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RESEARCH ARTICLE

Equal Pass: Comparing Passing Networks of England's Top Women's and Men's Football Leagues

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ABSTRACT

With women's football finally receiving more attention, more and more studies explore differences to men's football, mostly focussing on physical and technical indicators. This study is the first to compare the players' collaboration between genders using social network analysis based on 328 matches of the FA Women's Super League and 760 matches of the English Premier League. To compare overall team collaboration, patterns of density and transitivity were analysed. Additionally, the study examined degree centrality, closeness, betweenness, and eigenvector centrality as metrics to assess individual behaviors within the network. All statistical analyses were performed using Wilcoxon signed-ranked tests. We found no significant gender differences for all of the investigated metrics. Higher-ranked teams, in both genders, achieved significantly higher values than lower-ranked teams across all metrics except for eigenvector centrality, with larger effect sizes for density ($r_{female} = 0.47$, $r_{male} = 0.54$). Practical differences between home and away teams could only be seen in men's football, but with very small effect sizes. Therefore, this study can contribute to the state of research in three ways. Firstly, all the investigated network metrics except eigenvector can be used as football performance indicators without gender differences. Further, for both genders and all metrics there are no differences of practical meaning regarding home and away teams. Finally, we could show that there are no differences between male and female teams for the investigated performance indicators.

Keywords: Gender differences, network analysis, passing network, women's football.

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1. Introduction

On August 20, the 2023 Women's World Cup came to an end. Although nearly 2 million fans watched the game and set a new record, it is dwarfed by the nearly 1.5 billion viewers of the 2022 Qatar Men's World Cup final (FIFA, n.d.). 'Beyond Greatness' is an exciting mission statement, but it also stands in ironic contrast to the negative harassment and scandals that the championship team suffered after the game. This brings us back to a sports cliché, are women inferior to men in the same sport? Is the "lack of viewing" of women's sports based on the "fact" of different physiological structures or the long-standing discrimination of the whole society?

Football, being the world's most popular team sport, is not only widely welcomed by the audience, but also a frequent subject of research in the field of sports science. De Jong *et al*. (2023) divide the performance of football players into three major aspects: physical, technical, and tactics. Physical performance allows players to reach various positions on the field, technical skills include the actions players perform on the field, and tactics refer to the execution of the overall strategy and the interaction between players (Datson *et al*., 2014; Low *et al*., 2020; Rampinini *et al*., 2009). Previous studies identified substantial differences between men's and women's football in all these aspects.

Regarding physical performance, numerous studies have shown that female athletes perform lower than male athletes on aerobic and anaerobic fitness tests (Bradley *et al*., 2011; Mujika *et al*., 2009).

With regard to football players, many studies have assessed the physical performance of male and female football players separately (Datson *et al*., 2014; Stølen *et al*., 2005), but few studies have directly designed studies comparing the physical performance of male and female football players (Mujika *et al*., 2009; Nikolaidis, 2010; Roth *et al*., 2016). All of their studies point to power- and endurance-related physical performance differences between male and female football players (Krustrup *et al*., 2005). de Araújo *et al*. (2020) investigated gender differences in German Bundesliga football players and found that women were less capable in relation to explosive and intermittent endurance.

Football requires more than physical performance for athletes, and technical performance such as passing and possession seems to be more concerned. There are a few studies that have investigated gender differences in technical performance. Bradley *et al*. (2014) found that female players concede more balls and have a lower pass success rate in UEFA Champions League games. Pappalardo *et al*. (2021) further showed that male football players had higher pass accuracy and longer passing distance. Furthermore, Garnica-Caparrós and Memmert (2021) examined gender inequality in European football by evaluating key differences between male and female football players in match action data, based on various technical performance indicators. They utilized unbiased feature extraction and machine learning algorithms for their analysis. Some scholars have noted that, in both the men's Premier League and the women's World Cup, high-ranked teams achieve significantly more successful passes and greater pass accuracy compared to low-ranked teams (Araya & Larkin, 2013; Kubayi & Larkin, 2020; Lepschy *et al*., 2020; Yang & Kolbinger, 2024).

