists and performance analysts in Gaelic football and other ball playing sports which involve use of both the hands and feet, such as Australian Rules football and some positions in Rugby, Association football (soccer) and American football. More specifically, coaches of players in these sports need to be aware of the different laterality profiles which exist in players, including unilateral, consistent bilateral, partial bilateral, crossed lateral and mixed laterality. A greater knowledge of these categories may aid coaches in improving their players' skills by providing feedback matched to the player's laterality profile. In addition, an awareness of the potentially varied laterality profiles could guide coaches and analysts to more effectively evaluate opposition players. At the very least, coaches in such ball sports should see laterality, and analysis of opposition players, as being skill-specific rather than a general characteristic of a player. The marginal difference in laterality profiles between males and females means these findings apply to coaches and analysts in the men's and women's games. Additionally, the potential for left-side dominant players to be more bilateral should also encourage coaches to be cognisant of their expectations when developing right- and left-side dominant individuals.

## *Limitations and further considerations for future investigators*

This exploratory project was not without its limitations. Firstly, factors other than individual preferences may influence the assessment of players' laterality using in-match data; such factors could include position on the pitch and opponent proximity. For example, players who play in central positions may have more opportunities to use both limbs than players whose role is largely restricted to one side of the playing area (Marcori et al., 2022). Future research should code additional contextual variables around skill execution. A second limitation relates to the relatively small sample size. As the primary objective of this exploratory study was to identify the different laterality profiles present, not their prevalence, and as all possible profiles were present within the dataset, the sample size was sufficient for this objective. Nonetheless, particularly the limited number of left-sided players present likely reduced the statistical power of some analyses, compromising the ability to detect significant effects. Further studies with larger, more balanced samples are needed to better understand the role of laterality in player performance. Finally, this study is focused on adult high-performance players. A study of laterality profiles in younger male and female players may provide useful insights into the development of different laterality profiles.

## Conclusion

In conclusion, laterality in Gaelic football is complex with a wide variety of profiles evident. There were minimal differences between males and females with respect to laterality profiles. Left-sided male and female players were significantly less lateralized than their right-sided counterparts for the kick pass, solo, hand pass and hop. Researchers, coaches and practitioners are encouraged to recognize the possibilities of a player being unilateral right, unilateral left, consistent bilateral, partial bilateral, mixed handed, mixed footed and crossed lateral, depending on the skills being executed. Recognizing the idiosyncratic nature of limb dominance has applications for coaches involved in non-dominant skill development, opposition analysis of the dominant side and sport scientists involved in talent identification.

More broadly, the findings from hand and foot actions in Gaelic football provide valuable insights into laterality in general, demonstrating that it is not a fixed or uniform characteristic but one that can vary across limbs and tasks/skills. Unlike previous studies that conflated mixed laterality with bilaterality, this research distinguishes between bilaterality, mixed-footedness and mixed-handedness, offering a more precise framework for understanding motor laterality By making this distinction, our study contributes not only to Gaelic football but also to the broader field of laterality research, bringing a more nuanced perspective to the area.

## Acknowledgements

The authors would like to thank Rob Carroll, Micheál Duffy, Martin Feeney, Fiadhna Tangney and Alex Porter for their involvement in data collection.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

## Funding

This research was supported by the Irish Research Council Postgraduate Award Scheme.

## Data availability statement

Data is available on request from the corresponding author.

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## References

Ball, K. (2008). Biomechanical considerations of distance kicking in Australian Rules football. *Sports Biomechanics*, *7*(1), 10–23. https://doi.org/10.1080/14763140701683015

Barut, C., Ozer, C. M., SevİNc, O., Gumus, M., & Yunten, Z. (2007). Relationships between hand and foot preferences. *International Journal of Neuroscience*, *117*(2), 177–185.

Bondi, D., Prete, G., Malatesta, G., & Robazza, C. (2020). Laterality in children: Evidence for task-dependent lateralization of motor functions. *International Journal of Environmental Research and Public Health*, *17*(18), Article 6621. https://doi.org/10.3390/ijerph17186621

Bryden, P. J. (2016). The influence of M. P. Bryden's work on lateralization of motor skill: Is the preferred hand selected for and better at tasks requiring a high degree of skill? *Laterality*, *21*(4-6), 312–328. https://doi.org/10.1080/1357650x.2015.1099661

Buckingham, G., Main, J. C., & Carey, D. P. (2011). Asymmetries in motor attention during a cued bimanual reaching task: Left and right handers compared. *Cortex*, *47*(4), 432–440. https://doi.org/10.1016/j.cortex.2009.11.003

Carey, D. P., Smith, D. T., Martin, D., Smith, G., Skriver, J., Rutland, A., & Shepherd, J. W. (2009). The bi-pedal ape: Plasticity and asymmetry in footedness. *Cortex*, *45*(5), 650–661.

