Original Article

Badminton World Championship stress zones and performance factors: The key to success through log-linear analysis

RAÚL VALLDECABRES[1], ANA MARÍA DE BENITO[1], JOSÉ LUÍS LOSADA[2], CLAUDIO ALBERTO CASAL[1]

[1]*Department of Physical Activity and Sports Science, Valencia Catholic University San Vicente Mártir, Valencia, Spain*

[2]*Department of Social Psychology and Quantitative Psychology, University of Barcelona, Barcelona, Spain*

ABSTRACT

The main purpose was to analyse the frequency and effectiveness of different kind of shots and players' footwork performed by single men badminton players on World Championship depending on court zone. 18 matches were randomly selected and evaluated with a total of 1,273 points and 5,710 play actions. The most stressed court zone is Z5 and Z8 (middle zone) followed by Z10 (deep and lateral zone), while the most successful areas are Z8 (left middle zone) and Z10. When analysing footwork depending on distance covered by players, large footwork is performed mostly to Z1 and Z2. Hitting the shuttlecock with no previous movement is the most common situation from Z4 and Z5. When gathering in three court zones, the most stressed one is middle zone with similar values for Net and deep court zone. On the contrary, the most successfully gathered court zone is deep one, followed by middle and Net zones.

Keywords: Log-linear analysis; Badminton; Performance factors; Stressed zones.

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Corresponding author. *Department of Physical Activity and Sports Science. Valencia Catholic University San Vicente Mártir. C/ Ramiro de Maeztu, 14. 46900, Torrente, Valencia, Spain.* https://orcid.org/0000-0001-9458-6345

E-mail: ca.casal@ucv.es

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INTRODUCTION

Badminton research studies, even being one of the most racket sports played around the world, are still limited (Lees, 2003). Some of the previous works have focused on physiological parameters as hearth rate, Vo2Max and blood lactate concentration (Cabello *et al.,* 1995; Cabello & González-Badillo, 2003; Cabello *et al.,* 2004; Faude *et al.,* 2007); technical parameters as shots analysis (Abián-Vicén *et al.,* 2013; Chen *et al.,* 2011; Fontes *et al.,* 2014; Laffaye *et al.,* 2015; Lee *et al.,* 2005; Pearce, 2002) and temporal parameters in badminton (rally time, rest time, rest between sets, rest at point 11, work density, match duration and total of real time played) has been analysed throughout Olympic Games (Abián *et al.,* 2014; Abián-Vicén *et al.,* 2013; Abián-Vicén *et al.,* 2018; Chiminazzo *et al.,* 2018; Torres-Luque *et al.,* 2019), World Championship (Abdullah *et al.,* 2018; Valldecabres *et al.,* 2017a) and International Championships (Abdullahi & Coetzee, 2017; Barreira *et al.,* 2016; Cabello *et al.,* 2004; Chen & Chen, 2008; Chen *et al.,* 2011; Ming *et al.,* 2008; Pearce, 2002; Perálvarez *et al.,* 2015). Besides, players' footwork has been analysed by Valldecabres *et al*. (2017) and found that almost 50% of players' court footwork is diagonal and close to 5% longitudinal to the Net in both genders.

However, a deeper and wider knowledge about badminton complexity and play actions in a real context is needed to detect performance factors that determine players' success. For that purpose, match analysis it is essential to identify success patterns, where the systematically observation it is an objective and reliable tool to get information and recognise relevant events (Carling *et al.,* 2009). The use of this methodology allows to identify play actions in a real scenario within the context in which it takes place, which is used in many sports (e.g. Alonso & Argudo, 2011; Arbulu *et al.,* 2016; Castañer *et al.,* 2009; Cuadrado *et al.,* 2010; De Benito *et al.,* 2011; Fernández *et al.,* 2009; Losada *et al.,* 2015; Pradas *et al.,* 2012).

