

The Causal Relationship between Dominant Region and Offense-Defense Performance - Focusing on the Time of Ball Acquisition

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[Received June 14, 2012; Accepted June 4, 2013]

In football games, quantitative evaluation of group sport skills has been an important issue. In this study, we examined the causal relationship between offensive-defensive performance and dominant region, which is defined as the area occupied by the team. The dominant regions of both teams in the team area formed by defense-side positions were calculated for various plays involving successful and unsuccessful offensive performances. The difference of the dominant regions between the offensive performances of both teams was then analyzed statistically. The results showed that the dominant regions of both teams in successful offense were significantly narrower than those for unsuccessful offense when the turnover position was located around the middle of the field. This finding indicates that the dominant region is closely related to offensive performance and suggests that group sport skills that have been evaluated qualitatively may be evaluated quantitatively in terms of the dominant region.

Keywords: Football, game performance analysis, Voronoi, dominant region, team-area

[Football Science Vol.11, 1-17, 2014]

1. Introduction

Contemporary football is characterized by a high level of organization, and the importance of this organization is now widely recognized (JFA Technical Committee, 2002). Reflecting this trend, a considerable amount of instruction is now provided in relation to organizational aspects such as coordinated moves and tactics, and a large number of reports have appeared that relate to team tactics, such as those produced by the JFA Technical Committee. However, there is currently a lack of measurement techniques that can be used in the quantitative evaluation of football teams' organization. Most of the methods that have been developed for evaluating team organization rely on qualitative analysis by team coaches. Suzuki (2004) noted that, in the past, game performance analysis has been implemented based on visual examination by experienced coaches, and that little attempt has been made to quantify the data so that it can be made more widely available to players and coaches. Hughes & Bartlett (2002) noted the vital importance of coach cultivation from the point of view of strengthening teams' competitiveness,

and advocated the quantification of the qualitative expert appraisal criteria that have been used in the past. Viewed from this perspective, it can reasonably be assumed that the establishment of quantitative evaluation methods for team tactics and organization (hereafter referred to collectively as "group sports skills") could help to deepen players' and coaches' understanding of group sports skills and contribute to the enhancement of team competitiveness through the sharing of knowledge.

Both within Japan and overseas, it is not uncommon to see professional football teams coaches dismissed and replaced. In most cases this results from unsatisfactory team performance, for which the coach often gets the blame. However, replacing the coach solely on the basis of game results without taking into account the nature of the games played would, logically speaking, not necessarily be expected to result in an improvement in team performance. That is to say, replacing the coach is unlikely to bring positive benefits unless evaluation of the coach's ability to provide effective coaching for group sports skills shows that the team's poor performance is attributable to a deficiency in this area. From this

point of view, there is a clear necessity for evaluation of coaches' coaching skills, and so methods are needed for implementing quantitative evaluation not only of match results, but also of aspects relating to group sports skills. A further point is that, as noted in Suzuki (2004), if the evaluation criteria for coaches providing coaching for players who are still developing their skills is based solely on match results and tournament performance, then despite the fact that there are a large number of different skills that need to be imparted to players in this age group, there is likely to be an unhealthy emphasis on coaching that is directly related to winning matches. For coaches working at the player development stage also, therefore, there is a need for evaluation methods that take coaching content into account.

The establishment of quantitative evaluation methods for group sports skills constitutes an important means for solving these problems. By means of (1) providing useful feedback to players and coaches, (2) establishing detailed evaluation methods for the coaching that coaches provide, and (3) helping to mitigate the excessive emphasis on winning games at the player cultivation stage, the establishment of quantitative evaluation methods can be expected to produce a variety of ripple effects that are linked to enhancement of competitiveness.

Prior research on quantitative evaluation of group sports skills includes the work by Taki et al. on the dominant region (Taki, Matsumoto, Hasegawa and Fukumura, 1996). Unlike the situation in sports such as basketball and handball where the ball can be picked up by hand, by and large, there is not considered to be any standard technique for ball control and retention in football (Matsumoto and Suzuki, 2001); emphasis is placed on the concept of space for developing effective attacks once in possession of the ball. Taki et al. (1996) viewed space as constituting a form of "sphere of influence" for the player, and attempted to quantify and visualize space. More specifically, by entering location data for individual players that had been extracted from video footage into an acceleration pattern, they were able to quantify those areas that a given player could reach more quickly than other players as that player's dominant region, and proposed a team player evaluation method based on the extent and locational relationship of the dominant region of each team. In addition, Taki and Hasegawa (1998) used the temporal change accompanying the development of an attack

in the dominant region as an evaluation yardstick, so as to assess coordinated movement by the team. Their findings showed that, as play progressed from the start of an attack towards scoring, the size of the attacking team's dominant region tended to increase, while the defending team's dominant region tended to shrink. Fujimura and Sugihara (2004) also made use of the dominant region concept, reflecting actual human motion data from experiments in their model parameters so as to be able to calculate the dominant region more realistically, and demonstrating that dominant region had the potential to be an effective feature value for football teamwork evaluation. They found that, by taking over defending players' dominant region, attacking players could render the defending players' activity ineffective. On the basis of these research findings, it would appear that the expansion of the dominant region by the attacking team can create a situation where it is easier for them to initiate attacks, while expansion of the dominant region by the defending team facilitates defense, suggesting that the dominant region can serve as an effective feature value for the evaluation of group sports skills.

Fujimura and Sugihara (2004) also applied the dominant region concept to an examination of the relationship between the change in intensity of pressure over time and whether or not a given move is successful, by using the minimum time taken by defending players to reach attacking players as a proxy for the intensity of pressure. In addition, they quantified and analyzed the receivable pass variation (RPV) indicator for each player by taking the position of the ball as the center of observation, simulating a total of 54,000 different possible passes (passes made at any angle between 0° and 360° at 1-degree intervals, and at any speed between 0 km/h and 150 km/h at 1 km/h intervals, for a total of $150 \times 360 = 54,000$ possible passes) and then calculating the minimum time it would take each to reach the path taken by the pass. In this way, by applying the concept of the dominant region, evaluation of group sports skills can also be implemented from the point of view of pressure and the pass line; provided that the appropriateness and effectiveness of these feature values can be verified, it should be possible to perform evaluation of many of the situations that can develop in football.