Carey, D. P., Smith, G., Smith, D. T., Shepherd, J. W., Skriver, J., Ord, L., & Rutland, A. (2001). Footedness in world soccer: An analysis of France '98. *Journal of Sports Sciences*, *19*(11), 855–864.

Carroll, R. (2023). *Statistical Analysis Report 2023: GAA Senior Football Championship*. Gaelic Stats/GAA. https://www.gaa.ie/api/images/image/upload/jnzxgojbqegfuazafezy.pdf

Castañer, M., Andueza, J., Hileno, R., Puigarnau, S., Prat, Q., & Camerino, O. (2018). Profiles of motor laterality in young athletes' performance of complex movements: Merging the MOTORLAT and PATHoops tools. *Frontiers in Psychology*, *9*, 916. https://doi.org/10.3389/fpsyg.2018.00916

Cherbuin, N., & Brinkman, C. (2006). Hemispheric interactions are different in left-handed individuals. *Neuropsychology*, *20*(6), 700–707. https://doi.org/10.1037/0894-4105.20.6.700

Cuellar-Partida, G., Tung, J. Y., Eriksson, N., Albrecht, E., Aliev, F., Andreassen, O. A., Barroso, I., Beckmann, J. S., Boks, M. P., Boomsma, D. I., Boyd, H. A., Breteler, M. M. B., Campbell, H., Chasman, D. I., Cherkas, L. F., Davies, G., de Geus, E. J. C., Deary, I. J., Deloukas, P., & Medland, S. E. (2021). Genome-wide association study identifies 48 common genetic variants associated with handedness. *Nature Human Behaviour*, *5*(1), 59–70. https://doi.org/10.1038/s41562-020-00956-y

Díaz-Pereira, M. P., López-Araujo, Y., & Lorenzo-Martínez, M. (2023). Examining variations between everyday life handedness and lateral preferences for sport-specific skills in children. *Research Quarterly for Exercise & Sport*, *94*(2), 368–373. https://doi.org/10.1080/02701367.2021.1994121

Dillon, K., Sherwin, I., & Kearney, P. E. (2024). Profiling bilateral skills in high-performance male and female Gaelic footballers. *Perceptual and motor skills*. Advance online publication. https://doi.org/10.1177/00315125241238307

Elias, L. J., Bryden, M. P., & Bulman-Fleming, M. B. (1998). Footedness is a better predictor than is handedness of emotional lateralization. *Neuropsychologia*, *36*(1), 37–43. https://doi.org/10.1016/s0028-3932(97)00107-3

Fagard, J., & Corroyer, D. (2003). Using a continuous index of laterality to determine how laterality is related to interhemispheric transfer and bimanual coordination in children. *Developmental Psychobiology*, *43*(1), 44–56. https://doi.org/10.1002/dev.10117

Ferrero, M., West, G., & Vadillo, M. A. (2017). Is crossed laterality associated with academic achievement and intelligence? A systematic review and meta-analysis. *PLoS One*, *12*(8), e0183618. https://doi.org/10.1371/journal.pone.0183618

Field, A. (2009). *Discovering Statistics Using SPSS* (3rd ed.) Thousand Oaks, CA: Sage Publications Inc.

Giovanini, B., Marcori, A., Monteiro, P., & Okazaki, V. (2020). Does game pressure affect hand selection of NBA basketball players? *Psychology of Sport and Exercise*, *47*, 101635, 1–6. https://doi.org/10.1016/j.psychsport.2019.101635

Grouios, G., Kollias, N., Koidou, I., & Poderi, A. (2002). Excess of mixed-footedness among professional soccer players. *Perceptual and Motor Skills*, *94*, 695–699. https://doi.org/10.2466/PMS.94.2.695-699

Gualdi-Russo, E., Rinaldo, N., Pasini, A., & Zaccagni, L. (2019). Hand preference and performance in basketball tasks. *International Journal of Environmental Research and Public Health*, *16*(22), Article 4446. https://doi.org/10.3390/ijerph16224446

Habib, M., Gayraud, D., Oliva, A., Regis, J., Salamon, G., & Khalil, R. (1991). Effects of handedness and sex on the morphology of the corpus callosum: A study with brain magnetic resonance imaging. *Brain and Cognition*, *16*(1), 41–61. https://doi.org/10.1016/0278-2626(91)90084-l

Hancock, D. J., Seal, K., Young, B., Weir, P. L., & Ste-Marie, D. M. (2013). Examining mechanisms that contribute to relative age effects in pre-pubescent female ice hockey players. *Talent Development and Excellence*, *5*, 59–66.

