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Journal of Sports Sciences

ISSN: 0264-0414 (Print) 1466-447X (Online) Journal homepage: www.tandfonline.com/journals/rjsp20

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To cite this article: Daniel Link, Otto Kolbinger, Hendrik Weber & Michael Stöckl (2016) A topography of free kicks in soccer, Journal of Sports Sciences, 34:24, 2312-2320, DOI: 10.1080/02640414.2016.1232487

To link to this article: https://doi.org/10.1080/02640414.2016.1232487

Published online: 26 Nov 2016.

JOURNAL OF SPORTS SCIENCES, 2016
VOL. 34, NO. 24, 2312–2320
http://dx.doi.org/10.1080/02640414.2016.1232487

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A topography of free kicks in soccer

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ABSTRACT

This study investigates the spatial relationship of performance variables for soccer free kicks. In order to suggest ways in which players might optimise their performance, we collected data from free kicks (<35 m to goal line) of two German Bundesliga seasons (2013/14, 2014/15) (n = 1624). In the analysis, we applied the ISO-map approach using colour gradients to visualise the mean values of a variable on a 2D-map of the pitch. Additionally, variograms were used to describe the degree of spatial dependence of the free kick variables. Results show that DENSITY, TYPE OF PLAY, PLAYERS IN WALL, DISTANCE TO WALL and RULE VIOLATION were strongly spatially dependent. Centrality and proximity to the goal increased the variables PLAYERS IN WALL, RULE VIOLATIONS and INTERRUPTION TIME, and the ratio of goals scored increased from 5.9% (central far) to 10.9% (central near). In 70.9% of the shots, players preferred a switched laterality, which did not result in a higher success rate. Furthermore, there was no statistical advantage for the defensive team when DISTANCE TO WALL was below 9.15 m or when there was a RULE VIOLATION. Crosses had a success rate (i.e., first controlled ball contact after the cross) of 20.8%. Played with natural laterality, they were 5% more successful than with switched laterality. Crosses from the right side outside the penalty box were 10% more successful than from the left side. Therefore, it might be worthwhile practising the defence of balls coming from this side.

ARTICLE HISTORY
Accepted 25 August 2016

KEYWORDS
Performance analysis; free kick; soccer; topography; variography

1. Introduction

Free kicks represent an important component of performance in soccer. Previous research has found an average number of 30–40 per game (Casal, Maneiro, Ardá, Losada, & Rial, 2014; Ensum, Williams, & Grant, 2000; Hernández Moreno et al., 2011; Olsen, Larsen, Reilly, Bangsbo, & Hughes, 1997; Siegle & Lames, 2012) and that they are the most effective set play from which goals are scored (Carling, Williams, & Reilly, 2005). Analyses of World Cups from 1982 to 2014 showed that between 25% and 35% of goals result from free kicks or corner kicks (Acar et al., 2009; Grant, Williams, Reilly, & Borrie, 1999; Jinshan, Xiaoke, Yamanaka, & Matsumoto, 1993; Njororai, 2013; Yiannakos & Armatas, 2006; Yiannis, 2014). Furthermore, successful teams needed fewer set plays to score goals than less successful ones (Bell-Walker, McRobert, Ford, & Williams, 2006).

Existing studies have sought to identify the factors that increase the probability of successful shots or crosses resulting from set plays. Regarding shots on goal, the chances of success clearly increased for high-velocity shots (Kerwin & Bray, 2006), as well as for positions close to the goalposts (Acar et al., 2009; López-Botella & Palao, 2007; Morya, Bigatao, Lees, & Ranvaud, 2005). The results are not as conclusive with regard to free kicks played as crosses. Carling et al. (2005) reported that crosses directed towards the centre of the penalty area or in the zones in front of the goalposts increase the chances of scoring, whereas Casal et al. (2014) could not find any correlation between position and scoring. A study by Taylor, James, and Mellalieu (2005) suggests that corner kicks are more successful when they are played near the six-yard line. Furthermore, out-swinging corner kicks led to more shots and in-swinging corner kicks to more goals.

To date, there have been relatively few findings on the effects of the position from which a free kick is executed and the characteristic variables related to this position. Only two studies exist that have classified free kicks into distinct groups depending on their location and then described differences between them. Firstly, Alcock (2010) reported that, during the 2007 Women's World Cup, there was an increased scoring rate for direct free kicks if these were taken within a 7 m radius of the penalty spot. However, the small sample of only 65 free kicks does not seem sufficient to derive a general statement in this respect. The second study considered 783 free kicks played as crosses during the 2010 World Cup and the 2012 European Cup (Casal et al., 2014). In this study, the position of the free kick could not be found to influence either the scoring rate or the shot rate. Additionally, laterality was not found to influence success either. Due to the discretisation of free kick positions, neither of these studies provides detailed conclusions on the continuous profile of the variable values.

However, continuous profiling approaches exist in other scientific disciplines, such as geostatistics. For instance, *variography* (Isaaks & Srivastava, 1989) examines the spatial dependency of parameters and is mostly used in combination with

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prognosis models. Applications can be found in mining (Samal, Sengupta, & Fifarek, 2011), hydrology (Lepioufle, Leblois, & Creutin, 2012) or ecology (Reis, Ferreira da Silva, Sousa, Patinha, & Fonseca, 2007). In sport, a similar approach has been used for the analysis of golf shots (Stöckl, Lamb, & Lames, 2012) and to describe patterns of play in hockey (Stöckl & Morgan, 2013).