The physical and technical performance of players is crucial in football, but these metrics typically focus on individual analysis. A thorough analytical approach that integrates metrics like ball possession and passing is crucial for understanding team dynamics. Football success relies heavily on the overall organization and collaboration among players, who must operate dynamically and interdependently to reach a commom goal (Lago-Ballesteros & Lago-Peñas, 2010; Ribeiro *et al*., 2017). Passos *et al*. (2011) and Grund (2012) were among the first to apply social network analysis to visualize passing interactions in team sports, representing players as nodes and passes as directed links between these nodes. Originating from sociology and graph theory, this approach typically represents social agents as nodes and their connections as edges. Since then, many scholars have begun to apply this method in the field of sports science, such as Castellano and Echeazarra (2019), who proposed a separate network evaluation of the passing order. However, these studies are all aimed at male football. At present, only De Jong *et al*. (2023) have conducted research based on the social network analysis method using the Women's Super League, European Cup, and World Cup data. The study found that successful professional women's teams, similar to men's teams, are highly connected with concentrated possession distribution and efficient ball movement and passing throughout a season or tournament. The gap in the existing literature lies in the comparative analysis of passing networks between men's and women's football.

Excluding the classification and analysis of the different types of performance mentioned above, "home field advantage" is also one of the hot topics in the sports world in recent years, which is defined as "the unanimous conclusion that the home team wins more than 50% of the games in a sports game with a balanced home and away arrangement" (Courneya & Carron, 1992). Destefanis *et al*. (2022) found that in the post-pandemic season, the visiting team's offensive and defensive efficiency improved significantly, while the home team saw minimal improvement in offensive efficiency and almost no change in defensive efficiency. Whether attacking or defending, effective ball control and successful passing are extremely important. This makes us wonder whether the women's football team will also have a different home advantage in terms of passing performance. There are currently only two papers discussing the topic of home field advantage in women's football (Krumer & Smith, 2023; Szabó & Kerényi, 2023), which, however, only looked at final results and yellow cards and found that the away team received more yellow cards and that empty stadiums had no impact on the home advantage regarding game outcome.

In previous studies, researchers have examined the physical and technical performance of both genders' football, with some focusing on gender differences in these aspects. Generally, findings suggest that male football players outperform female players in aerobic and anaerobic exercises, as well as in technical and tactical indicators such as ball possession and passing. However, there is still a notable gap in the literature regarding tactical differences between genders, particularly in the context of home advantage and performance across different levels of competition.

To fill this gap, we used social network analysis (SNA) to examine the passing networks in England's top men's and women's football leagues, a country renowned for its prominence in the sport for both genders. We used two network-wide indicators, transitivity and density, alongside four node-based metrics: degree centrality, closeness centrality, betweenness centrality, and eigenvector centrality. A detailed description of these metrics will be provided in the methods section.

The overarching goal of this study is to identify gender differences in these network-based and individual node-based indicators. Our research specifically aims to address the following questions:

TABLE I: Data Sample Details

Gender	Competition name	Season	Team number	Match number
Female	Super league	2020–2021	12	131
Female	Super league	2019–2020	12	87
Female	Super league	2018–2019	11	110
Male	Premier league	2017–2018	20	380
Male	Premier league	2015–2016	20	380

Note. The 2017/18 English Premier League data was provided by Stats LLC, and the remaining seasons is publicly available from Statsbomb.

1. Do notable differences exist in the passing networks between men's and women's football teams?
2. Do performance levels (top vs. bottom teams) affect these networks differently for men and women?
3. Is there a difference in home field advantage reflected in the passing networks of men's and women's teams?

2. Method

2.1. Sample

This study utilized data from the top-tier men's and women's football leagues in England, covering the 2015/16 and 2017/18 Premier League seasons, as well as the FA Women's Super League for the 2018/19, 2019/20, and 2020/21 seasons. The 2017/18 English Premier League event data was provided by Stats LLC, and the rest of the event data is from Statsbomb company makes freely available on its website and can be used upon declaration (StatsBomb, n.d.). In the 2019/20 FA Women's Super League season, 45 matches were canceled due to the Covid-19 pandemic, and in the 2020/2021 season the game of Tottenham Hotspur Women to Birmingham City WFC was cancelled, which leading to a lower number of available games (see Table I).

