



Passing Network Analysis of Positional Attack Formations in Handball

by

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The aim of this study was to characterize handball from a social network analysis perspective by analyzing 22 professional matches from the 2018 European Men's Handball Championship. Social network analysis has proven successful in the study of sports dynamics to investigate the interaction patterns of sport teams and the individual involvement of players. In handball, passing is crucial to establish an optimal position for throwing the ball into the goal of the opponent team. Moreover, different tactical formations are played during a game, often induced by two-minute suspensions or the addition of an offensive player replacing the goalkeeper as allowed by the International Handball Federation since 2016. Therefore, studying the interaction patterns of handball teams considering the different playing positions under various attack formations contributes to the tactical understanding of the sport. Degree and flow centrality as well as density and centralization values were computed. As a result, quantification of the contribution of individual players to the overall organization was achieved alongside the general balance in interplay. We identified the backcourt as the key players to structure interplay across tactical formations. While attack units without a goalkeeper were played longer, they were either more intensively structured around back positions (7 vs. 6) or spread out (5 + 1 vs. 6). We also found significant differences in the involvement of wing players across formations. The additional pivot in the 7 vs. 6 formation was mostly used to create space for back players and was less involved in interplay. Social network analysis turned out as a suitable method to govern and quantify team dynamics in handball.

Key words: social network analysis, temporal networks, centrality measures, performance analysis, tactical analysis, team sports.

Introduction

Matches in team sports are complex dynamic systems that result from frequent interaction between players (Glazier and Davids, 2009). Teams work together collectively to achieve the common goal of winning (Lusher et al., 2010). In fact, the synchronized action of players in a team is regarded as a crucial part of the key factors to successful performance (Grund, 2012). Here, passing, which is a common performance variable in notational analysis of team sports, is the foundation for the collective action of players in a team (Passos et al., 2016).

In handball, ball circulation is crucial to establish an optimal position for throwing the ball into the goal of the opponent team (Wagner et al.,

2014). However, varying environmental constraints, such as the configuration of the opposing line-ups, require different interaction patterns in order to succeed (Araújo and Davids, 2016). There is a set of different tactical formations that are played during a handball game, often induced by two-minute suspensions or the addition of an offensive player replacing the goalkeeper as allowed by the International Handball Federation (IHF) since 2016. Therefore, studying the interaction patterns of handball teams considering the different playing positions under various attack formations contributes to the understanding of the sport and its actual development.

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Social network analysis (SNA) has proven successful in the study of ball passing dynamics by breaking down the complexity within the web of interactions between players (Passos et al., 2011). As a match analysis tool, SNA is able to quantify the contribution of individual players to the general interplay as well as detect patterns in the passing structure of teams (Clemente and Martins, 2017).

At a micro-level, focusing on individual performance, professional matches in soccer have been analyzed predominantly. As midfielders are responsible for building attacks, they are identified as the most prominent players in the majority of studies (Clemente et al., 2015a; Pena and Touchette, 2012). Clemente and Martins (2017) also consider different tactical formations in their computation of network metrics in professional soccer. At a macro-level, focusing on general team performance, several studies suggest a strong correlation between successful team performance and frequent but also balanced interplay between players (Clemente et al., 2015b; Duch et al., 2010; Grund, 2012).

In summary, most of the studies using SNA are conducted in soccer. The majority of studies in handball, however, rather discuss physical and technical attributes of the sport (Karcher and Buchheit, 2014; Michalsik and Aagaard, 2015; Póvoas et al., 2012). Tactical components, especially in terms of interplay, have not been studied extensively yet. Korte and Lames (2018) offer the first insight into the interplay in handball at an aggregate match-level. They identify the backcourt players as most central in terms of structuring interplay, but do not account for different tactical formations. The newly introduced rule to replace the goalkeeper in attacking phases alongside the frequent occurrence of temporary suspensions has enriched the sport with an extensive set of attacking formations or constellations and thus varying constraints for attacking teams. According to Gruic et al. (2006) the resulting tactical setup during attack phases influences the interplay of attacking teams. In particular, they found that backcourt players adapted their passing behavior according to changes in the tactical setup. However, their analysis is rather qualitative and tactical formations under the new IHF rule were not considered. Hence, analyzing

the collective organization of teams and their passing patterns during different types of attack phases would be very important to better understand the sport of handball.

Therefore, the aim of this study was to characterize interplay by focusing on positional attacks across different tactical formations. As we also differentiated between playing positions, the focus did not only lie on the general structure of interplay, but also on the individual contribution of players within a team. At a micro-level, we calculated the weighted in-/out-degree and flow centrality to assess the overall involvement of playing positions in attacks across a match and their contribution to structuring plays within attack units. At a macro-level, density and weighted degree centralization was computed to better understand the level of cohesion between players and balance of interplay.

To our knowledge, this is the first study that attempted a tactical analysis of interplay in handball by differentiating between prevalent tactical formations as well as playing positions exploiting metrics of SNA. Moreover, it pioneers the breakdown of the assessment at the attack unit level to take the temporal component of handball into account.