In the light of the above, this study aims to provide a continuous spatial description of free kick parameters and to identify their influence on success. Some of these parameters, such as execution type, interruption period and laterality have already been examined, though with a different focus and/or with smaller sample sizes. Other parameters used in this study such as the number of players in the wall formation, distance to the wall formation and rule violations of players in the wall have not previously been taken into account. The current study thus allows new insights into the performance structure of soccer and suggests ways in which coaches and tacticians could improve and optimise the performance of their players.

2. Methods

2.1 Sample

In line with the objectives of our study, we applied a non-participative observational approach. The sample comprises all free kicks from all 612 matches of the German Bundesliga seasons 2013/14 and 2014/15. Free kicks were registered by a professional competition information company (Opta Corp., London) and provided by the German Professional Soccer League (DFL).

2.2 Performance variables

For all free kicks, POSITION was collated by the competition information provider. In order to describe the frequency rate of free kicks, we divided the pitch into 1 m^2 sectors. DENSITY represents the number of free kicks counted in each sector. Additionally, for each free kick with a distance of less than 35 m to the goal line, the following performance parameters were collected (Table 1): INTERRUPTION TIME, DISTANCE TO WALL, PLAYERS IN WALL, RULE VIOLATION, LATERALITY, TYPE OF PLAY, OUTCOME OF SHOT and OUTCOME OF CROSS.

DISTANCE TO WALL was measured in the last four rounds of the 2014/15 season (encompassing 36 matches) using video footage containing a view of the entire pitch without camera panning and homography. All other variables were observed by two trained human experts based on video recordings. Due to video availability and cutting, some free kicks could not be considered in our study. The quality of the data was evaluated by an inter-rater reliability test based on the two observers. Cohen's kappa statistics showed substantial to almost perfect agreement (κ = 0.69 up to 0.90).

2.3 Calculation of performance topographies

An approach introduced by Stöckl and Lames (2012) was used to visualise the patterns of the different performance variables. This method provides a continuous topography, a so-called *ISO-map*, of the investigated performance characteristic. The topography values are an approximate average of the measurements and are generated in four steps:

(1) A grid is put on the field of play. The grid size was 0.5 m in this study.
(2) At each grid node, a representative value is calculated using exponential smoothing. To ensure that the representative value is based solely on close measurements, a small smoothing factor had to be chosen. In this study, the smoothing value was 0.2 for all performance

Table 1. Performance variables, categories and operationalisation.

Variable	Value	
POSITION	2D-position of free kick (m). Coordinates are normalised to playing direction of executing team.	
ZONE	Free kick location grouped according to Figure 1.	
DENSITY	Number of free kicks in a 1 m^2 sector.	
INTERRUPTION TIME	Timespan (s) between the foul that causes the free kick and the moment of ball contact. Only collected for free kicks where vanishing spray was not used.	
DISTANCE TO WALL	Shortest distance (m) between ball and wall in the moment of ball contact.	
PLAYERS IN WALL	Number of players participating in the wall.	
RULE VIOLATION	*True*: At least one player inside the wall tries to reduce distance to the ball for more than 30 cm after the referees allows the execution of the free kick.	
	False: Otherwise.	
LATERALITY	*Natural*: For crosses: ball was played from the left side with left foot or from the right side with the right foot. For shot at goal: ball was played from central left with the left foot or from central right with the right foot.	
	Switched: Otherwise.	
TYPE OF PLAY	*Shot at goal*: Player intends to score a goal directly with the ball contact.	
	Cross: Player plays the ball from outside into the penalty box. Ball trajectory has a length of at least 10 m.	
	Pass: Otherwise.	
OUTCOME OF SHOT	*Goal*: Goal was scored.	On target
	Border: Ball touched the border of the goal.	
	Saved: Ball was caught, fisted or defended by the goalkeeper.	
	Off target: Ball passes the goal line outside the goal.	Missed
	Block outside: Ball was blocked by player outside the wall.	
	Block: Ball was blocked by player inside the wall.	Wall
OUTCOME OF CROSS	*Shot at goal*: Player intends to score a goal with the first ball contact after the cross.	Successful
	Flick-on: Controlled flick-on in goal direction or to teammate.	
	No control: Ball was touched by the attacking team without control.	Not successful
	Opponent: Ball was touched by the opponent team.	
	Block: Ball was blocked by player inside the wall.	

variables, meaning that about the 10 closest measurements to a grid node are considered.

(3) The values between the grid nodes are interpolated using a cubic smoothing spline. A relatively strong smoothing value of 0.1 was used for all performance variables.

(4) Two-dimensional representations of the performance variables were determined. They illustrate discrete levels of the values of the respective performance variable, which are colour coded.

Generally, this approach requires triplets (x,y,z), where (x,y) denotes the location of a measurement, and z denotes the measured value of a performance. All performance variables provided measurements consisting of the location and a performance characteristic, either measured as part of a ratio scale (INTERRUPTION TIME, DISTANCE TO WALL, PLAYERS IN WALL, DENSITY) or as binary value (RULE VIOLATION, TYPE OF PLAY, OUTCOME OF SHOT, OUTCOME OF CROSS). For the ratio scaled parameters, the ISO-maps illustrate the raw values. For the binary parameters, one parameter was set 1, such as goal, and the other 0, such as no goal. The resulting topographies, then, visualise the percentage of cases fulfilling the parameter option which was set 1.