In the studies referred to so far, both the methods used and the conclusions reached have been based on temporal variation in the dominant region in samples

of successful attacks. However, unless the values for the dominant region in a sample of unsuccessful attacks are investigated alongside the sample of successful attacks, one cannot be certain whether the dominant region values observed for the sample of successful attacks are really characteristic values, and it will not be possible to determine whether there is a causal relationship between the dominant region and the success or failure of an attack. In the present study, of the various feature values, the focus is placed on the dominant region; by comparing the dominant region between a sample of successful attacks and a sample of unsuccessful attacks, the existence and nature of a causal relationship between the dominant region and attacking success is statistically clarified.

2. Methodology

2.1. Sampling Definitions

2.1.1. Effective Offense

In the present study, the sample is divided into two groups: the effective offense group and the non-effective offense group. Yoshimura et al. (2002) define an effective offense as where, after the ball has been acquired, a series of plays lead to a goal, shooting, or centering, or where an additional successful play can be expected to lead on to a goal, shooting, or centering. Yoshimura (2003) defines an effective offense as either scoring a goal (which is the ultimate objective in football) or an attack which leads to a shot at goal. Higuchi (2010) defines an effective offense as an offense that results in either shooting, a final pass, or retention of the ball by the attacking team within the opposing team's penalty area. In light of this prior research, the present study defines an effective offense in qualitative terms as an attack which leads to shooting at goal, an attack which penetrates the penalty area, or an attack which leads to a cross.

2.1.2. Ball Acquisition—Methods and Categories

According to Taki and Hasegawa (1998), as the dominant region value will vary at different points in time during an attack, comparison of the dominant region value between different offense performance samples needs to implement comparison at the same phase in the attack. Yamanaka et al. (1994) broke down the implementation of an offensive move into four phases: preparation, start, breakdown, and

ending. This breakdown helps to make explicit the wide range of different forms taken by attacks in football, where an attack may not proceed beyond a given stage because the ball has been lost to the other side, or a particularly fast attack may omit a particular stage. Matsumoto et al. (1997) note that: "Possession of the ball determines which team is the attacking team and which the defending team." It can therefore be said that, while the manner in which attacks develop is not uniform, all attacks develop from gaining possession of the ball. That is to say, the only phase that is common to both samples of effective offense and samples of non-effective offense is the moment of ball acquisition, so the timing of dominant region measurement is unified at the time of ball acquisition.

A technical report (JFA Technical Committee, 2010) published with regard to the 2010 Fédération Internationale de Football Association (FIFA) World Cup in South Africa explicitly noted the importance of the integration of offense and defense, and stressed the need for offense and defense to be treated as constituting an integrated whole. Sai (2000) notes that the significance of the changeover between attack and defense has been recognized since the early days of football, and that it is emphasized even more today. As Matsumoto et al. (1997) point out, possession of the ball determines which team is attacking and which is defending; the switchover between offense and defense thus arises out of acquisition of the ball. It can thus be seen that, in modern football, the moment of ball acquisition (i.e. the moment of the switchover between attacking and defending) constitutes an extremely important phase in the game. Besides the implication that this moment can be used to provide a uniform time of comparison for effective offense and non-effective offense, it would also seem reasonable to assume that it can serve as an effective timing point for analysis of group sports skills.

A broad distinction can be made in methods of acquiring the ball between acquisition of the ball while the ball is in play (hereafter referred to as "ball acquisition") and acquisition through the restarting of play (hereafter referred to as "restart"). Since questions could be raised about the validity of comparison of sample attacks from a restart (which gives both the attacking and defending team time to reorganize their formation) and from ball acquisition, where everything happens much more quickly, attacks deriving from restarts have been excluded

from the scope of measurement in the present study. Additionally, while the sample originally contained a number of instances in which ball acquisition involved the goalkeeper, these were excluded on similar grounds. Measurement was therefore confined to instances of attacks beginning with ball acquisition where only field players were involved.

Two criteria were set for ball acquisition: The ball had to be touched twice by the same player, or else there must have been at least one pass to a teammate. Regarding the timing of ball acquisition, in the former case ball acquisition was deemed to take place at the time of the first touch, and in the latter case it was deemed to take place when the passing player struck the ball.

2.2. Sample

The sample was based on two university football championship games that took place in 2009 and 2010. Instances of ball acquisition were divided into three categories: regular ball acquisition, ball acquisition via the goalkeeper, and ball acquisition via restart; only instances of regular ball acquisition were included in the sample. Of the total of 363 instances of regular ball acquisition included in the sample, 68 instances comprised effective offense and 295 comprised non-effective offense. For the attacks that were the subject of analysis, the dominant region was measured at the time of ball acquisition.

2.3. Photographic and Video Image Processing Method

The Direct Linear Transformation method (hereafter referred to as the “DLT method”) was used to obtain two-dimensional coordinate data for the players. As shown in **Fig. 1**, field coordinates were obtained from the video coordinates of player location in the game videos. This method can reasonably be assumed to be more accurate than the traditional method of tracing positions on a scaled-down map of the football ground by hand (Ishii and Nishiyama, 1990). The location of the players on the pitch and their speed of movement, as obtained using the DLT method, were then used to calculate the dominant region using the method outlined below.

The resolution of the HD video camera used in the present study was $1,440 \times 1,080$ pixels; the speed of image capture was 30 frames per second (fps). Video

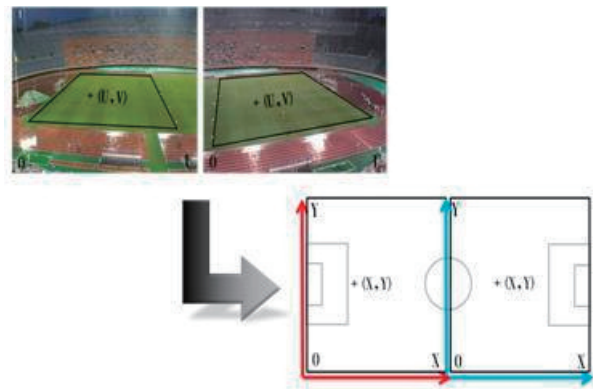


Fig. 1 Video Coordinates and the Corresponding Field Coordinates

filming was performed with a fixed camera position, with no use of panning or zoom. Given the size of a football pitch, it would be difficult to cover the whole pitch with just one camera; even using an HD video camera positioned at a distance, the resolution would be unacceptably low, and it would be hard to determine player location with a high degree of precision. For this reason, two fixed-position cameras were used, each recording the action in half of the pitch; the cameras used were Full HD video cameras manufactured by Sony. The video cameras were positioned on the top level of the main stand, in such a way as to be able to cover the area from the corners in their respective halves of the pitch up to the halfway line.