Methods

Samples

A total of 22 matches of the 2018 EHF European Men's Handball Championship were analyzed in this study including all encounters from the main round, two semi-finals, the third-place match and the final. A total of 3,100 directed adjacency matrices, one for each attack unit, captured an aggregated amount of 17,420 passes between players in our analysis.

Procedures

Conducting SNA requires passing networks constructed from a set of nodes and edges. The nodes represent players, whereas the edge weights stand for the number of passes between them. Following Ramos et al. (2018), we conducted our analysis on the attack basis instead of the aggregated match level to consider the temporal character of handball. That means, instead of aggregating the passing data of a team throughout a whole match before running analysis, we evaluated each attack separately. That way, we could track and analyze actual

sequences of interplay instead of average connections across a series of attacks.

When focusing on attacks, literature differentiates between counter-attacks and positional attacks in handball (Karcher and Buchheit, 2014). We only focused on the latter, meaning organized positional attacks with offensive as well as defensive players having taken their respective playing position (Yamada et al., 2014). This is because we wanted to focus on the structured and controlled interaction to overcome defensive lines which constituted 87% (1,993 in total) of all attacks in our study. As ball possession of attacking teams is often subdivided into multiple sub-attacks or offensive attempts, caused by a referee decision, throw-in or re-possession of a deflected ball (Pfeiffer and Perl, 2006), we defined these as our smallest units of attack (3,100 in total) to most accurately represent the concept of interplay (Ramos et al., 2018).

To characterize the different types of sub-attacks, we differentiated between four common tactical formations, namely 6 vs. 6, 6 vs. 5, 5 + 1 vs. 6 and 7 vs. 6. Whereas the first number described the number of offensive players, the second number stated the number of defensive players within the sub-attack, accordingly. 6 vs. 6 can be seen as the most common *base formation*, 6 vs. 5 implies a two-minute penalty in the defending team, 5 + 1 vs. 6 reflects a two-minute suspension in the attacking team which is compensated by replacing the own goalkeeper with an additional attacking player. The tactical formation 7 vs. 6, on the other hand, implies a goalkeeper replacement by the attacking team, as described above, without having suffered a temporary suspension. In our study, most of the sub-attacks were played in a 6 vs. 6 formation (74.5%), 10.3% in 5 + 1 vs. 6, 7.7% in 6 vs. 5 and 3.9% in a 7 vs. 6 formation. The remainder consisted of other infrequently played formations such as 5 vs. 5 or 7 vs. 5. However, we focused on the four most frequent tactical formations that totaled 96.4% of all attack units.

To better understand attack formations and be able to characterize handball as such, we tracked playing positions and not players (Póvoas et al., 2012). In handball, we may find a clear differentiation between tactical roles (Cardinale et al., 2016). Therefore, we codified the following playing positions: i) a left wing (LW); ii) a left back (LB); iii) a center (C); iv) a right back (RB); v)

a right wing (RW); vi) a pivot (P); and vii) an additional pivot in 7 vs. 6 (P7). As the goalkeeper is not involved in positional attacks, we dropped this playing position from analysis.

To overcome the issue of frequent substitutions, especially in the backcourt, we reassigned playing positions (Michalsik and Aagaard, 2015). The tracking and codification process was completed by researchers with more than 15 years of experience in handball. It was executed through video analysis applying the software Dartfish®.

To ensure the reliability of the data, we computed Cohen's kappa and Gwet's AC1 inter-rater statistic in a two-stage process (Gwet, 2001). Using Gwet's statistic, we first analyzed the agreement on the occurrence of passes. In a second step, Cohen's Kappa tested the agreement on the pass executer and receiver. Moreover, the agreement on the tactical formation was tested. 15% of the overall data was assessed for reliability purposes. The Kappa (Gwet) values were above 0.95 (0.80) for passing and 0.83 for the agreement on tactical formations, meeting the requirements for observer agreement (Robinson and O'Donoghue, 2007).

Network Metrics

Matlab® software was used to carry out the analysis and the visualization of networks was enabled through Cytoscape®. A set of individual and team centrality metrics was computed. It allowed quantification of the involvement of playing positions in executing and structuring interplay as well as the overall distribution and layout of passing within an attacking team. We considered weighted directed graphs to include both passing directions between any set of two attacking players. At a micro-level, the weighted in-/out-degree as well as flow centrality were computed. At a macro-level, density and weighted degree centralization were calculated to assess the general structure of interplay in different formations.

Weighted In-Degree

The weighted in-degree, also referred to as prestige in SNA, is the sum of all incoming weighted edges of a particular node. Thus, in a handball context, it captures the number of received passes by a player during an attack unit. Let n_i be a node of weighted directed graph G with n nodes. Then, the weighted in-degree index,

$C_{WID}(n_i)$, for player i is calculated as

$$C_{WID}(n_i) = \sum_{\substack{j=1 \\ i \neq j}}^n a_{ji} \quad (1)$$

where a_{ji} corresponds to the frequency of passes from player j to i . The metric is often taken as the first indicator for the prominence of a player. A player that is being targeted frequently during an attack is mostly trusted by fellow players to structure the team's attacking plays (Clemente et al., 2015a; Korte and Lames, 2018).