The ISO-map calculations were performed using MATLAB R2014a (The MathWorks Inc., USA).

Table 2. Theoretical variograms determined for performance variables.

Indicator	Model	Nugget	Sill	Range (m)	Nugget-sill ratio
DENSITY	Ste (κ = 0.3)	3.0	15.7	173.8	.18
INTERRUPTION TIME	Gau	170.4	370.1	29.6	.46
DISTANCE TO WALL	Gau	0.7	3.1	79.0	.23
PLAYERS IN WALL	Gau	0.6	54.2	79.3	.01
RULE VIOLATION	Ste (κ = 10)	0.1	0.5	90.1	.22
LATERALITY	Sph	0.2	0.3	227.2	.88
TYPE OF PLAY	Gau	0.1	0.4	18.3	.22
OUTCOME OF SHOT	Ste (κ = 10)	0.1	0.1	1.3	.88
OUTCOME OF CROSS	Ste (κ = 10)	0.2	0.2	5.7	.98

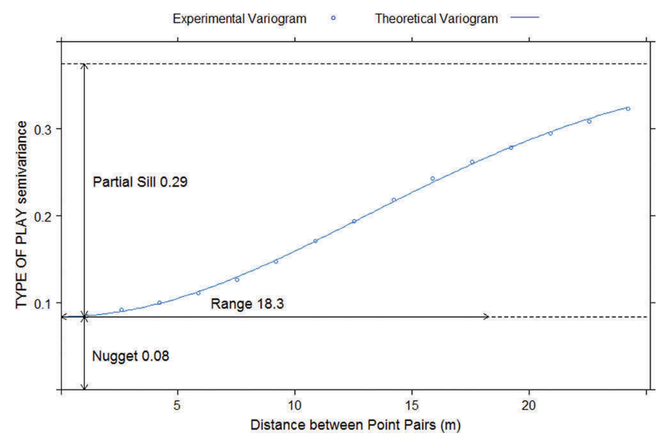

Figure 1. Experimental and theoretical variogram of TYPE OF PLAY.

2.4 Statistical analysis

One of the aims of this study was to investigate the spatial dependence of the different performance variables. For this purpose, the well-known geostatistical approach variography (Isaaks & Srivastava, 1989) was used. This studies the spatial dependence of a variable using variograms. A *variogram*, also called *semivariogram*, is a graph representing a function which describes the degree of spatial dependence between measurements at sample locations. Variography is conducted in several steps. First, an empirical semivariogram is calculated based on the sample data z_i as

$$\gamma(h) = \frac{1}{2|N(h)|} \sum_{i,j \in N(h)} \left(z_i - z_j\right)^2$$

where h is a small range of distances, and $N(h)$ denotes the set of observations which pairwise fulfil $\left|z_i - z_j\right| = h$ (Isaaks & Srivastava, 1989). Next, a theoretical variogram is fitted to the empirical semivariogram using different base functions. In particular, Gaussian functions (Gau) and Matern M. Stein's parameterisation functions (Ste) were used in this study (see Table 2).

The theoretical variograms provide the parameters nugget, sill and range (Figure 1). The *nugget* (C_0) describes the variability in the data at distance $h = 0$ and can be interpreted as the amount of variability which cannot be explained by the location in the measured area and/or are measurement errors. A nugget value of zero indicates that the location completely explains the variability. The *sill* (C) describes the maximal semivariance, which can be interpreted as there being no (spatial) correlation. The *range* is the distance within which the values are correlated. Furthermore, the *nugget-to-sill ratio* (NSR = C_0/C) can be used to quantify the spatial dependence of a studied property. According to Cambardella et al. (1994), an NSR smaller than 0.25 means a strong spatial dependence, 0.25–0.75 suggests moderate spatial dependence and a value >0.75 denotes weak spatial dependence.

Figure 1, for example, shows the variogram of one of the parameters investigated, TYPE OF PLAY. The circles illustrate the empirical variogram, and the line fitted to it is the theoretical variogram based on a Gaussian function. There is a nugget of 0.08 and a partial sill of 0.29. Those values add up to the sill, which is 0.37. Thus, the nugget-to-sill ratio is 0.22. The range of 18.3 m indicates that the execution type of free kicks was correlated with one of the other free kicks, which are 18.3 m away at maximum. In total, whether a free kick was executed as cross or as shot strongly depended on the location on the field of play.

In addition to geostatistical analyses, we used inferential statistics based on spatial groups. We defined discrete ZONEs (Figure 2) and determined differences in the outcome of shots and crosses between these zones using χ^2 tests. In order to increase the statistical power, we combined outcome categories. For OUTCOME OF SHOT, we used two sets of categories: firstly, *on target, missed* and *wall and*, secondly, *goal and no goal* according to Table 1. For OUTCOME OF CROSS, we tested the categories *successful* and *non-successful*. Before using the test procedures, the assumptions of normality were verified. The alpha level was set to 0.05. The statistical analyses were performed using R; in particular, the package *gstat* (Pebesma, 2004).