Despite the stress areas work from Perálvarez *et al.* (2015) and from the best of our knowledge, these researchers have not found any evidence of effectiveness and quantification in terms of stress court area. Therefore, the main purpose was to analyse the frequency and effectiveness of different kind of shots and players' footwork performed by single men badminton players on Jakarta 2015 World Championship depending on court zone. Obtained results would allow a better understanding of badminton play actions, knowing the most frequent and effective shots and court zones where the majority of play actions occurs.

METHODS

Observational design

This systematic observational analysis is suitable for nomothetic/follow up/multidimensional (N/F/M) design according to Anguera et al. (2011). The reason is that some players (nomothetic) are recorded in the rounds until the final match (follow up); in all matches, we have considered several performance indicators and time measures (multidimensional).

Moreover, the recording used an intrasessional follow-up (frame-by-frame analysis of different matches) and was captured using an ad hoc observational instrument in different matches. Data analysed belong to type IV Bakeman's classification (Bakeman, 1978).

Participants

18 matches of single men's 2015 Jakarta World Badminton Championship (ten from round 1/64, three from round 1/16, two from round 1/4, two from round 1/2 and one from the final round) were randomly selected and evaluated (www.random.org) with a total of 1,273 points and 5,710 play actions. 'Play' is the analysis'

unit, understood as the action performed by the observed player and it begins when the player hits the shuttlecock from the Serve until the last shot of the point occurs or when the shuttlecock touches the ground, the net or the other player body.

Observational instrument

Badminton Observational Tool (BOT) previously validated by Valldecabres, de Benito, Casal, & Pablos (2019) was applied to classify the behavioural patterns executed by the players. LINCE software program (Gabin et al., 2012) was employed for visualizing the matches recorded and registering the data. KINOVEA was used to register players' footwork and IBM SPSS Statistics v.23 (SPSS Inc., Chicago IL) was used for the statistical analysis. In addition, R statics software v3.1.1 with MASS and VCD library was used for log-linear regression analysis.

To carry out this analysis, the court was divided in 12 identical zones and named from Z1 to Z12 (Figure 1) and gathered in three as Net Zone, Middle Zone and Deep Zone (Figure 1) in order to perform the log-linear statics.

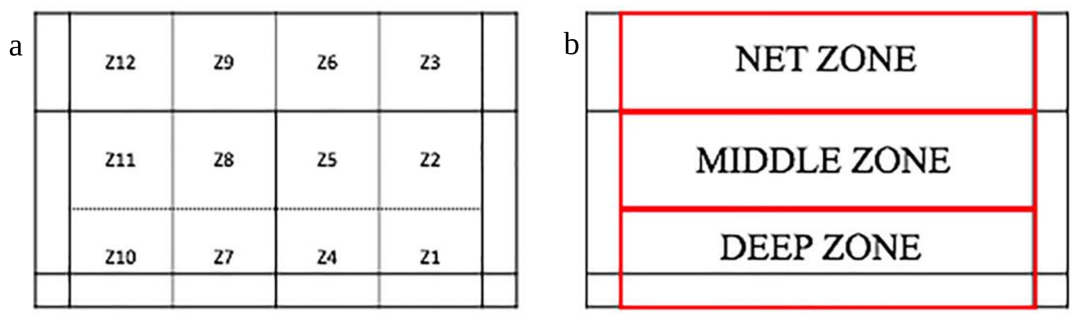

Figure 1. a) Primary court zone division; b) Gathered court zone division.

For carry out this work, independent variables from Badminton World Championship Jakarta 2015 and singles men event were selected. Behavioural variables were those related with player's work on the court: shots (Deep Serve, Short Serve, Clear, Drive, Drop, Lob, Net (including defensive Net, kill, Brush, and Top spin) and Smash), longitudinal footwork (short forward, short backward, large forward and large backward), transverse footwork (short left, short right, large left and large right), diagonal footwork (short right forward, short right backward, short left forward, short left backward, large right forward, large right backward, large left forward, large left backward). Result level was used for point result of the shot (successful and unsuccessful).