Weighted Out-Degree

The weighted out-degree, also referred to as centrality, takes the sum of all outgoing weighted edge values of a certain node. It therefore represents the number of executed passes by a player during an attack unit. Let n_i be a node of weighted directed graph G with n nodes. Then, the weighted out-degree index, $C_{WOD}(n_i)$, for player i is calculated as

$$C_{WOD}(n_i) = \sum_{\substack{j=1 \\ i \neq j}}^n a_{ij} \quad (2)$$

where a_{ij} corresponds to the frequency of passes from player i to j . In recent studies, this metric was often used to describe players with a high contribution to the overall ball circulation (Clemente et al., 2015a).

Both degree metrics were computed at an absolute as well as a relative level. We obtained relative values as a share of the aggregated degree levels across all playing positions. Moreover, we also carried out an analysis of a subset which only included attack units of at least three passes for these two metrics to provide a richer insight into passing patterns in handball by focusing on longer attacking plays.

Flow Centrality

Flow centrality is calculated as the fraction of passing sequences (or attack units) that a particular playing position is involved in relative to all plays of the team within a match (Fewell et al., 2012). In contrast to the weighted degree centrality metrics described above, flow centrality does not assess the average involvement of a particular player within attack units, but the overall prevalence in attack units across the entire match. This enters a new aspect

to the assessment of interplay. By only looking at the weighted degree, the intermediary role of a player, who is highly involved in the passing of only a small set of attack units across a match, might be overestimated. In contrast, flow centrality focuses on the share of attacks that a particular player is at least once involved in. As it offers a holistic evaluation of the involvement across an entire match, it is increasingly used to assess the intermediary role of individual players (Duch et al., 2010). The flow centrality index, $C_{FC}(n_i)$, for player i is calculated as

$$C_{FC}(n_i) = \frac{\sum_{k=1}^m s_k(n_i)}{s_m} \quad (3)$$

where s_m denotes the total number of m attack units in a match and $s_k(n_i)$ denotes the k -th attack unit in which n_i is involved at least once. By construction, all flow centrality values are bounded between 0 (player n_i is not involved in any attack unit of the team in a match) and 1 (player n_i is involved in all attack units of the team in a match). Contrary to the concept of betweenness, which focuses on paths, it rather considers walks. Paths are based on the strongest connections in terms of pass frequency between any set of two players. However, it does not necessarily describe an actual passing sequence. In contrast, walks consider direct interplay during attack phases (Borgatti, 2005). Thus, flow centrality is seen as a more appropriate metric to describe intermediary players (Ramos et al., 2018). In addition, we examined flow centrality restricted to interactions in the final three passes before a shot-on-goal situation to study network properties in the crucial phase of an attack unit, following Fewell et al. (2012). The index for this specific metric is defined as $C_{FC3}(n_i)$ for player i .

Density

Density is the number of actual connections between attacking players as a share of the potential connections. The latter is a connection (or technically: edge) that could potentially exist between any sets of two attacking players. Thus, this metric provides quantification of the general level of cohesion across a team within an attack unit. For the computation, we assessed the direction of the pass as irrelevant as the focus purely lay on the occurrence of a connection. For a weighted digraph G with n

nodes, the density index, C_D , is calculated as

$$C_D = \frac{2 * \sum_{j=1}^n c_{ij}}{(n-1) * n} \quad (4)$$

where c_{ij} is an indicator function that takes the value 1 if there is at least one pass from player i to j or vice versa. Otherwise, it takes the value 0. The metric is adjusted by the total number of potential connections between n nodes.

Weighted Degree Centralization

Weighted degree centralization takes the sum of all deviations from the weighted degree values of all nodes to the highest value in the network adjusted by the number of players and passing intensity (Freeman, 1978; Opsahl et al., 2010). The weighted degree value of a node is simply the sum of its weighted in-/out-degree values. In a sports context, the metric provides an indication to what level the cohesion is concentrated around certain players of the attacking team. For a weighted graph G with n nodes, the weighted degree centralization index, C_{WDC} , is calculated as

$$C_{WDC} = \frac{\sum_i^n C_{WD}^* - C_{WD}(n_i)}{(n-1) * C_{WD}} \quad (5)$$

where C_{WD}^* is the highest weighted degree value of a playing position in its team, $C_{WD}(n_i)$ the weighted degree value of playing position i and C_{WD} the aggregated weighted degree values of all playing positions, which can also be referred to as passing intensity (Grund, 2012). The adjustment according to the number of attacking players allowed a comparison between tactical formations.