2.2. Applied Social Network Analysis

There are various types of data analysis techniques in social network analysis, which can measure the overall structure of the network, such as network density and transitivity. Additionally, by measuring the centrality of nodes from various perspectives, we can gain a deeper understanding of the attributes and roles of individual nodes within the network. Commonly used centrality metrics include degree centrality, betweenness centrality, closeness centrality, and eigenvector centrality. The description of the indicators used in this study and their interpretation in the football passing network are shown in Table II. All data processing and analysis were conducted using Excel and R. The construction of the passing network and the calculation of indicators were primarily carried out with the igraph package (Csárdi *et al*., 2024). Given the structure of football matches, a team can have a maximum of 11 players on the field at any given time. Even considering substitutions, the number of passing network nodes for each team is quite limited. Therefore, when calculating density and transitivity—two network-level indicators—we treat substituted players and their substitutes as the same node. This approach ensures that the network node size remains consistent at 11 players in subsequent comparisons.

Also, when calculating the player's indicators, the substituted and substitute will no longer produce a passing relationship. This way we can make sure that the number of substitutions does not systematically affect the results.

2.3. Statistical Analysis

The primary goal of this study is to investigate whether gender differences exist in passing networks based on overall and individual social network metrics. For this purpose, we first investigate if higher values of these different social network metrics lead to better performance in the same way for both genders? To achieve this, the study will compare the overall network indicators (transitivity and density) and individual metrics (degree centrality, betweenness centrality, closeness centrality, and eigenvector centrality) for the top and bottom teams in the England Men's and Women's Football Leagues. Top and bottom teams were selected based on their final ranking of a season (top4 and bottom4 from female league, top6 and bottom6 from male league). Finally, we checked if there are differences between teams playing at home and away and if these patterns are affected by gender. To control for the opponent as a confounding variable, we constructed a dataset of these metrics for each team that played the same opponent both at home and away.

As the data in this study were not normally distributed, Wilcoxon signed-rank tests were conducted with a significance level of 0.05. When conducting statistical analysis on each question, our dependent

TABLE II: Description of Social Network Analysis Metrics Used in this Study and their Implications in Football Passing Networks

Metric	Level	Definition*	Football meaning
Density	Network	The ratio of the number of ties in the network to the number of theoretically possible ties.*	The ratio of player pairs passing the ball to each other to the total possible passing pairs in the team. A higher value indicates stronger cooperation within the team.**
Transitivity (the clustering coefficient)	Network	The ratio of the number of triples that actually exist in the network to the number of theoretically possible triples.[2]	This measures the triangular structure in the network, where a player has two passing options simultaneously. The greater the number of such triangle relationships within a team, the more passing opportunities and tactical options players have.
Degree centrality	Node	The ratio of how many relationships a node has to the maximum number of relationships a node can have in the network. (after standardization).*	The greater the degree centrality of a certain player, the more "core" the player is in the team.
Betweenness centrality	Node	The betweenness centrality of a point measures the extent to which the point controls interactions between others. If the betweenness centrality of a node is 0, it indicates that the node is on the periphery of the network. Conversely, if the betweenness centrality of a node is 1, it suggests that the node is at the core of the network and holds significant influence.*	Used to measure a player's "control" role as a bridge for the entire team's passing.
Closeness centrality	Node	If a node is connected to many other points through relatively short paths, we say that the point has high closeness centrality. A higher closeness centrality indicates that the actor in the network is less dependent on others.*	A measure of a player's "independence" in completing passes with other players without the need for a teammate to be an intermediary.
Eigenvector	Node	A node is also in core status if it is associated with nodes in other cores. In order to find the most core actors based on the overall structure of the network, factor analysis is used to find out the distances between each node. The position of each node in relation to each dimension is called an "eigenvalue," and a series of these eigenvalues forms an eigenvector.*	If a player has a higher eigenvector, it means that many players associated with him/her also have a more "important" position in the passing network.