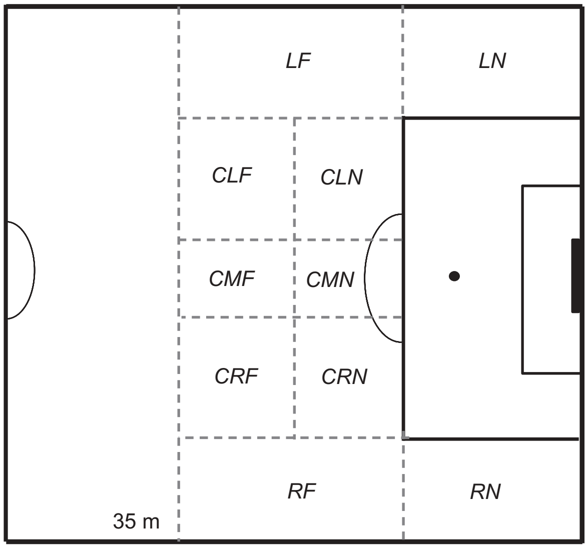

Figure 2. Discrete ZONEs of free kicks based on their POSITION: left near (LN), left far (LF), left = {LN, LF}, right near (RN), right far (RF), right = {RN, RF}, far = {LF, RF}, near = {LN, RN}, central left near (CLN), central mid near (CML), central right near (CRN), central near = {CLN, CMN, CRN}, central left far (CLF), central mid far (CMF), central right far (CRF), central far = {CLF; CMF, CRF}, central left = {CLN, CLF}, central right = {CRN, CRF}.

3. Results

During both seasons, there were 34.9 ± 7.6 (n = 21,414) free kicks on average per game. At a distance of less than 35 m from the goal line, there were 5.8 ± 2.48 (n = 3579) free kicks. Table 2 shows the results of the variography. We examine the details of those results in the following when talking about the different parameters.

DENSITY of the free kicks strongly depended on the location (NSR = 0.18): There was a cluster in the penalty area of the defending team and also four lengthwise strips were observable in the midfield, in which the DENSITY was about 30–50% higher compared to the surrounding area (Figure 3). The strips along the sidelines in the first part of the attacking half were especially pronounced. In the attacking last third of the pitch, the closer players got to the penalty area, the fewer free kicks were registered.

In the sample examined (n = 2681), 22.2% of the free kicks were played as shots (Table 3). For the remaining free kicks, the players brought the ball back into play via a pass or a cross (both were equally as likely). The influence of the location on the TYPE OF PLAY could be characterised as strong (NSR = 0.22). Shots in particular took place from central positions near the penalty area, while in the periphery of the field of play less than about 10% of the free kicks were played as shots (Figure 4(a)). With regard to LATERALITY, it was determined that 70.9% of the shots at goal were taken with switched laterality; for crosses, this was only the case 56.1% of the time. If both execution types were considered together, then 71.0% of free kicks on the left side were taken with switched laterality, whereas on the right side only 51.1% were (Figure 4(b)). This effect was weakly dependent on POSITION (NSR = 0.88).

The ratio of goals scored from free kicks (OUTCOME OF SHOT) was 7.6%, where 4.1% of the 1810 goals resulted from free kicks played as a shot (Table 4). An increase in the probability of a goal could be observed at around roughly 12 m in front of the penalty zone in the centre (Figure 4(c)). Although the spatial correlation was weak (NSR = 0.88), a 5.0% significant increase in probability of scoring could be observed for central and near free kicks. No significant effects of ZONE on the ratio of shots on goal, shots into the wall formation and shots that miss the goal were found. There were no differences between the probability of success from left and right,

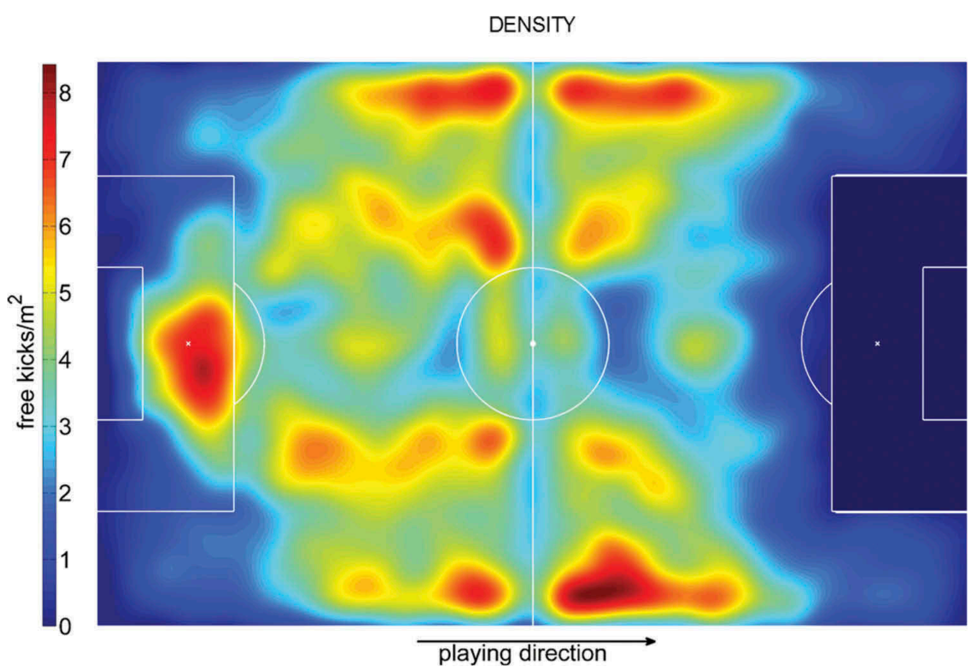

Figure 3. Spatial distribution of free kicks (DENSITY) visualised by ISO-maps (n = 21,414). Striking are four horizontal lines with increased number of free kicks count. The penalty box (offensive) was excluded by definition.