Statistical Procedures

For individual metrics, two-way ANOVA was carried out for each dependent variable, degree and flow centrality. Tactical formations and playing positions were the independent factors of our analysis. We conducted multiple one-way ANOVA to analyze the variance within each factor and Tukey HSD post-hoc tests for pairwise comparisons between tactical formations and playing positions, respectively. For team metrics, C_D and C_{WDC} , multiple one-way ANOVA was executed to test for statistical differences between tactical formations. All analyses were

conducted with Matlab at a 5% significance level. Following Ferguson (2009) and Clemente and Martins (2017), η^2 was reported to interpret the effect size according to the following criteria: no effect ($\eta^2 < 0.04$); small effect ($0.04 \leq \eta^2 < 0.25$); moderate effect ($0.25 \leq \eta^2 < 0.64$); strong effect ($\eta^2 \geq 0.64$).

Network Visualization

A visualization of the results is provided by a depiction of common network plots with nodes and edges representing playing positions and passing frequency, respectively. The 5 + 1 vs. 6, 7 vs. 6 and 6 vs. 5 formations are visualized as the relative difference values compared to 6 vs. 6, both positive and negative.

Results

Individual Variables

The results of the two-way ANOVA revealed significant differences in the independent variable of the playing position on C_{FC} ($p < .001$; $\eta^2 = 0.744$), C_{FC3} ($p < .001$; $\eta^2 = 0.625$), C_{WID} ($p < .001$; $\eta^2 = 0.163$) and C_{WOD} ($p < .001$; $\eta^2 = 0.197$). Moreover, significant differences were found with regard to the tactical formation on C_{FC} ($p < .001$; $\eta^2 = 0.023$), C_{WID} ($p < .001$; $\eta^2 = 0.007$) and C_{WOD} ($p < .001$; $\eta^2 = 0.008$). No statistical differences were found for the independent variable of the tactical formation with regard to C_{FC3} ($p = 0.121$; $\eta^2 = 0.007$). There were also statistically significant interactions between the tactical formation and playing position on C_{FC} ($p < .001$; $\eta^2 = 0.056$), C_{FC3} ($p = 0.003$; $\eta^2 = 0.040$), C_{WID} ($p < .001$; $\eta^2 = 0.008$) and C_{WOD} ($p < .001$; $\eta^2 = 0.006$) including the filtered subset focusing on attacks of at least three passes. That means formation changes affected playing position involvement, measured by our individual metrics, differently.

The results of the one-way ANOVA demonstrated significant effects between centrality levels of playing positions for each tactical formation with respect to all individual centrality measures. Table 1 shows that the highest average values were found for the center position, C, followed by both back positions (LB and RB) with respect to all relevant centrality measures.

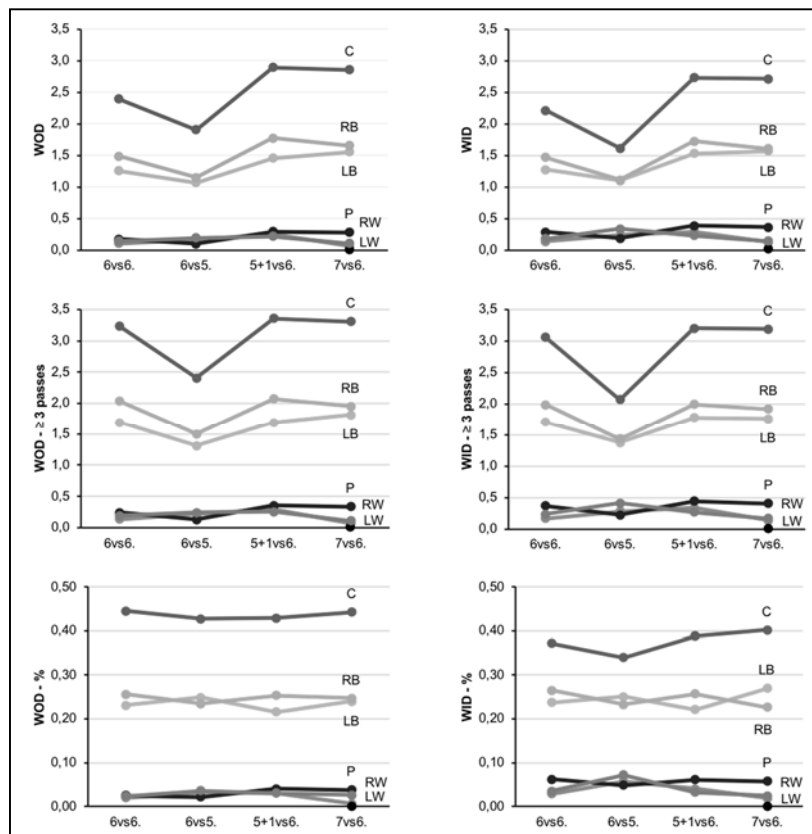


Figure 1 Mean results of C_{WOD} / C_{WID} metrics including ≥ 3 passes and %-values