Note. *Borgatti *et al*. (2018, pp. 150–153, 155–157, 165–168, 174–175, 173, 177–178, 168–169). **Grund (2012).

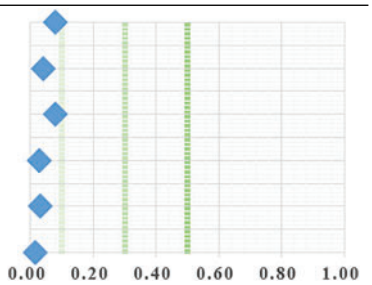
variables are the SNA metrics (transitivity, density, degree centrality, closeness centrality, betweenness centrality, and eigenvector centrality). The independent variables are gender, team performance level, and game location (home or away). This study also calculated effect sizes to assess the practical significance of the findings, using the correlation coefficient r. According to Cohen (2013), r values are interpreted as follows: less than 0.1 indicates an insubstantial effect, between 0.1 and 0.3 represents a small effect, between 0.3 and 0.5 denotes a medium-sized effect, and greater than 0.5 indicates a large effect.

3. Results

Table III shows gender differences in six different social network analysis metrics. Consider the p value from the result of the Wilcoxon signed-rank test, two indicators based on the overall network, density ($r = 0.08$) and transitivity ($r = 0.04$), and four centrality indicators based on individual players in the network, degree centrality ($r = 0.08$), betweenness centrality ($r = 0.03$), closeness centrality ($r = 0.03$) and eigenvector ($r = 0.03$) all show significant gender differences, but their r values are even lower than the lower limit for trivial effects (0.1), meaning that there are no practical gender differences. The approximation of the mean $\pm$ standard deviation between two genders of all these indicators can also be corroborated with the very small r value.

TABLE III: Gender Comparison Test Analysis Results of Six Social Network Analysis Indicators Based on Data from All Five Seasons

Metric	Mean ± SD		The Wilcoxon signed-rank test		The correlation coefficient
	Female	Male	P	Z	r
Density	3.23 ± 1.15	3.49 ± 1.36	<0.001	3.58	
Transitivity	0.91 ± 0.05	0.91 ± 0.05	0.046	2.00	
Degree centrality	3.91 ± 2.85	4.40 ± 3.01	<0.001	13.50	
Betweenness centrality	5.53 ± 6.61	5.10 ± 6.06	<0.001	4.55	
Closeness centrality	0.06 ± 0.01	0.06 ± 0.01	<0.001	5.50	
Eigenvector	0.53 ± 0.29	0.54 ± 0.30	<0.012	2.51	

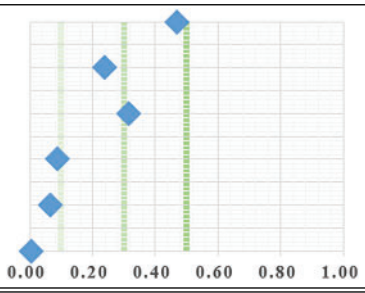


It can be clearly seen in Table IV that throughout all investigated metrics but one, the eigenvector, and for both genders that the top teams reach significantly higher values than the bottom teams. One team-level network indicator, density ($r_{female} = 0.47$, $r_{male} = 0.54$), have stronger effect size according to Cohen. Among the four individual indicators of players, the degree centrality has highest effect size ($r_{female} = 0.32$, $r_{male} = 0.18$). For the individual centrality metrics, only the eigenvector is not displaying a significant difference between top and bottom rank teams. Generally speaking, the two genders show similar trends in the differences in passing network indicators of teams with different performance level.

The results for home and away differences are shown in Table V. For male football, besides the eigenvector, although with very small effect size, other passing network metrics showed significant difference between home and away games. But for the female football, only the degree centrality showed home and away difference with only very lower effect size 0.02. In fact, all r values of both genders are smaller than 0.1, which showed almost non-existent effect size.