Table 3. Quantitative distribution of categories of TYPE OF PLAY, OUTCOME SHOT and OUTCOME CROSS (n = 2681 free kicks within 35 m to the goal line).

Indicator	%
TYPE OF PLAY	
Shot at goal	22.2
Cross	38.3
Pass	39.5
OUTCOME SHOT	
Goa	7.6
Border	2.8
Saved	27.7
Off target	31.7
Block	24.5
Block outside	5.6
OUTCOME CROSS	
Shot at goal	15.5
Flick-on	5.1
No control	7.8
Opponent	70.5
Block	1.0

central free kicks played from near the penalty zone and laterality of free kicks.

The success rate of crosses (OUTCOME OF CROSS) was 20.6% (Table 5). The ISO-maps (Figure 4(d)) as well as the variography show that, as for shots, there was only a very weak correlation with the position of execution (NSR = 0.98). However, using group statistics, it was possible to show that there was a significant increase in success, by 10%, for free kicks from the front right. This effect could not be observed for free kicks that were taken from further away. Free kicks that were played as crosses with natural laterality were about 5.6% more successful than those played with switched laterality. This effect was the same on both sides, although it only had a weak statistical significance on the right-hand side.

The INTERRUPTION TIME for free kicks was on average 46.0 ± 14.9 s. A moderate correlation with the position of execution was found (NSR = 0.46). Average interruption times of around 65 s occurred in the central zones next to the edge of the penalty area, while these times were between roughly 35 and 45 s on the pitch peripheries (Figure 5(a)). Analogously, PLAYERS IN WALL decreased with a decrease in centrality and distance (NSR = 0.01) (Figure 5(b)). Roughly six players took part in wall formations in the central area, whereas on the periphery, only 1–2 players did. Correspondingly, for shots at goal from the centre, walls were made up of 3.8 ± 1.7 players and 1.4 ± 0.6 players for crosses.

A RULE VIOLATION was observed for 17% of all free kicks. The variography showed a strong correlation with the location (NSR = 0.22). The probability was about 10% for the peripheral areas, whereas there was an observable reduction in distance by the attacking players in the goal critical zones for approximately 50–60% of the free kicks. A comparison of shots with the wall committing rule violations (n = 51) vs. no rule violation (n = 48), with the wall being in a central position, and situated less than 26.5 m away from the goal, showed no significant differences success-wise (χ^2 = 0.52, P > 0.77).

The DISTANCE TO WALL was on average 9.24 ± 0.90 m. The deviation from the nominal value was 0.66 ± 0.60 m. Although geostatistically there was a strong spatial dependence (NSR = 0.23), the value pattern was not as conclusive. The prescribed wall distance of 9.15 m was usually undercut during free kicks near the penalty area and was exceeded for long distance free kicks or free kicks taken from the sides (Figure 5(d)). The comparison of free kicks during which the regular wall distance was 0.5 m shorter (n = 41) with the group in which it was 0.5 m longer (n = 49) showed no differences with regard to success of shots (χ^2 = 0.66, P > 0.50) and crosses (χ^2 = 0.57, P > 0.45).

4. Discussion

The aim of this study was to describe the relationship between the location of execution, and the variables that characterise a free kick, as well as to analyse these with regard to performance. The ISO-map approach uses an averaging process and was based on moderate smoothing owing to the large variation of the performance indicators. Thus, the ISO-maps do not