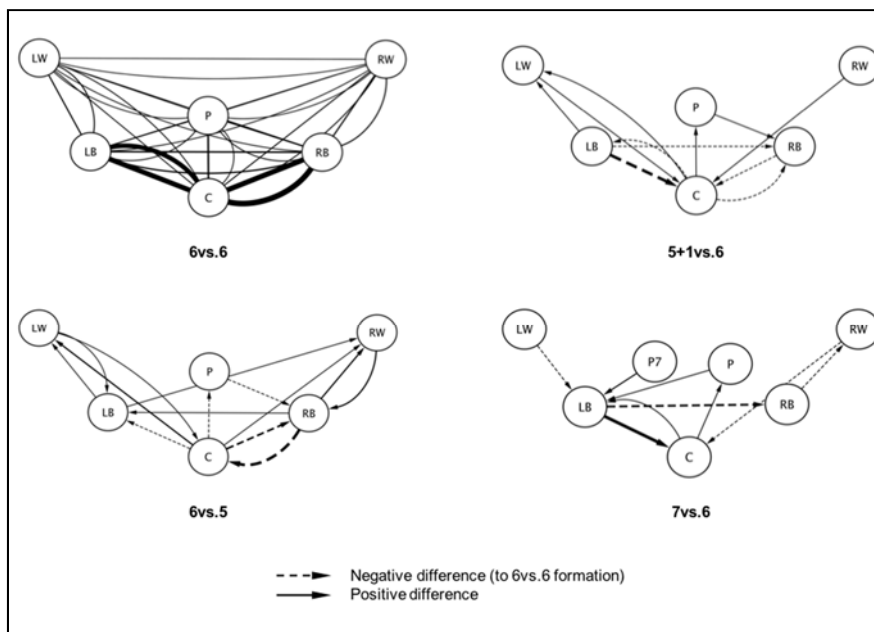


Figure 2 Visualization of passing networks and relative differences between formations

Table 1
Descriptive statistics and post-hoc results for individual metrics

	C	LB	LW	P	P7	RB	RW
<i>C_{WOD}</i>							
6 vs. 6	2.39 (1.82) all / all	1.25 (1.15) all / 516,76	0.10 (0.34) C,Bs / 65,516	0.17 (0.38) all / all	-	1.49 (1.30) all / 65	0.14 (0.38) C,Bs / 516
6 vs. 5	1.90 (1.36) all / all	1.07 (0.91) C,P,Ws / 516,76	0.17 (0.42) C,Bs / all	0.10 (0.30) C,Bs / all	-	1.15 (1.01) C,P,Ws / all	0.19 (0.46) C,Bs / -
5 + 1 vs. 6	2.89 (1.73) all / 66,65	1.45 (1.09) all / 66,65	0.25 (0.48) C,Bs / 66,65	0.29 (0.48) C,Bs / 66,65	-	1.77 (1.18) all / 65	0.22 (0.46) C,Bs / 66,76
7 vs. 6	2.85 (1.75) all / 66,65	1.56 (1.05) C,Ps,Ws / 66,65	0.06 (0.23) C,Bs / 65,516	0.28 (0.49) C,Bs / 66,65	0.01 (0.09) C,Bs	1.66 (1.15) C,Ps,Ws / 65	0.11 (0.31) C,Bs / 516
<i>C_{WID}</i>							
6 vs. 6	2.21 (1.83) all / all	1.27 (1.15) all / 516,76	0.13 (0.38) C,Bs,P / 65,516	0.28 (0.49) C,Bs / 65, 516	-	1.46 (1.28) all / 65,516	0.18 (0.43) C,Bs,P / 65
6 vs. 5	1.61 (1.27) all / all	1.10 (0.94) C,P,Ws / 516,76	0.23 (0.47) C,Bs / 66	0.19 (0.42) C,Bs / all	-	1.11 (0.99) C,P,Ws / all	0.34 (0.60) C,Bs / all
5 + 1 vs. 6	2.73 (1.71) all / 66,65	1.53 (1.12) C,P,Ws / 66,65	0.29 (0.50) C,Bs / 66,76	0.39 (0.52) C,Bs / 66,65	-	1.72 (1.17) C,P,Ws / 66,65	0.23 (0.49) C,Bs / 65
7 vs. 6	2.71 (1.70) all / 66,65	1.57 (0.97) C,Ps,Ws / 66,65	0.12 (0.33) C,Bs / 516	0.36 (0.50) C,Bs / 65	0.01 (0.09) C,Bs	1.61 (1.24) C,Ps,Ws / 65	0.14 (0.37) C,Bs / 65
<i>C_{FC}</i>							
6 vs. 6	0.95 (0.03) all / -	0.85 (0.06) C,P,Ws / 76	0.15 (0.08) all / 516	0.29 (0.09) all / -	-	0.86 (0.07) C,P,Ws / -	0.20 (0.09) all / 65
6 vs. 5	0.94 (0.12) P,Ws / -	0.89 (0.18) P,Ws / -	0.24 (0.23) C,Bs / -	0.24 (0.34) C,Bs / 516	-	0.83 (0.23) P,Ws / 516	0.33 (0.25) C,Bs / 66
5 + 1 vs. 6	0.97 (0.08) P,Ws / -	0.88 (0.14) P,Ws / -	0.28 (0.24) C,Bs,P / 66,76	0.41 (0.26) all / 65	-	0.92 (0.10) P,Ws / 65	0.24 (0.21) C,Bs,P / -
7 vs. 6	0.99 (0.03) Ps,Ws / -	0.96 (0.07) Ps,Ws / 66	0.12 (0.17) C,Bs,Ps / 516	0.43 (0.39) C,Bs,P7,Ws / -	0.02 (0.08) all	0.92 (0.10) Ps,Ws / -	0.21 (0.26) C,Bs,Ps / -
<i>C_{FC3}</i>							
6 vs. 6	0.94 (0.08) all / -	0.72 (0.12) all / 76	0.12 (0.10) all / -	0.21 (0.11) C,Bs,LW / -	-	0.77 (0.12) all / -	0.18 (0.11) all-P / 65
6 vs. 5	0.92 (0.20) RB, P, Ws / -	0.82 (0.40) P,Ws / -	0.23 (0.31) C,Bs / -	0.20 (0.36) C,Bs / -	-	0.72 (0.35) C,P,Ws / -	0.33 (0.26) C,Bs / 66, 516
5 + 1 vs. 6	0.96 (0.20) all / -	0.76 (0.37) C,P,Ws / 76	0.17 (0.20) C,Bs / -	0.26 (0.17) C,Bs / -	-	0.73 (0.35) C,P,Ws / -	0.13 (0.26) C,Bs / 65
7 vs. 6	0.97 (0.29) RB,Ps,Ws / -	0.95 (0.32) RB,Ps,Ws / 66,516	0.11 (0.29) C,Bs,P7 / -	0.19 (0.30) C,Bs,P7 / -	0.0 (0.00) all	0.71 (0.38) all / -	0.14 (0.30) C,Bs,P7 / -