Hughes, M., Evans, S., & Wells, J. (2001). Establishing normative profiles in performance analysis. *International Journal of Performance Analysis in Sport*, *1*, 1–26.

Johnstone, L. T., Karlsson, E. M., & Carey, D. P. (2021). Left-handers are less lateralized than right-handers for both left and right hemispheric functions. *Cerebral Cortex*, *31*(8), 3780–3787. https://doi.org/10.1093/cercor/bhab048

Judge, J., & Stirling, J. (2003). Fine motor skill performance in left- and right-handers: Evidence of an advantage for left-handers. *Laterality*, *8*(4), 297–306. https://doi.org/10.1080/13576500342000022

Loffing, F., Sölter, F., & Hagemann, N. (2014). Left preference for sport tasks does not necessarily indicate left-handedness: Sport-specific lateral preferences, relationship with handedness and implications for laterality research in behavioural sciences. *PLoS One*, *9*(8), e105800. https://doi.org/10.1371/journal.pone.0105800

Luders, E., Cherbuin, N., Thompson, P. M., Gutman, B., Anstey, K. J., Sachdev, P., & Toga, A. W. (2010). When more is less: Associations between corpus callosum size and handedness lateralization. *Neuroimage*, *52*(1), 43–49. https://doi.org/10.1016/j.neuroimage.2010.04.016

Marcori, A. J., Giovanini, B., Monteiro, P. H. M., Nascimento, V. B., Brito de Souza, D., & Okazaki, V. H. A. (2022). How positional constraints affect footedness in football: A notational analysis of five leagues in Europe. *Journal of Motor Behavior*, *54*(3), 382–390. https://doi.org/10.1080/00222895.2021.1980367

McGrath, R. L., & Kantak, S. S. (2016). Reduced asymmetry in motor skill learning in left-handed compared to right-handed individuals. *Human Movement Science Sci*, *45*, 130–141. https://doi.org/10.1016/j.humov.2015.11.012

McKenzie, T. L., & van der Mars, H. (2015). Top 10 research questions related to assessing physical activity and its contexts using systematic observation. *Research Quarterly for Exercise & Sport*, *86*(1), 13–29. https://doi.org/10.1080/02701367.2015.991264

Moffat, S. D., Hampson, E., & Lee, D. H. (1998). Morphology of the planum temporale and corpus callosum in left handers with evidence of left and right hemisphere speech representation. *Brain*, *121*(Pt 12), 2369–2379. https://doi.org/10.1093/brain/121.12.2369

Moreno, M., Capdevila, L., & Losilla, J. M. (2022). Could hand-eye laterality profiles affect sport performance? A systematic review. *PeerJ*, *10*, e14385. https://doi.org/10.7717/peerj.14385

Murray, K. J., Burns, C., Lacey, S., O' Neill, C., & Coughlan, E. K. (2023). An examination of bilateral skill proficiency and frequency of pass in selected and nonselected youth academy Gaelic footballers. *Journal of Motor Learning and Development*, *11*(3), 480–496. https://doi.org/10.1123/jmld.2023-0025

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, *9*(1), 97–113. https://doi.org/10.1016/0028-3932(71)90067-4

Packheiser, J., Schmitz, J., Arning, L., Beste, C., Güntürkün, O., & Ocklenburg, S. (2020). A large-scale estimate on the relationship between language and motor lateralization. *Scientific Reports*, *10*(1), 13027.

Papadatou-Pastou, M., Jones, G. V., & Munafò, M. R. (2010). Sex and location as determinants of handedness: Reply to Vuoksimaa and Kaprio (2010). *Psychological Bulletin*, *136*(3), 348–350. https://doi.org/10.1037/a0019215

Papadatou-Pastou, M., Martin, M., Munafò, M. R., & Jones, G. V. (2008). Sex differences in left-handedness: A meta-analysis of 144 studies. *Psychological Bulletin*, *134*(5), 677–699. https://doi.org/10.1037/a0012814