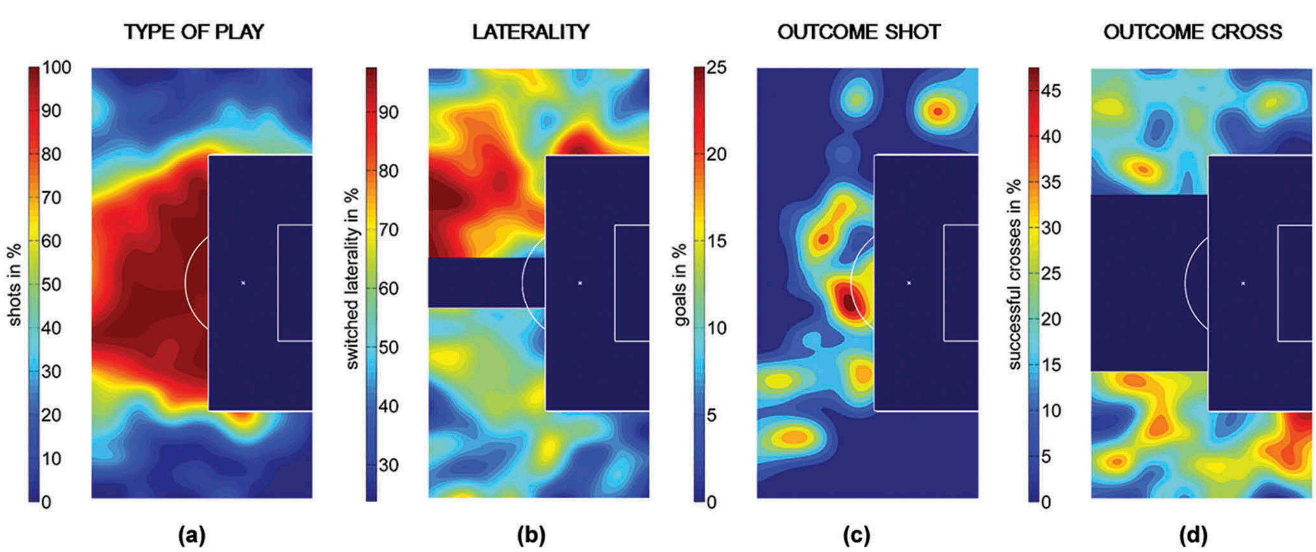

Figure 4. Spatial distribution of free kick performance variables visualised by ISO-maps. (a) proportion of free kicks with type of play = shot at goal (n = 1833), (b) proportion of free kicks with LATERALITY = switched (n = 1820), (c) proportion of free kicks with OUTCOME SHOT = goal (n = 968) and (d) proportion of free kicks with OUTCOME CROSS = successful (n = 1028). The central zones in maps b and d were excluded by definition.

Table 4. Quantitative distribution of category OUTCOME SHOT grouped by spatial ZONE and LATERALITY.

	OUTCOME OF SHOT									
	n	On target (%)	Missed (%)	Wall (%)	χ^2	*P*	Goal (%)	No goal (%)	χ^2	*P*
ZONE										
Central near	356	35.1	38.8	26.1	1.13	.57	10.9	89.1	5.00	.03*
Central far	229	33.7	36.2	30.1			5.9	94.1		
Central left	234	30.3	38.9	30.8	1.38	.50	9.4	90.6	0.16	.92
Central mid	112	34.8	34.8	30.4			8.9	91.1		
Central right	239	37.7	36.4	25.9			8.4	91.6		
LATERALITY										
Natural	138	39.1	31.9	29.0	3.35	.19	5.8	94.2	2.29	.13
Switched	335	31.9	40.0	28.1			10.1	89.9		
Natural left	43	34.9	30.2	34.9	1.73	.42	7.0	93.0	0.37	.54
Switched left	190	28.9	41.1	30.0			10.0	90.0		
Natural right	95	41.1	32.6	26.3	1.24	.54	5.3	94.7	1.95	.16
Switched right	145	35.2	39.3	25.5			10.3	89.7		

Only free kicks in the listed zones were considered (n = 585).
*significance at level 0.05.

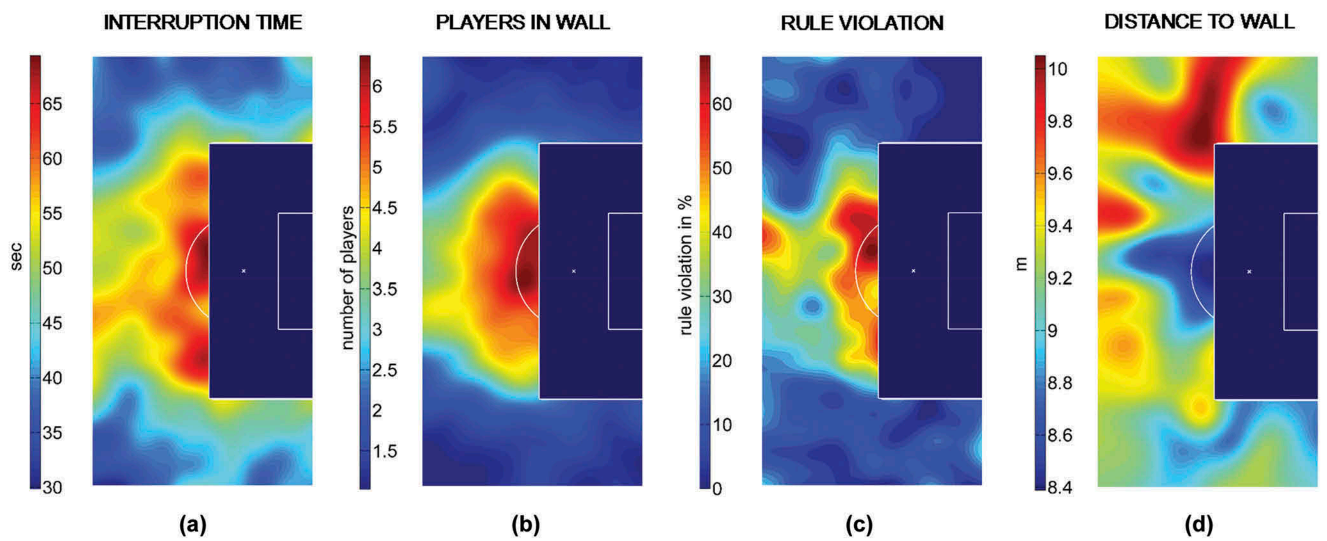

Figure 5. Spatial distribution of free kick performance variables visualised by ISO-maps. (a) INTERRUPTION TIME (n = 1624), (b) PLAYERS IN WALL (n = 1,624), (c) proportion of free kicks with RULE VIOLATION = true (n = 1,624) and (d) DISTANCE TO WALL (n = 175).