Subscripts indicate to which playing positions (part before /) or tactical formation (part after /) given value is statistically different for $p < .05$, e.g. C: given value is statistically different to the value of the center; 66: given value is statistically different to the value in the 6 vs. 6 formation; All: statistically different to all other playing positions / formations; Bs include LB and RB; Ws include LW and RW; Ps include P and P7

Table 2

Descriptive statistics and post-hoc results for team metrics

	6 vs. 6	6 vs. 5	5 + 1 vs. 6	7 vs. 6
C_D	0.17 (0.09) 516	0.17 (0.08) 516	0.22 (0.11) all	0.19 (0.09) 516
C_{WDC}	0.34 (0.07) 516	0.33 (0.08) 76	0.32 (0.08) 66,76	0.35 (0.07) 65,516

Subscripts indicate to which tactical formation given value is statistically different for $p < .05$, e.g. 66: given value is statistically different to the value in the 6 vs. 6 formation; All: statistically different to all other tactical formations

Wings (LW and RW) and pivot(s) (P and P7 for 7 vs. 6) scored lowest for each tactical formation. Focusing on flow centrality, C was involved in at least 94% of all attacking interplays for each tactical formation and at least 92% when focusing solely on the final three passes before a shot on the goal. No significant differences were found between the back positions here.

The pivot, P, was significantly more involved in attack units than the wing positions, apart from the 6 vs. 5 formation in which the LW and RW were more prevalent. Between those two playing positions we only found significant differences within the 6 vs. 6 formation. The additional pivot, P7, was only part of the interplay in about 2% of all attack units taking place in the 7 vs. 6 formation.

The results of the multiple one-way ANOVA of C_{WID} , C_{WOD} , C_{FC} and C_{FC3} per playing position for each tactical formation can also be taken from Table 1. For C and the other two back positions, LB and RB, absolute C_{WID} and C_{WOD} values were significantly higher in the 5 + 1 vs. 6 and 7 vs. 6 formation than in 6 vs. 6 and 6 vs. 5, respectively. Figure 1 shows that for attacking plays with more than three passes, there were no significant differences between 5 + 1 vs. 6, 7 vs. 6

and 6 vs. 6 for the three back positions. C_{WID} and

C_{WOD} values of wing players were lowest in the 7 vs. 6 formation, independently of the length of the attacking plays, though only partly significantly. They scored highest in the 6 vs. 5 (RW) and 5 + 1 vs. 6 formation (LW). In general, 5.5 passes were played in the 6 vs. 6 formation per sub-attack, 6.9 passes (+25.5%) in the 5 + 1 vs. 6 setup, 6.5 passes (+18.2%) in the 7 vs. 6 formation, while there were only 4.6 passes (-16.4%) on average in the 6 vs. 5 formation.

Focusing on the relative shares in C_{WID} and C_{WOD} values across tactical formations, we only found few significant differences, as visualized in Figure 1. However, the center position had a significantly lower share in received passes in attack units played in the 6 vs. 5 formation, whereas the wing players showed significantly higher values during these attack phases in comparison to the other formations.

Our analysis also showed significant differences in the overall attack involvement (C_{FC} and C_{FC3}) per playing position for each tactical formation. However, the ranking across tactical formations in terms of the individual metric values was mixed for playing positions. When

focusing on the final three passes of an attack, we

only found significantly higher flow centrality values for the LB in the 7 vs. 6 formation against 6 vs. 6 and 5 + 1 vs. 6 as well as the RW in the 6 vs. 5 formation against 6 vs. 6 and 5 + 1 vs. 6.