TABLE IV: The Passing Network Metrics Comparison of the Top and Bottom Teams in Different Male's and Female's Football

Metric	Female			Male		
	P	Z	r	P	Z	r
Density	<0.001	7.61		<0.001	14.50	
Transitivity	<0.001	5.01		<0.001	8.27	
Degree centrality	<0.001	29.70		<0.001	26.00	
Betweenness centrality	<0.001	8.32		<0.001	8.44	
Closeness centrality	<0.001	6.25		<0.001	6.14	
Eigenvector	0.567	0.57		0.220	1.23	



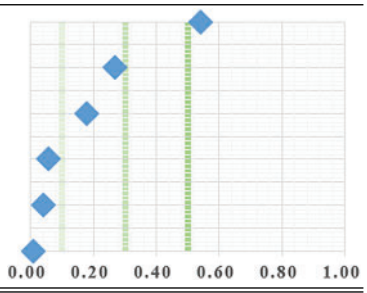
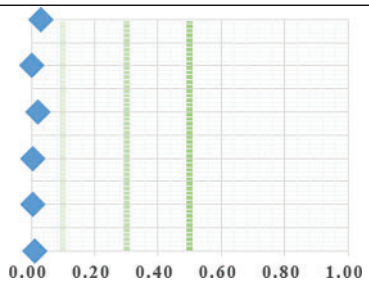
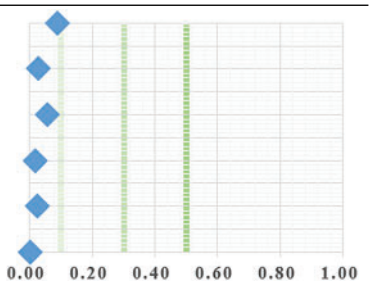


TABLE V: The Passing Network Metrics Comparison of the Home and Away Games in Different Male's and Female's Football

Metric	Female			Male		
	P	Z	r	P	Z	r
Density	0.075	1.78		<0.001	7.69	
Transitivity	0.705	0.38		0.070	1.81	
Degree centrality	0.041	2.05		<0.001	8.13	
Betweenness centrality	0.701	0.38		0.010	2.58	
Closeness centrality	0.647	0.46		0.000	3.57	
Eigenvector	0.314	1.01		0.614	0.50	





4. Discussion

The primary aim of this study is to investigate gender differences in passing networks within the top-tier men's and women's football leagues in England. Using social network analysis (SNA), we analyzed transitivity, density, and four node-based metrics: degree centrality, closeness centrality, betweenness centrality, and eigenvector centrality. Previous studies, both for male and female athletes, and even more specifically for male and female football players, have shown significant differences in physical performance such as strength and endurance (Bradley *et al*., 2014; de Araújo *et al*., 2020; Krustrup *et al*., 2005; Low *et al*., 2020; Rampinini *et al*., 2009). The same difference can also be seen regarding technical skills, with scholars generally finding that male football players perform better than female football players (Araya & Larkin, 2013; Carmichael *et al*., 2001; Jones *et al*., 2004; Lago & Martín, 2007; Lago-Ballesteros & Lago-Peñas, 2010; Pappalardo *et al*., 2021). Interestingly, overall the gender differences in passing networks found in this study are smaller compared to the studies mentioned above.

In addition to directly comparing gender differences in various dimensional indicators of the passing network, we also aimed to determine whether these indicators exhibit similar trends across different genders in terms of team performance. Unlike traditional track and field events where performance is measured in terms of distance and time, it is more important for players to cooperate with each other to achieve a common goal. And "control" of the ball is the key to achieving the tactical intent, both in the organisation of the attack and in the defensive response.

This is also reflected in our comparison of the performance of top and bottom ranked teams in the passing network. We found that both male's and female's teams in the top rankings significantly outperformed the bottom ranked teams in terms of network performance, which is also similar to the results of a large number of previous studies that have demonstrated significant differences in team possession across levels (Carmichael *et al*., 2001; Jones *et al*., 2004; Lago & Martín, 2007; Lago-Ballesteros & Lago-Peñas, 2010). However, we found that this relationship between passing network metrics and final team rankings did not show significant gender differences. While previous studies have not compared gender differences, several studies have shown that both in the Men's Premier League and the Women's World Cup, highly ranked teams have significantly higher numbers of successful passes and passing accuracy than lower ranked teams (Araya & Larkin, 2013; Kubayi & Larkin, 2020; Lepschy *et al*., 2020), which corroborates our findings.