The recorded images were transferred to PC using the Edius Neo 2 video editing software produced by Grass Valley (formerly Thomson GrassValley Canopus). As the two cameras were not synchronized when recording video footage, adjustment was implemented on a frame-by-frame basis to allow for discrepancies in the movement of the ball and players between the footage from the two cameras, after which the video images were synchronized.

Programs developed using MATLAB 2007b (Math Works) were employed for ball acquisition image identification, digital processing of player location, and conversion from video coordinates to field coordinates. For ball acquisition images, the video images were replayed in MATLAB at 30 fps, and the relevant frames were selected by eye. Digitization of player location was performed using manual digitization. Specifically, the video frame images were displayed on the screen, a point mid-way between the player's feet was selected as the player location (as shown in **Fig. 2**), and that location was then inputted



Fig. 2 Digitization of Player Location

using the mouse.

The conversion from video coordinates to field coordinates did not take player height into account; the calculation for the conversion of player position from video coordinates to field coordinates was implemented using the two-dimensional DLT method. If the video coordinates for player location are expressed as (U,V) and the field coordinates are expressed as (X,Y), the relationship between the two is as shown in the following formula:

$$U = \frac{L_1X + L_2Y + L_3}{L_7X + L_8Y + 1}$$

$$V = \frac{L_4X + L_5Y + L_6}{L_7X + L_8Y + 1}$$

where L_1 to L_8 are DLT parameters. With regard to calibration, as shown in **Fig. 3**, the left and right halves of the pitch were each covered by one video camera, for a total of two cameras, with the four corners of each half being used as control points.

DLT parameters were calculated with the simultaneous equation shown below, using the video coordinates (U_i, V_i) and field coordinates (X_i, Y_i) ($i=1,2,3,4$) for the four control points.



Fig. 3 Setting of Control Points

$$\begin{pmatrix} X_1 & Y_1 & 1 & 0 & 0 & 0 & -U_1X_1 & -U_1Y_1 \\ 0 & 0 & 0 & X_1 & Y_1 & 1 & -V_1X_1 & -V_1Y_1 \\ X_2 & Y_2 & 1 & 0 & 0 & 0 & -U_2X_2 & -U_2Y_2 \\ 0 & 0 & 0 & X_2 & Y_2 & 1 & -V_2X_2 & -V_2Y_2 \\ X_3 & Y_3 & 1 & 0 & 0 & 0 & -U_3X_3 & -U_3Y_3 \\ 0 & 0 & 0 & X_3 & Y_3 & 1 & -V_3X_3 & -V_3Y_3 \\ X_4 & Y_4 & 1 & 0 & 0 & 0 & -U_4X_4 & -U_4Y_4 \\ 0 & 0 & 0 & X_4 & Y_4 & 1 & -V_4X_4 & -V_4Y_4 \end{pmatrix} \begin{pmatrix} L_1 \\ L_2 \\ L_3 \\ L_4 \\ L_5 \\ L_6 \\ L_7 \\ L_8 \end{pmatrix} = \begin{pmatrix} U_1 \\ V_1 \\ U_2 \\ V_2 \\ U_3 \\ V_3 \\ U_4 \\ V_4 \end{pmatrix}$$

The DLT parameters obtained using the above formula were then used to solve the simultaneous equation given below, to calculate the field coordinates (X,Y) from the video coordinates (U,V).

$$\begin{cases} (L_1 - UL_7)X + (L_2 - UL_8)Y = U - L_3 \\ (L_4 - VL_7)X + (L_5 - VL_8)Y = V - L_6 \end{cases}$$

In manual digital processing, the mid-point between the players' left and right feet was determined by visual inspection. When seeking to digitize this location, video coordinate errors were unavoidable with mouse-click entry. The measurement error accompanying manual digitization was therefore verified using the following method. For a group of players, the location of each individual player was inputted using the mouse 20 times, and the variation in the video coordinates at the time of mouse input was then checked. The results showed that the standard deviation for the video coordinates when digitization was performed repeatedly by hand was 1.2 pixels in the case of the X-axis, and 0.9 pixels for the Y-axis. Next, the effect that error in the video coordinates would have on error in the field coordinates was checked. As the video footage was taken with the cameras sited along the long side of the pitch, the further away a player was in terms of the short side of the pitch, the smaller the image would appear, so the impact of error in the video coordinates on error in the field coordinates would not be uniform. In order to be able to verify the impact of error in the video coordinates on error in the field coordinates quantitatively, the change in the field coordinates when the video coordinates were altered by 1 pixel in the X-axis and in the Y-axis was checked. More specifically, the football pitch was divided into a grid of 106 parts along its length and 68 parts along its width. For each 1 m square in the grid, the video coordinates corresponding to the

field coordinates were obtained, and then the change in the field coordinates when the video coordinates were altered by 1 pixel in the X-axis and in the Y-axis was checked. The average change, smallest amount of change and greatest amount of change in the field coordinates when the video coordinates were altered by 1 pixel were calculated to be 7.5 cm, 4.3 cm, and 11.1 cm respectively along the length of the field and 26.2 cm, 9.4 cm, and 50.0 cm respectively across the width of the field. In this way, it was possible to determine that the average error, minimum error and maximum error in the field coordinates corresponding to the standard deviation in video coordinate error resulting from manual digitization was 9.0 cm, 5.2 cm and 13.3 cm along the length of the field and 24.3 cm, 8.7 cm and 45.9 cm respectively across the width of the field.

2.4. Calculation of the Dominant Region based on a Player Movement Model

The player movement model used to calculate the dominant region in the present study was based on the model proposed by Fujimura and Sugihara (2004). In this model, the dominant region is defined as the set of points that each player can reach before any other player at any given time during the match. In order to determine the dominant region, a method is needed to predict how players will move, so as to be able to compare the time taken by different players to reach a particular point. To this end, a player movement model must be created that allocates an initial location and initial speed to players, along with the minimum time needed to reach any given point. Regarding the creation of this player movement model, Taki and Hasegawa (1998) assume that player acceleration is uniform. However, with this assumption there is an infinite potential for increase in player speed over time, which does not conform to the pattern of player speed and acceleration in real life. The present study therefore follows Fujimura et al. by using a movement model that assumes that, when an individual is moving under their own power, a force proportional to magnitude of the player's movement is operating in the opposite direction to the movement. The two-dimensional player movement model proposed by Fujimura et al. can be expressed using the formula shown below:

$$m \frac{d}{dt} \vec{v} = \vec{F} - k\vec{v}$$

where m denotes mass, v denotes speed vector, k is a resistance constant, $\vec{F} = F\vec{e}$ is the maximum motive force vector, F is the maximum motive force, and \vec{e} is the unit vector in an arbitrary direction. The second term from the right in the above formula represents friction acting against the player's momentum. With this model, it is assumed that, regardless of the direction in which a player is moving or the speed with which they are moving, the player can exert maximum muscular effort equally in any direction. The formula for the displacement vector \vec{x} required for the differential equation is as shown below:

$$\vec{x} - \vec{x}_0 = V \max \left[t - \frac{1-e^{-\alpha t}}{\alpha} \right] \vec{e} + \frac{1-e^{-\alpha t}}{\alpha} \vec{v}_0$$

where x_0 denotes the initial location vector, v_0 is the initial speed vector, $V \max = F/k$ is the magnitude of the maximum speed, $\alpha = k/m$ is a coefficient based on the magnitude of the resistance and the mass, corresponding to the time at which a player reaches a given speed. According to the player movement model displacement formula, for a player with initial speed of \vec{v}_0 and initial location of \vec{x}_0 when $t = 0$, the possible dominant region at the time t ($t > 0$) is the region within the circle expressed by:

$$\left[\begin{array}{cc} \text{Center} & \text{Radius} \\ \text{中心 } \vec{x}_0 + \frac{1-e^{-\alpha t}}{\alpha} \vec{v}_0, \text{半径 } & V \max \left[t - \frac{1-e^{-\alpha t}}{\alpha} \right] \end{array} \right]$$

Fujimura et al. performed experiments with movement in a straight line; they compared the experimental data with the model, using the least-squares method. Their testing to obtain the model coefficient α and $V \max$ gave the following results: $\alpha = 1.3$, $V \max = 7.8$ m/s. The present study uses these values for α and $V \max$, with the same values being used for all players.

Regarding the calculation of initial speed, the present study referred to the work of Oe et al. (2007). Oe et al. undertook research relating to the speed of motion of a player with the ball at the time of passing the ball, and of the receiving player at the time of receiving the ball. The speed was obtained by measuring the difference in position between

the time of passing or receiving the ball and a point one-third of a second earlier. In the present study, a similar method was adopted, with initial speed being determined based on the difference in location coordinates between the time of gaining possession of the ball and a point in time one-third of a second (10 frames) earlier.

On the basis of the player movement model described above, the dominant region was calculated using the following procedure. First, a football pitch 106 m long and 68 m wide was divided into 25 cm grid squares, giving a grid of 115,328 squares (424×272). Next, the time of ball acquisition was taken as the initial point and, using the player movement model, the time taken for each player to reach each square in the grid was obtained for all players based on the initial location and initial speed; for each team, the squares that a player from that team could reach first (before any other player) were taken as the dominant region for that team. This procedure was followed for every square on the grid, to determine each team's dominant region with respect to the entire pitch. The time interval used when calculating the dominant region was $1/300$ of a second. In order to determine each team's dominant region with respect to every square in the grid covering the whole pitch, calculation of the dominant region was performed at the specified interval covering a period of 15 seconds after possession was taken of the ball. **Fig. 4** shows an example of the dominant region as obtained using this procedure.

When determining the dominant region in this way, as the area reachable by a player will vary depending on the player's initial speed, the Voronoi region obtainable by the player from the initial location will also vary. However, in the present study, as the coefficient α and V_{\max} were assumed to be identical for all players, with an initial speed of $v_0 = 0$ for all players, the players able to reach the center of the grid in the shortest possible time are consistent with the players whose initial position is closest to the center of the grid, thereby ensuring consistency between the dominant region and the Voronoi region.

2.5. Measurement Items

As the dominant region is calculated for all regions on the pitch, evaluation based only on the size of the dominant region would not provide an effective feature value. When seeking to overcome

this problem, Fujimura and Sugihara (2004) used a weighting system, assigning a higher score to those dominant regions closer to the goal and to the ball, and a lower score to those dominant regions further away. However, the determination as to whether a dominant region has real value cannot be made simply on the basis of proximity to the goal or to the ball. In the present study, therefore, we identified dominant regions within team areas for comparison.

Oe et al. (2007) defined the extent of the team-area by constructing a quadrilateral extending in one direction from a line across the pitch bisecting the position occupied by the foremost player to a line bisecting the position of the most rearward player (excluding the goalkeeper), and in the other direction from a line bisecting the position occupied by the left-most player and a line bisecting the position occupied by the right-most player; this method made it possible to gauge the extent of the area covered by the team, and the rough position of the players. Takii (1995) expressed the distribution of the players on the pitch in terms of breadth and depth, noting that breadth and depth of formation were important both for offense and defense. Similarly, a JFA Coaching Handbook (2007) notes that, in principle, an attacking team should strive to maintain breadth and depth, while a defending team should occupy positions focused on the ball and on the protection of the goal. It can thus be seen that, from an analytical and a coaching point of view, importance also needs to be attached to the region of concentration of defending players in the pitch. As noted in Section 1 above, space is an important concept with respect to both possession of the ball and making effective attacks. It would thus seem appropriate to measure the value of the dominant region at regions where the ball is likely to pass through during the development of attacks and where defending players are concentrated. Following the prior studies referred to above, as shown by the quadrilateral located close to the center of the pitch in Fig. 4, the team-area is defined as a quadrilateral inscribed by the position of the members of the team that have just lost possession of the ball that have the smallest and largest coordinate values in both the longitudinal and latitudinal directions. The team-area, and the dominant region contained within it, was then measured. In the figure, black arrows represent the players of the team that has gained possession, while white arrows represent the players of the team that has lost possession. The tip of the arrow denotes the

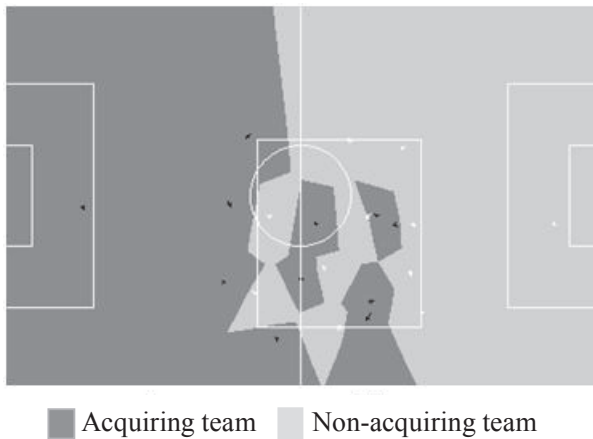


Fig. 4 Dominant Region and Team-area

location occupied by the player at the time when the ball was acquired; the base of the arrow denotes the location occupied by that player 10 frames previously.