Papadatou-Pastou, M., Ntolka, E., Schmitz, J., Martin, M., Munafò, M. R., Ocklenburg, S., & Paracchini, S. (2020). Human handedness: A meta-analysis. *Psychological Bulletin*, *146*(6), 481–524. https://doi.org/10.1037/bul0000229

Pavely, S., Adams, R. D., Di Francesco, T., Larkham, S., & Maher, C. G. (2010). Bilateral clearance punt kicking in rugby union: Effects of hand used for ball delivery. *International Journal of Performance Analysis in Sport*, *10*(2), 187–196. https://doi.org/10.1080/24748668.2010.11868513

Peters, M. (1988). Footedness: Asymmetries in foot preference and skill and neuropsychological assessment of foot movement. *Psychological Bulletin*, *103*, 179–192. https://doi.org/10.1037/0033-2909.103.2.179

Przybyla, A., Coelho, C. J., Akpinar, S., Kirazci, S., & Sainburg, R. L. (2013). Sensorimotor performance asymmetries predict hand selection. *Neuroscience*, *228*, 349–360. https://doi.org/10.1016/j.neuroscience.2012.10.046

Sabatino, D. A., & Becker, J. T. (1971). Relationship between lateral preference and selected behavioral variables for children failing academically. *Child Development*, *42*(6), 2055–2060.

Shaywitz, S. E., Shaywitz, B. A., McGraw, K., & Groll, S. (1984). Current status of the neuromaturational examination as an index of learning disability. *The Journal of Pediatrics*, *104*(6), 819–825. https://doi.org/10.1016/s0022-3476(84)80474-6

Starosta, W. (1988). Symmetry and asymmetry in shooting demonstrated by elite soccer players. In T. Reilly, A. Lees, K. Davids, & W. J. Murphy (Eds.), *Science and football: Proceedings of the First World Congress of Science and Football, Liverpool, 12–17th April 1987* (pp. 346–355). E & FN Spon. https://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=SPH230878&site=ehost-live&scope=site

Stöckel, T., & Carey, D. P. (2016). Chapter 14 - Laterality effects on performance in team sports: Insights from Soccer and Basketball. In F. Loffing, N. Hagemann, B. Strauss, & C. MacMahon (Eds.), *Laterality in sports* (pp. 309–328). Academic Press. https://doi.org/10.1016/B978-0-12-801426-4.00014-6

Stöckel, T., & Vater, C. (2014). Hand preference patterns in expert basketball players: Interrelations between basketball-specific and everyday life behavior. *Human Movement Science*, *38*, 143–151. https://doi.org/10.1016/j.humov.2014.09.002

Stöckel, T., & Weigelt, M. (2012). Plasticity of human handedness: Decreased one-hand bias and inter-manual performance asymmetry in expert basketball players. *Journal of Sports Sciences*, *30*(10), 1037–1045. https://doi.org/10.1080/02640414.2012.685087

Tran, U. S., & Voracek, M. (2016). Footedness is associated with self-reported sporting performance and motor abilities in the general population. *Frontiers in Psychology*, *7*, 1199. https://doi.org/10.3389/fpsyg.2016.01199

Tuncer, M. C., Hatipoğlu, E. S., & Ozateş, M. (2005). Sexual dimorphism and handedness in the human corpus callosum based on magnetic resonance imaging. *Surgical and Radiologic Anatomy*, *27*(3), 254–259. https://doi.org/10.1007/s00276-004-0308-1

Ullman, D. G. (1977). Children's lateral preference patterns: Frequency and relationships with achievement and intelligence. *Journal of School Psychology*, *15*(1), 36–43. https://doi.org/10.1016/0022-4405(77)90059-0

van der Mars, H. (1989). Observer reliability: Issues and procedures. In P. W. Darst, D. B. Zakrajsek, & V. H. Mancini (Eds.), *Analyzing physical education and sport instruction* (2nd ed., pp. 53–80). Human Kinetics. http://articles.sirc.ca/search.cfm?id=242053

Westerhausen, R., Kreuder, F., Dos Santos Sequeira, S., Walter, C., Woerner, W., Wittling, R. A., Schweiger, E., & Wittling, W. (2004). Effects of handedness and gender on macro- and microstructure of the corpus callosum and its subregions: A combined high-resolution and diffusion-tensor MRI study. *Brain Research. Cognitive Brain Research Brain*, *21*(3), 418–426. https://doi.org/10.1016/j.cogbrainres.2004.07.002

Witelson, S. F. (1985). The brain connection: The corpus callosum is larger in left-handers. *Science*, *229*(4714), 665–668. https://doi.org/10.1126/science.4023705