As another finding of this study, the extremely low effect sizes for various network-based indicators in both men's and women's football reveal the non-existence of a home field advantage. In men's football, previous studies have explored differences between home and away teams using traditional metrics like possession and passing rates (Bradley *et al*., 2014; Gama *et al*., 2016; Zeng & Zhang, 2022), and they have similarly identified a home advantage. There are currently only two papers discussing the topic of home advantage in women's football but they mainly focused on the yellow card and final results which were not affected (Krumer & Smith, 2023; Szabó & Kerényi, 2023). This study found that from the perspective of players' cooperative interactions, the so-called home field advantage is not significant in women's football. Traditionally, the reasons for home advantage are believed to include familiarity with the playing environment (Moore & Brylinsky, 1995; Neave & Wolfson, 2003), the absence of travel-related fatigue (Ponzo & Scoppa, 2018; Van Damme & Baert, 2019), and the support of the home crowd (Buraimo *et al*., 2013; Pollard & Pollard, 2005). It's not unlikely that those factors are not similar for men's and women's football. On one hand, male football players are probably less affected by travel fatigue due to higher financial support. On the other hand, women's football teams have lower levels of attention (live spectators) that contribute to the difference of audience support. For instance, according to Euromonitor International (2023), while the English Women's Super League experienced a 729% growth in attendance between 2017 and 2022, the highest-attended women's games at the last three Women's Football World Cups still only reached about 70% of the attendance at the highest-attended men's games. This difference regarding home field advantage in women's football is an interesting topic for further research.

It is important to acknowledge some limitations of this study. First, the passing network is based solely on successful passes, as data on the intended recipients of unsuccessful passes could not be extracted from the available datasets. Secondly, even with the same data, we cannot assume that the teams have the same tactical intentions. The same ball control and passing rates may be due to higher aggressiveness and obvious attacking intentions, or it may be a more conservative strategy. For example, tactics based on counterattacks will intentionally give up possession of the ball, which is difficult to reflect in a passing network based on possession and successful passing. Thirdly, the ideal situation is to use the same season of men's and women's football data for analysis, but now it is difficult to obtain the data for free from public resources. We can only try our best to use seasons with similar years, which may also cause some problems, but this currently cannot be resolved. Finally, it is worth

mentioning that the eigenvector did not have a direct relationship with the performance of the team, and in all the analyses in this article, it showed different trends compared to other network indicators.

5. Conclusion

Overall, this study demonstrates that, from the perspective of the passing network, there are no significant gender differences in team and individual performance. Social network analysis, originally developed in fields such as graph theory and sociology, has only recently been applied to sports science. Whether various overall and individual-based network analysis indicators can better reflect sports performance and improve work efficiency needs further exploration, and this study complements this work. This study not only contributes to a deeper understanding of the performance differences of different ranked teams from the perspective of passing networks and home and away differences, but more importantly, reveals that the so-called gender differences are not significant from the perspective of player interaction. Women's football, like men's football, has the same fierce collision, the same ingenious coordination, and the same pursuit of excellence. We believe, and hope, that women's football is an interesting topic that deserves to be explored more from other perspectives in the future.

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Availability of Data and Materials

The datasets analysed during the current study from Statsbomb are available in the Statsbomb website, https://github.com/statsbomb/open-data.

Another data from Stats LLC was provided by Stats LLC to us with the permission to use it for scientific studies and publish the findings, but not publicly available.

Author Contributions

C.Y. and O.K. worked together to complete conceptualization and methodology, C.Y. processed data and wrote the main manuscript text, O.K. reviewed and edited the manuscript. All authors reviewed the final manuscript.

Conflict of Interest

The authors declare that they do not have any conflict of interest.

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