If the team-area has a large value, then regardless of how good or bad the players' positions are or how fast they are moving, the dominant regions for both teams can be expected to display a high value. For this reason, the ratio of the size of the dominant region to the size of the team-area was calculated, and defined as the dominant region ratio.

The sample included numerous situations where there were no defending players in regions outside the team-area, and where the path of the ball did not pass through these areas as the attack developed. In other words, how appropriate it is to use these regions as feature values depends on the pattern of how the attack develops after ball acquisition has taken place (if these regions lie behind the defensive line of the team that has lost possession of the ball, then a through pass or long pass to the area behind the defensive line, etc., may result in an effective offense); more analysis is needed regarding the classification of offense patterns. For the purposes of the present study, therefore, regardless of what results were obtained for these regions, it was deemed that the causal relationship with offensive or defensive performance could not be determined, and they were therefore excluded from the scope of analysis.

2.6 Acquisition Third Classification

Given that the location of acquisition of the ball can be expected to affect the value not only of the dominant region but also of the team-area, the dominant region and team-area were checked for every ball acquisition location. To this end, following

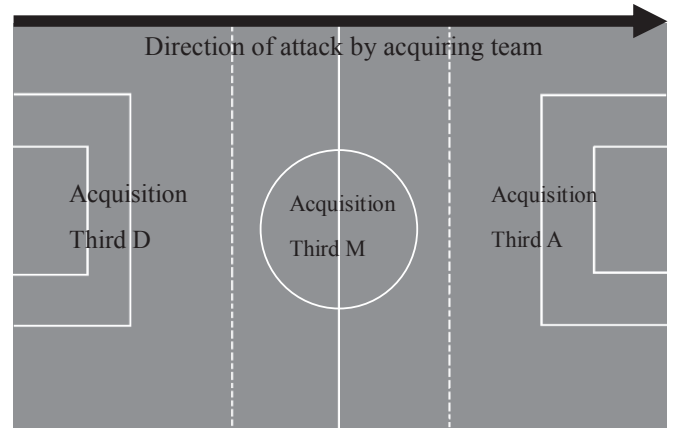


Fig. 5 Acquisition Third

Rees & Van der Meer (2007), as shown in **Fig. 5**, the football pitch was divided into three equal segments: Acquisition Third D, Acquisition Third M, and Acquisition Third A. For each third, the effective offense group and the non-effective offense group were compared, to facilitate comparison between similar cases.

2.7 Statistical Analysis Methods

Using the criteria outlined above, two-level (effective offense group and non-effective offense group) distribution analysis was performed for each acquisition third, taking the team-area, dominant region and dominant region ratio as the dependent variables. Statistical analysis was performed using IBM SPSS Statistics 19 (IBM Japan). In every case, the level of significance was set at 0.05. Both teams had the same value for dominant region ratio distribution kurtosis, and the absolute value for skewness was equal giving positive-negative inversion. Consequently, when inter-level comparison was performed on the dominant region ratio, the same value was obtained for the inter-group mean square and the intra-group mean square for both teams. Both teams also had same *f* values and *p* values.

3. Results

3.1. Test Results for Acquisition Third A

The test results for Acquisition Third A are shown in **Table 1**. No significant difference was seen between the effective offense group and the non-effective offense group for any of the dependent variables.

Table 1 Summary Statistics and Test Results for Acquisition Third A

Acquisition Third A			Team-area	Dominant region (m ²)		Dominant region ratio (%)	
				Acquiring team	Non-acquiring team	Acquiring team	Non-acquiring team
Effective	n=23	M	1096	545	551	49.9	50.1
		SD	315	169	177	7.8	7.8
Non-effective	n=30	M	1065	499	566	46.0	54.0
		SD	254	177	133	9.0	9.0
F-value			.157	.895	.117	2.623	2.623
Mean square			12454.023	26961.648	2767.016	.019	.019
P-value			.694ns	.349ns	.734ns	.112ns	.112ns

Notes: 1. The unit used for team-area and dominant region is the m² ; the unit used for dominant region ratio is the percentage (%).
 2. The mean square is the inter-group mean square.

3.2. Test Results for Acquisition Third M

The test results for Acquisition Third M are shown in **Table 2**. A significant disparity was seen in the value of the team-area and the value of the two teams' dominant region; in both cases, the effective offense group had a higher value than the non-effective offense group (Team-area: $F(1.184) = 5.785$, mean square = 779297.095, $p = .017 < .05$; Acquiring team's dominant region: $F(1.184) = 4.727$, mean square = 208214.035, $p = .031 < .05$; Non-acquiring team's dominant region: $F(1.184) = 5.010$, mean

square = 181879.470, $p = .026 < .05$).

3.3. Test Results for Acquisition Third D

The test results for Acquisition Third D are shown in **Table 3**. No significant difference was seen between the effective offense group and the non-effective offense group for any of the dependent variables.

Table 2 Summary Statistics and Test Results for Acquisition Third M

Acquisition Third A			Team-area	Dominant region (m ²)		Dominant region ratio (%)	
				Acquiring team	Non-acquiring team	Acquiring team	Non-acquiring team
Effective	n=31	M	1384	638	746	45.3	54.7
		SD	433	250	209	6.3	6.3
Non-effective	n=155	M	1210	548	662	44.7	55.3
		SD	353	201	187	7.1	7.1
F-value			5.785	4.727	5.010	.164	.164
Mean square			779297.095	208214.035	181879.470	.001	.001
P-value			.017**	.031*	.026**	.686ns	.686ns

Notes: 1. The unit used for team-area and dominant region is the m²; the unit used for dominant region ratio is the percentage (%).
 2. The mean square is the inter-group mean square.
 3. $p < .05$ is denoted by *; $p < .03$ is denoted by **; $p < .01$ is denoted by ***

Table 3 Summary Statistics and Test Results for Acquisition Third D

Acquisition Third A			Team-area	Dominant region (m ²)		Dominant region ratio (%)	
				Acquiring team	Non-acquiring team	Acquiring team	Non-acquiring team
Effective	n=14	M	1630	786	844	47.5	52.5
		SD	455	297	268	9.1	9.1
Non-effective	n=110	M	1524	669	856	43.6	56.4
		SD	323	199	198	7.6	7.6
F-value			1.211	3.841	.040	8.046	3.046
Mean square			139627.016	172309.339	1716.827	.019	.019
P-value			.273ns	.052ns	.842ns	.083ns	.083ns

- Notes: 1. The unit used for team-area and dominant region is the m² ; the unit used for dominant region ratio is the percentage (%).
 2. The mean square is the inter-group mean square.