represent exact variable values; rather, they provide a visualisation of the spatial change in value ranges. The statistical analysis was carried out on the basis of the parameters χ^2 and NSR. While the χ^2 test compares data of groups of free kicks from different discrete spatial zones with each other, variography compares data of free kicks which are within a certain distance range from each other pairwise. NSR represents the spatial dependency over the whole defensive third, while the χ^2 statistics examines differences between discrete pitch zones within this third. ISO-maps, variography and group statistics therefore shed light on different aspects of the spatial dependency of the parameter values so that seemingly divergent results (such as the spatial dependency of the success of crosses) are not necessarily conflicting results.

In total, 21,414 free kicks were taken during the 2013/14 and 2014/15 German Bundesliga games. This means that there were 34.9 free kicks per game on average, which is in line with previous studies (Casal et al., 2014; Ensum et al., 2000; Olsen

Table 5. Quantitative distribution of category OUTCOME CROSS grouped by spatial ZONE and LATERALITY.

	OUTCOME OF CROSS				
	n	Successful (%)	Non-successful (%)	χ^2	*P*
ZONE					
Near	339	20.9	79.1	0.03	.86
Far	689	20.5	79.5		
Left	494	18.2	81.8	3.36	.07
Right	534	22.8	77.2		
Near left	155	15.5	84.5	5.22	.02*
Near right	184	25.5	74.5		
Far left	339	19.5	80.5	0.41	.52
Far right	350	21.4	78.6		
LATERALITY					
Natural	451	23.8	76.2	4.81	.03*
Switched	577	18.2	81.8		
Natural left	168	22.2	77.8	4.03	.05*
Switched left	327	16.3	83.7		
Natural right	283	24.7	75.3	2.93	.09
Switched right	250	20.8	79.2		

Only free kicks in the listed zones were considered (n = 1028).
*significance at level 0.05.

et al., 1997). The increased incidence of free kicks in the defending team's central penalty area can be explained by the great number of fouls committed by the attacking team (e.g., in the context of challenge for the ball). The four widthwise strips may be derived from the common four-player-chain-formations of many teams. In these areas, there might be an increased probability of players being present, and, therefore, an increased probability of fouls occurring. One hypothesis to explain the tendency for free kicks to occur at the sidelines could be the heightened frequency of tackling. Defending players might have expected a better risk reward relationship for tackling. This is because when successful, the ball can, in contrast to when tackling occurs in the middle of the field, be played so that it is no longer on the pitch, thus ensuring an interruption to the game. The decreasing number of free kicks occurring with decreasing distance to the opponents' goal can be explained by the fact that these zones cannot be reached as often (Link, 2014). Another reason could be that fouls are risked less when defending players are closer to their own goal. This can be explained by the weighting of the danger of a goal resulting from a possible free kick against the consequences of losing a challenge for the ball (Johnson, 2006).

Only the 5.8 free kicks per game which were closer than 35 m to the goal should be directly relevant for goals. As Figure 5(a) shows, centrality of the free kick has a crucial influence on the decision to take a shot. Players seem to view the angle to the goal as more important for success than distance. The relatively low proportion, 38.3%, of the free kicks that were played as crosses points up the fact that players do not evaluate the chances of success of crosses as particularly high. This seems plausible as 70.5% of crosses are intercepted by the opponent, and only 15.5% (21.8% in Casal et al. study in 2014) result in shots on goal. Other studies report scoring rates of 1.1% for crosses during open play (Vecer, 2014) and 2.3% from indirect free kicks, respectively (Casal et al., 2014).

With decreasing distance from the goal, the chance of scoring increases. This was to be expected and is consistent with the results presented in a study by Pollard, Ensum, and Taylor (2004). Potentially, this can be explained by the shorter amount of time that the goalkeeper has to react and/or a higher target accuracy (Alcock, 2010; López-Botella & Palao, 2007; Morya et al., 2005). In answer to the question as to which of these effects is most apparent, one could argue that a significantly reduced target accuracy for free kicks taken from further away also means more shots that miss. As this cannot be observed, the amount of time available to the goalkeeper may be hypothesised as the more important factor.

The high proportion of shots with switched laterality indicates that this variant is more likely to be categorised as promising regarding success. Although the differences in this study were not significant, the slightly higher scoring rate (+4.3%) could indicate that this expectation is not completely unjustified. The higher proportion of misses (+8.1%) could perhaps be interpreted as demonstrating a higher risk for shots.

For crosses, no such clear differences in LATERALITY were found. They were usually executed with switched laterality on the left side and natural laterality on the right. This could be owing to the higher proportion of right-footed players in the population. Natural laterality increases the probability of success (+5.6%) of a cross. An explanation for this could be that this kind of execution type favours an out-swinging trajectory of the ball. The ball thus tends to turn away from the goalkeeper as well as the defending players (as long as they are closer to the goal and are not playing the offside trap), and so possibly increases the probability of a player from the attacking team making ball contact. This is consistent with the results of a corner kick study by Taylor et al. (2005), who, albeit based on a small sample consisting of 145 corners, determined that there were 14% more shots on goal if the ball trajectory was out-swinging.