Team Variables

We found significant differences between tactical formations for C_D ($p < .001; \eta^2 = 0.024$) and C_{WDC} ($p < .001; \eta^2 = 0.013$). On average, the density values (0.17) were significantly higher and centralization values (0.33) significantly lower in the 5 + 1 vs. 6 formation than in the all others, though with nearly no effect size. The average density value of 0.17 implies that 17% of possible connections between the attacking players were utilized for interplay which amounts to 2.4 of the 15 potential connections on average. The weighted degree centralization value was highest within the 7 vs. 6 formation, though not significantly different from the other formations. Table 2 presents the results of our analysis.

Network Visualization

The aggregated passing distribution between playing positions in Figure 2 confirms the relatively lower share in passing of the C and a higher share for wing positions in the 6 vs. 5 formation. Moreover, it shows the increased prevalence of the LB in attacking plays and low involvement of wing positions in the 7 vs. 6 formation compared to 6 vs. 6.

Discussion

The study reveals statistical significance with respect to differences of centrality measures, at both micro and macro levels, between tactical formations and playing positions. Effect sizes found were small to moderate.

Across the four most prevalent tactical formations in handball, the overall involvement of playing positions in attack units per match and their average passing involvement per attack unit vary differently. Our analysis shows that the effect is mostly moderated by differences between playing positions within each formation and less by substantially changing centrality levels of individual playing positions across different formations. Here, we also observed significant differences. However, effect sizes were small to negligible.

We found that interplay was dominated

positions, i.e. C, LB and RB across all formations. This is in line with Srhoj et al. (2001) who found that this was partly induced by the favorable position on the court which was also prevalent in all tactical formations. The dominance was demonstrated in the explicitly high flow centrality values indicating an almost persistent involvement in each attack unit, while wing and pivot players were only involved in every third or fourth positional attack unit. One explanation for these findings is that attack efficiency in handball was found to decrease with increasing duration of positional attacks (Rogulj et al., 2011). Towards the beginning of an attack the opposing team might struggle to form an effective defense which offers back players an easier scoring opportunity. According to the authors, players in back positions therefore attempt to finalize attacks as early as possible and, thus, often without the inclusion of wing or pivot players. The high C_{WID} and $C_{(WOD)}$ values underline that the backcourt is not only more prevalent in attacks during the match, but also structures them within. The average number of pass executions and receptions was highest for C, who can be seen as the key player in structuring plays, followed by the back players. Wing and pivot players have similar passing numbers on average, but are significantly less involved in structuring interplay. This is in line with Foretic et al. (2013) who, in their study on situational efficiency in men's top-level handball, ascribe back players the task of organizing the game with the aim of creating a favorable position for attack completion. The resulting three hierarchy layers of centrality also reveal a symmetric level of involvement between left- and right-sided players, especially in regard to the LB and RB.

Although a mutual hierarchy is visible among playing positions in terms of interplay involvement across formations, a closer look at the results of the passing statistics and centrality metrics also shows differences in passing behavior and general interplay between tactical formations. First, they differ in their average number of passes per positional attack. Attack units with no goalkeeper such as 7 vs. 6 and 5 + 1 vs. 6 are played significantly longer on average (+20%) than 6 vs. 6 and 6 vs. 5. One explanation for that finding could be that teams in a 5 + 1 vs. 6

by and structured around the three back

formation intend to lapse time while playing in

minority. As we find a similar result for the 7 vs. 6 formation, the missing goalkeeper could also be a factor. Teams might avoid sudden shot attempts as they fear an almost certain turnover goal and hence decide to rather pass on the ball. For the 6 vs. 5 formation, in contrast, it is most likely that attacking teams either want to efficiently exploit their majority play or are simply able to quicker find the necessary gaps in the decimated defense, both resulting in shorter passing sequences on average.

Combining passing statistics with the results from the team metrics offers a richer insight into understanding the style of interplay. The density values are significantly higher in the 5 + 1 vs. 6 than other formations meaning that more potential connections between players are exploited in this formation. However, the magnitude is quite small and does not even add up to a complete additional connection on average in comparison to the other formations. The centralization values are quite balanced and differences are low in magnitude and effect size implying that the concentration of interplay around certain focal points is balanced between formations. However, it is important to point out that by construction of the centralization metric the highest average value across formations, which is documented for the 7 vs. 6 formation, might underestimate the true level of concentration around crucial positions. The adjustment due to the higher number of attacking players naturally decreases its centralization value especially as passing involvement of the additional pivot, P7, is neglectingly low. This is the first hint, that, although interplay takes on average longer in the 7 vs. 6 formation, it is in fact more concentrated around the back positions in contrast to the other formations.