4. Observations

This section begins by examining the test results for Acquisition Third M, which were deemed to be statistically significant, before going on to examine the results for Acquisition Thirds A and D, which were not deemed significant.

4.1. Transfer of Possession in Acquisition Third M

For team-area, the effective offense group had significantly higher values than the non-effective offense group. With regard to dominant region, for both the acquiring team and the non-acquiring team, the effective offense group had significantly higher values than the non-effective offense group. No significant disparity was seen in the dominant region ratio (the relative area ratio for the dominant region). On the basis of these results, a causal relationship could be established between the team-area and the two teams' dominant regions defined within the team-area on the one hand, and offensive and defensive performance on the other.

Takii (1995) and the JFA Coaching Handbook (2007) suggest that maintaining a compact defensive formation can enhance the defending team's defensive performance. Figure 7(a) and 7(b) show examples of the dominant region of the non-effective offense group in Acquisition Third M; Figures 7(c) and 7(d) show corresponding examples for the effective offense group. As can be determined by visual

comparison of these figures, in the present study also, having a smaller team-area tended to prevent an effective offense, conforming to the results obtained in prior research in this field.

A further point is that, regarding the acquiring team's dominant region, in light of the studies undertaken by Taki and Hasegawa (1998) and by Fujimura and Sugihara (2004), as well as the normal effects of having space, it would seem reasonable to assume that having a larger dominant region would contribute to being able to maintain possession of the ball and implement an effective offense. With the results obtained in the present study, for the effective offense group, the acquiring team's dominant region displayed a significantly high value, indicating that the acquiring team's dominant region was contributing to enhancement of attacking performance. **Fig. 7** compares the effective offense group and the non-effective offense group, showing that the team-area is significantly larger in the effective offense group, and that the dominant region is significantly larger for the acquiring team. Since, in many of the sample attacks, the team-area corresponds to the path taken by the ball when the attack is being developed, this would seem to create advantageous conditions for the development of further attacks later on. In this way, the undertaking of analysis that makes use of the dominant region concept provides support for the hypothesis put forward in the past suggesting that the adoption of a compact formation by the defending team can enhance defensive performance, and makes



(a)



(b)



(c)



(d)



Fig. 6 Examples of Dominant Region in Acquisition Third M
 (a) and (b) are from the non-effective offense group; (c) and (d) are from the effective offense group.

it possible to visualize the internal forces.

By contrast, no significant disparity was seen in the dominant region ratio, which constitutes a relative value for the teams' dominant regions. This indicates that the amount of variation in the dominant region of the acquiring team and in the dominant region of the non-acquiring team is roughly the same across the effective offense and non-effective offense groups. It is apparent that there is an underlying relationship between the dominant region ratio for the acquiring team, which tends to be around 45%, and that of the non-acquiring team, which tends to be around 55%, an underlying relationship that is not itself related to offensive and defensive performance. This indicates that the size of the dominant region within the team-area is an absolute rather than relative value, and as such can serve as a useful feature value. Similarly, as no meaningful difference was seen in the relative values, it would appear that the disparity in dominant region between the two teams was attributable to the significant disparity in team-area; thus, in order to restrict the size of the acquiring team's dominant region, the most appropriate measure for the non-acquiring team to take is to keep the size of their own team-area small. The remarks presented above regarding team-area can reasonably be assumed to constitute suitable advice for team coaching.

Regarding the dominant region of the non-acquiring team, according to Taki and Hasegawa (1998), the size of the attacking team's dominant region tends to increase as the attack progresses, while the defending team's dominant region tends to shrink. Fujimura and Sugihara (2004) found that the attacking players can render the movement of the defending players ineffective by "stealing" the defending team's dominant region. It would thus appear that, similar to the situation with offensive performance, having a larger dominant region contributes to an enhancement of the defending team's defensive performance. However, the results obtained in the testing undertaken in the present study appeared to contradict this; when the defending team had a small dominant region, they actually displayed superior defensive performance. To verify this contrary result, a detailed examination was undertaken of the situation when the defending team has a large dominant region.

As noted above, for attacking players, having a larger dominant region makes it easier to maintain possession of the ball and to develop effective attacks. However, besides the fact of not possessing

the ball, the defending players also labor under other disadvantages in terms of having lost the initiative and having to respond to the attacking team's moves (Matsumoto and Suzuki, 2001); this means that having a large dominant region offers less benefit to the defending team than it does to the attacking team. While the importance to the defending team of reducing the attacking players' dominant region has been demonstrated not only in past studies but also in the present study, it has not been clearly demonstrated that it is advantageous to the defending players to have a large dominant region themselves. As can be seen from examining Figures 6(a) to 6(d), when the defending players have a large dominant region, they tend to be located in parts of the pitch with low player density. It therefore cannot be said that having a large dominant region will always make it possible to achieve higher defensive performance; depending on one's viewpoint, for the defending players to have a large dominant region may be seen either as having no relationship with the state of play, or as indicating that the defending players are not implementing an effective defense against the attacking players. An attempt was therefore made in simulation described below to use pressure intensity (which quantified the amount of pressure placed on attacking players by the defending players) in combination with dominant region as an applied feature value.

First, simulation was performed to examine the relationship between player location and dominant region; the results obtained are shown in **Fig. 7**. The players denoted using white arrows are defending players; the three players represented by black arrows are attacking players; it is assumed that the attacking player in the bottom left hand corner has possession of the ball. In **Fig. 7(a)**, the defending player is located a long way away from the three attacking players denoted by black arrows, and the defending player's dominant region is large (Defending Player Dominant Region (a): 147 m²). In **Fig. 7(b)**, defending player is located close to the attacking players; in this case, the defending player's dominant region is more constricted than it was in the previous case (Defending Player Dominant Region (b): 46 m²). Thus, the closer the defending player is to their opponents, and the more he enters areas where there is a high density of opposing team players, the more likely the defending player dominant region is to have a low value. **Fig 8** (a) and 8(b) show the potential presence region (based on the minimum