Crosses also show a 10.0% higher probability of success if they were played from the right-hand side. Two explanations can be put forward for this phenomenon: firstly, more free kicks were executed from the right side with natural laterality, which results in an out-swinging trajectory. Secondly, everyone has a dominant eye that processes and transmits information better (Knudsona & Klukab, 1997). When a free kick is played from the right side, the ball usually flies towards the attacking players from the right side and towards the defending players from the left side (because of their orientation towards or with their back to the goal). Since more people are right eye dominant (Bourassa, McManus, & Bryden, 1996), it might be easier for the attacking players to anticipate and to intercept these free kicks.

These last two results are not consistent with those of Casal et al. (2014), who did not find any differences in the proportion of shots on goal or goals in terms of execution side and LATERALITY. This could be owing to the differently chosen success criteria. In contrast to previous studies (Casal et al., 2014; Taylor et al., 2005; Vecer, 2014), where the ratio of goals and/or shots on goal were used as criteria for success, we also included a controlled flick-on by the attacking team in this category. In our interpretation, in the case of a flick-on there is a realistic chance of a dangerous situation being created, even though no goal was scored, or no shot was taken. Independently, a study of corner kicks (Casal, Maneiro, Ardá, Losada, & Rial, 2015) also reported an increase of 7.3% in the proportion of shots on goal when executed from the right and an increase of 8.1% for natural laterality. Whether both these factors benefit scoring rate could be reliably verified in this study. However, it might be a good idea to investigate whether playing the majority of crosses with a switched laterality (60% in this study) is advisable from a tactical viewpoint.

Regarding INTERRUPTION TIME, PLAYERS IN WALL and RULE VIOLATIONS, the respective ISO-maps show a radially decreasing profile of the parameter values from the middle point of the 16 m line. This can be interpreted as a tactical reaction to the increasing probability of success for central free kicks that are played from positions close to the penalty area. It could be assumed that the probability of scoring from shots on goal also decreases radially (Pollard et al., 2004). However, this cannot be conclusively verified due to the low number of goals (n = 74). The generated ISO-maps for PLAYERS IN WALL can be used as an indicator for how many players should be included in the formation of the wall.

The increase of INTERRUPTION TIME near the goal is consistent with Siegle and Lames (2012). Possible reasons could be longer interruption periods due to injuries to the fouled player, the player committing the foul being penalised, the formation of a wall made up of several players, corrections to the wall formation by the referee or a lengthened period of concentration and orchestration of the player about to shoot. Further potential influencing factors include the increased use of the vanishing spray near the goal (Kolbinger & Link, 2016), as well as the score (Siegle & Lames, 2012). For this reason, free kicks where vanishing spray was used were excluded from this sample.

The wall distance of 9.15 m prescribed by the rulebook (IFAB, 2016) is estimated by referees during matches. The estimates usually have an error of about 0.60 m. The ISO-map patterns of DISTANCE TO WALL can be interpreted as a weak indication that the players shorten the distance during goal-critical free kicks when forming the wall. Furthermore, the somewhat greater wall distances during free kicks from the sides and free kicks from positions that are far away from the goal indicate that players and referees do not see distance as a relevant factor here.

The data shows that neither DISTANCE TO WALL nor RULE VIOLATION has an effect on the success of free kicks. Thus, the advantage of a smaller distance between the ball and the wall within the possible limits is too small to generate a crucial advantage for the defending team. If there is one, then it might only be relevant in specific cases. Owing to the small sample, the results discussed in this paragraph must be viewed with reservation.

The variography shows that the individual performance indicators are influenced differently by the position of execution. The weak spatial dependence of OUTCOME OF CROSS and OUTCOME OF SHOT compared to PLAYERS IN WALL, RULE VIOLATION, TYPE OF PLAY, DISTANCE TO WALL and INTERRUPTION TIME can be explained by the fact that they are not solely determined by the location of execution. They are more heavily influenced by individual constellations, group dynamics, fast accelerations, position changes and random factors, which create perturbations in the defensive system (Hughes, Dawkins, David, & Mills, 1998; James et al., 2012; Lames & McGarry, 2007). Individual skills, such as good timing ability or jumping power, are also crucial in determining which player is the first to make ball contact after a cross. For OUTCOME OF SHOT, it must be considered that goals only occur rarely, and that the variography only reveals a limited significance in this case. Aside from this consideration, all performance parameters demonstrate a nugget value greater than 0. This means that variability cannot be explained solely by the location for any parameter. Rather, a whole range of potential influencing factors come into play, such as the score, the remaining playing time or game tactical elements, such as coach's instructions or the assessment of the abilities of the player executing the shot.

5. Conclusion

Geostatistical approaches can be used to examine the continuous spatial profiles of free kick parameters in soccer. According to the results of this study, crosses played into the penalty area are not very likely to result in scoring. It might be more effective to increase the proportion of passes from side free kicks and to try to reach the opposing team's penalty area using short passes and dribbles. As natural laterality promises a higher probability of success, this should also be accorded particular importance on the left side of the pitch. Since right-side free kicks tend to be more successful, it might be worthwhile practising the defence of balls that come in from this side.

Disclosure statement

No potential conflict of interest was reported by the authors.

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