To better understand the impact of playing positions on interplay, it is crucial to look at the differences in individual centrality metrics per playing position for each formation. The number of executed and received passes of the three back positions is significantly higher in 5 + 1 vs. 6 and 7 vs. 6 than in the other two formations. As the relative degree values of the backs and C remain quite stable across formations, it is evident that the longer average passing is evenly structured around these three particular playing

interplay in the two formations that replace their goalkeepers is their different levels of inclusion of wing and pivot positions. Wing players in the 5 + 1 vs. 6 formation show significantly higher passing values than in 7 vs. 6. This supports the argument that longer passing sequences and the higher level of cohesion in 5 + 1 vs. 6 is also used to spread interplay to wings. In contrast, wing positions face the lowest values in the 7 vs. 6 formation. Whereas the passing involvement of the (standard) pivot position is even between formations, the additional pivot from 7 vs. 6 is nearly never targeted for interplay. Instead, it appears that its role is that of a blocker to provide better shooting opportunities for the back positions. This assumption is also supported by the significantly higher involvement of the LB, which is often referred to as the key shooting position, in 7 vs. 6 attack units (Karcher and Buchheit, 2014). This is especially true for the final three passes before a shot on the goal.

Turning to the basic 6 vs. 6 formation, one would expect that the interplay is quite similar to the 5 + 1 vs. 6 formation given that the same numbers of attacking and defending players face each other. Indeed, the respective involvement of players in attacks and the relative share of involvement in interplay per attack unit is similar or nearly exact. The main difference lies in the significantly higher average number of executed and received passes of three backcourt players in 5 + 1 vs. 6. As the average increase in passing is mostly spread across three positions, and also wing and pivot players are stronger involved, the difference is not detectable in the relative shares of involvement and centralization values. Thus, the general interplay structure, especially with respect to balance of interplay, is similar. However, the significant differences in interplay involvement completely neutralize for backcourt players when filtering for attack units with at least three passes. It suggests that the lower average number of passes in the 6 vs. 6 formation is mostly due to its higher share of positional attack units with less than three passes. In fact, the share amounts to 30.7% in 6 vs. 6, while it is 16.6% in 5 + 1 vs. 6. Once longer offensive plays are initiated, there are no significant differences in general structure and interplay.

The 6 vs. 5 formation stands out as the

positions. What turns out to be different between

most different from the others in terms of

interplay. In contrast to the majority interplay in 7 vs. 6, plays are structured shorter in 6 vs. 5, which can be seen by the low average passing number and 26.2% share of attacks that take less than three passes. It appears that exploiting gaps in the decimated defense is easier. Moreover, wing positions are involved quite frequently as supported by two arguments. First, the involvement ratio in the last three passes before a shot on the goal is highest in the 6 vs. 5 formation. Second, these playing positions show increased C_WID values, implying that wing positions are passed to more frequently, most likely to spread interplay and create open space on the wings as an alternative to breaking through in the backcourt.

The main limitation seen in this research study was related to the unbalanced prevalence of different attack formations in the European Championship with the 6 vs. 6 formation adding up to most of the attack units. A bigger sample size might increase the prevalence of other attack formations. Second, the different number of attacking players (P7 only present in the 7 vs. 6 formation) had a slight effect on the computation of the team metrics which naturally increased the complexity of our comparison. This should be noted in future research on other team sports such as field hockey or water polo, which also have temporary suspensions that influence the number of active players on the pitch. Moreover, this study focuses on the passing interaction leading towards a favorable shooting position. As it does not include the attack outcome itself, it does not break down the actual shooting performance. In general, it is important to stress that neither the situational efficiency of playing positions is assessed nor a differentiation between specific attack models provided. Similarly, defense formations during positional attacks, which could potentially impact ball passing dynamics, were not considered.

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Conclusion

The aim of this study was to characterize the nature of interplay in handball through analyzing passing sequences of positional attacks in the most prevalent tactical formations. By applying centrality metrics from social network analysis, we can quantify the involvement of playing positions and assess the playing style within different formations. Thus, this is the first study that offers a profound analysis of interplay in handball especially under the consideration of the new constraint of goalkeeper replacement in attacking plays. Moreover, our analysis, for the first time in handball, breaks down the complexity of interplay to separate attack units and thus considers actual passing sequences instead of average connections.

The main findings of this study were the significant differences in the attack involvement between playing positions across the most prevalent tactical formations. Attacking plays were predominantly structured by the C and back positions, regardless of the tactical lineup. Average passing sequences were longest in attack formations without a goalkeeper and shortest in the 6 vs. 5 majority formation. Whereas longer plays in 7 vs. 6 were mostly structured around back positions, interplay in 5 + 1 vs. 6 included wing positions more frequently. The highest level of inclusion of wing players was found within the 6 vs. 5 formation, most likely to exploits gaps in the decimated defense.

Future studies should consider variations in the tactical behavior of defensive formations to more accurately account for the dynamic processes taking place between opposing teams in handball.

Ultimately, SNA turned out as a suitable method to govern and quantify the dynamics of ball passing in handball. In addition to traditional performance indicators, it provides an in-depth analysis of passing sequences leading to a better understanding of the nature of the sport and the role of its players.

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