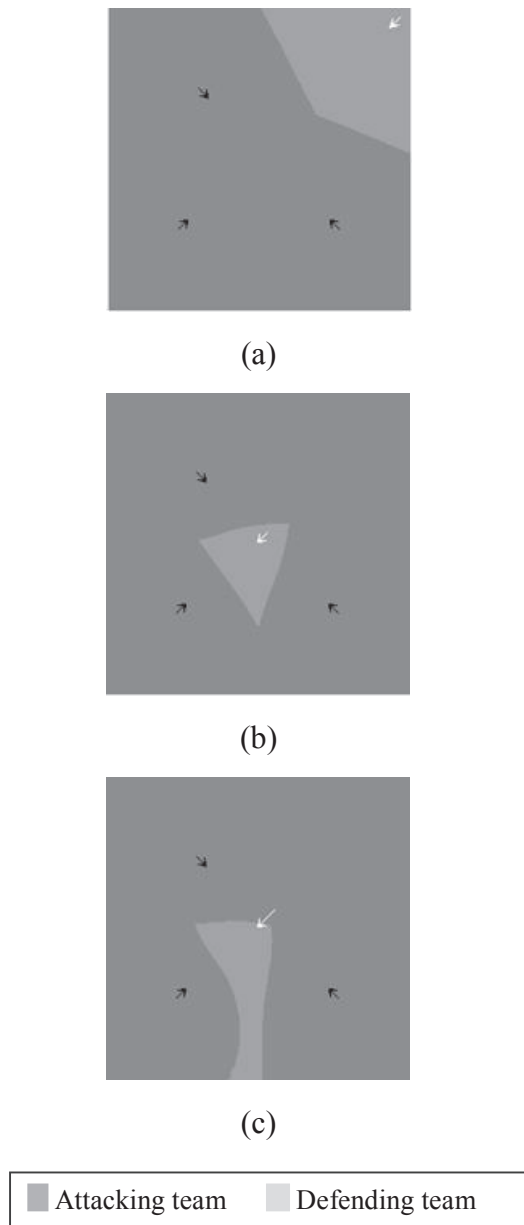


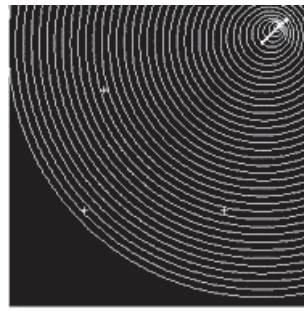
Fig. 7 Dominant Region Simulation Results

(a) Defending players are located far away; (b) Defending players are located nearby; (c) Defending players are located far away, but with high initial speed.

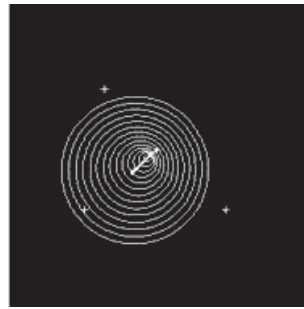
The potential presence region is calculated in a field 30m long and 30m wide, for a period continuing until 4 seconds later, at 1/300 second intervals, and the dominant region is then calculated from this. For examples (a) to (c), all of the members of the attacking team are assumed to have an initial speed of 4.2 m/s. In (a) and (b) the defending players are assumed to have an initial speed of 4.2 m/s; in (c) the defending players are assumed to have an initial speed of 7.2 m/s.

arrival time), given the same conditions as for Fig. 7. With the large defending player dominant region of Fig. 8(a), the minimum time needed to reach the player with the ball is long (Minimum Arrival Time (a): 3.89 seconds); in Fig. 8(b), the minimum time needed to reach the player with the ball is shorter (Minimum Arrival Time (b): 1.48 seconds). That is to say, if minimum arrival time is converted into pressure intensity (defined in terms of the minimum amount of time needed to reach the player with the

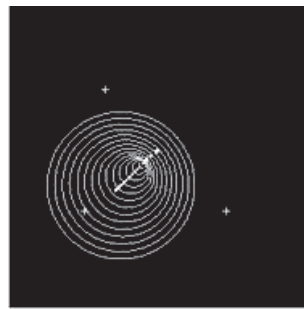
ball), the smaller defending player dominant region shown in Fig. 7(b) imposes more intense pressure on the attacking players. In other words, if the defending team as a whole maintains a dense formation, and maintains a close distance from the attacking players, then even though the defending team's dominant region may have a low value, the defending players will still be able to exert high pressure on an attack no matter what path the attack develops along, and overall defensive performance can be expected to



(a)



(b)



(c)



Fig. 8 Potential Presence Region Simulation Results

(a) Defending players are located far away; (b) Defending players are located nearby; (c) Defending players are located far away, but with high initial speed

The concentric circles shown in (a) denote the potential presence region within 4 seconds at 1/10 second intervals; the concentric circles shown in (b) and (c) denote the potential presence region within 1.6 seconds at 1/10 second intervals.

be enhanced. This finding is in conformity with the present study's test results that showed that non-effective offenses were associated with a significantly low team-area value, and with a low dominant region value (within the team-area) for the non-acquiring team.

Fig. 7(c) shows the dominant region with the same player locations as in Fig. 7(b), but with the defending player's initial speed changed to 7.2 m/s. By comparison with Fig. 7(b), where the initial speed was 4.2 m/s, although the defending player location is the same, because of the higher initial

speed, the defending side's dominant region is larger (Defending Player Dominant Region (c): 61 m²). Fig. 8(c) shows the potential presence region for Fig. 7(c). As can be seen from this, because of the defending player's higher initial speed, the minimum arrival time to reach the player with the ball is shorter than in Fig. 8(b) (Minimum Arrival Time (c): 1.23 seconds), giving a higher level of pressure intensity. That is to say, unlike the previous comparison, it is Fig. 7(c), with the larger dominant region, that has the higher pressure intensity. For the defending players, therefore, there are situations in

which having a larger dominant region is associated with high pressure intensity, but there are also situations where it is associated with low pressure intensity. Therefore, while the dominant region cannot necessarily be evaluated from the viewpoint of pressing the opposing team's players, it would seem appropriate to implement evaluation based on pressure intensity. However, when seeking to develop the Soccer Defending Skill Scale, Suzuki (2004) notes that, besides the opposing team's players, the management of space is also important for defending players; covering, a space-oriented defense approach, is a well-established concept in football. In other words, when it comes to measurement indicators for defensive performance, besides measuring the area of the dominant region calculated according based on minimum arrival time with respect to the pitch (space), there is a need for research and evaluation methods relating to the combined use of pressure intensity calculated on the basis of minimum arrival time to reach the opposing players.

4.2. Transfer of Possession in Acquisition Thirds A and D

With no significant disparity seen in team-area, or in either team's dominant region or dominant region ratio, no causal relationship was apparent between these values and attacking or defending performance when transfer of possession of the ball took place in Acquisition Third A. The probable explanation for this situation is that, when transfer of possession of the ball takes place in Acquisition Third A, as the transfer of possession is happening a maximum of 35 m from the goal and 20 m from the penalty area, with the skill levels for the sample used in the present study, it should be possible to implement an effective offense play – defined in the present study as shooting, making an inroad into the penalty area, or providing a cross-ball – regardless of the formation used by the other team and one's own team. **Fig. 9(a)** is an example of an effective offense being implemented despite the fact that the defending team has maintained a small team-area. **Fig. 9(b)** is an example of an attack being rendered non-effective despite the fact that the ball was acquired in a situation with a large team-area. As can be seen from examples such as these, in this third of the other factors (particularly technical factors) are more important than the formation of one's own team or the

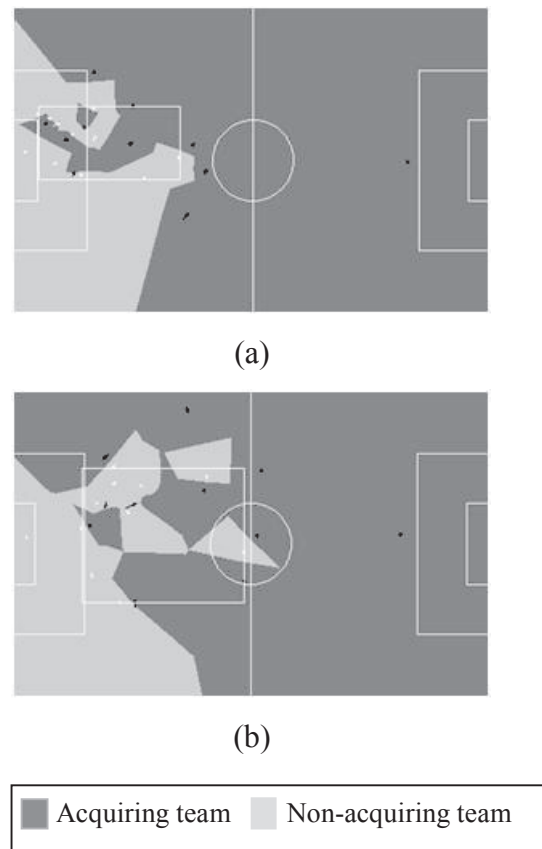


Fig. 9 Dominant Region in Acquisition Third A
(a) Effective offense group; (b) Non-effective offense group.

opposing team.

When transfer of possession of the ball occurred in Acquisition Third D, here again, no significant disparity was seen in the team-area, or in either team's dominant region or dominant region ratio. Where the transfer of possession took place in Acquisition Third D, as shown in **Fig. 10(a)** and **10 (b)**, the team-area tended to be large for both the effective offense group and the non-effective offense group, so it can be deduced that this created favorable conditions for developing an attack. However, as Acquisition Third D is the furthest away of the three acquisition thirds from the opposing team's goal, giving the defending team more time to prepare their formation, the situation at the time of ball acquisition can be expected to have only a relatively slight impact on attacking and defending performance. Regarding this point, verification is needed not only of the situation at the moment of ball acquisition, but also of the subsequent temporal changes in the team-area and dominant region.

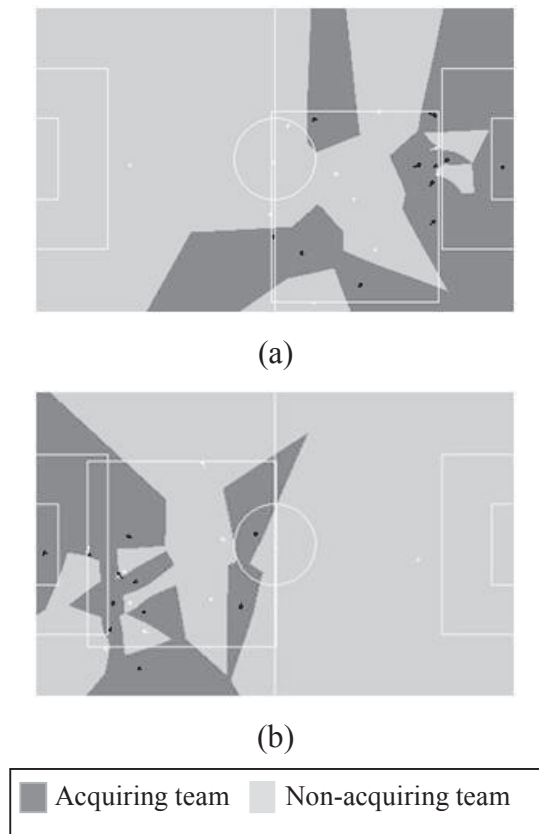


Fig. 10 Dominant Region in Acquisition Third D
(a) Effective offense group; (b) Non-effective offense group.

4.4. General Observations

As noted above, in Acquisition Third M there was a causal relationship between team-area and the two teams' dominant region and dominant region ratio on the one hand and offense-defensive performance on the other. A high value for team-area and acquiring team's dominant region was found to make a positive contribution to offense performance. This result is in conformity with the findings of past research in this area. By contrast, for the defending team, unlike the situation found in past studies, having a small value for the dominant region was found to contribute positively to defense performance. These results demonstrate the need to add pressure intensity to the dominant region as an evaluation yardstick in order to achieve more precise analysis.

The present study's results show that, whereas Acquisition Third A where ball acquisition takes place deep in opposing team territory, or Acquisition Third D, where ball acquisition takes place deep in the own team territory, offense and defense performance are determined without being affected by these feature values, in cases such as that seen in Acquisition Third M where ball acquisition takes place close to

the middle of the pitch, there is a causal relationship between team formation (which embodies these feature values) and performance.

On the basis of the results obtained in this study, the following issues have been identified that will require examination in the future.

(1) In the present study, testing was limited to 1 frame taken at the moment of ball acquisition. There would therefore appear to be a need to consider dominant region time-series features and to examine their relationship to the results obtained in the present study.

(2) While examination was undertaken of the dominant region as delineated within the team-area, further examination is needed regarding the dominant region within other areas, and regarding the size of the areas.

(3) The sample used in the present study was limited to football matches involving university teams. Further research is needed to see whether the results obtained in the present study also apply to other age groups and other proficiency levels.

5. Conclusions

The first part of the present study comprised a comparison of dominant region and team-area between offensive and defensive performance. The results obtained showed that a causal relationship exists between dominant region and team-area on the one hand and offensive and defensive performance on the other, confirming the appropriateness of undertaking quantitative evaluation of group sports skills taking dominant region as a feature value. For the defending team, pressure intensity was calculated in addition to the dominant region; it is suggested that this approach makes it possible to implement more precise analysis. In the future, it is intended to undertake further, more detailed verification of the causal relationship between dominant region and offensive and defensive performance, so as to firmly establish the appropriateness of applying quantitative evaluation methods to group sports skills.

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