Procedures

A systematic observational methodology with a non-participant observer in a natural context was applied (Anguera, 1979). Matches were recorded from TV emitted images and were registered and analysed post-event. According to The Belmont Report (Belmont, 1978), the use of public images for research purpose does not require informed consent or the approval of an ethical committee.

Data quality control

One researcher and expertized badminton player/coach performed the analysis. Prior to data collection, the observer was trained during ten observing sessions, following Losada & Manolov (2015). Intra-observer reliability was tested by analysing 872 random actions from different sets and matches for two times with two weeks between each observational session to exclude any learning effects following Mitchell (1979). According to Remmert (2003), 80% was assumed as a critical value. Observer concordance analysis data quality control was checked by Cohen's Kappa (Cohen, 1960) for each category. > 0.96 mean values were obtained for all criteria, being all above 0.81 which is considered by Fleiss et al. (2003) 'almost perfect'.

Statistical analyses

All data were examined for normality and found suitable for parametric testing using Kolmogorov-Smirnov test. A descriptive analysis (mean ± standard deviation) and comparative analysis of absolute and relative frequencies of the different variables were carried out. Likewise, shot and footwork categories were analysed according to the 'event's result'. After that, a log-linear analysis was run, proceeding to obtain a parameters estimation for a posterior interpretation and design of a mosaic graphic (Friendly, 1994).

RESULTS

Following table 1, it could be observed that Z5 and Z8 show the highest shot frequency values (15.4% and 16.0% respectively). The next hot zone is Z10 with 11.8% of shots realized. On the contrary, Z7, Z11 (5.4% both) and Z4 (4.9%) shows the least hitting frequency.

Table 1. Zone footwork frequencies according to direction.

Zone	Stress (%)	SU (%)	NS (%)	D (%)	L (%)	T (%)	NM (%)	Total (%)	Large (%)	Short (%)	NM (%)	Total (%)
Z1	7.1	11.6	6.5	95.8	0	4.2	0	100	74.4	0	25.6	100
Z2	5.6	3.8	5.8	36.4	0.7	62.9	0	100	73.9	0	26.1	100
Z3	6.2	6.6	6.2	98.7	1.3	0	0	100	55.0	0	45.0	100
Z4	4.9	6.3	4.7	60.6	24.4	9.8	5.3	100	14.6	5.3	80.1	100
Z5	15.4	10.9	15.9	26.5	2.8	29.5	41.2	100	11.2	41.2	47.6	100
Z6	8.3	7.9	8.4	57.0	42.2	0.5	0.2	100	15.0	0.2	84.7	100
Z7	5.4	5.0	5.5	62.9	24.4	5.1	7.6	100	15.3	7.6	77.1	100
Z8	16	15.7	16.0	16.1	7.1	29.7	47.1	100	4.6	47.1	48.3	100
Z9	8.2	7.1	8.3	43.0	56.5	0	0.5	100	9.2	0.5	90.3	100
Z10	11.8	14.6	11.4	98.0	0.2	1.9	0	100	61.6	0	38.4	100
Z11	5.4	4.5	5.5	28.9	1.9	68.9	0.4	100	65.9	0.4	33.7	100
Z12	5.8	6.1	5.8	98.3	1.4	0.3	0	100	51.7	0	48.3	100
Total (%)	100	100	100	-								
Net	28.5	27.7	28.7	70.5	29.1	0.2	0.2	100	31.4	68.3	0.2	100
Middle	42.3	34.9	43.2	24.2	4.0	39.0	32.8	100	23.9	43.3	32.8	100
Deep	29.2	37.5	28.1	84.6	8.7	4.4	2.3	100	48.2	49.5	2.3	100
Total (%)	100	100	100	-								

SU: successful shot; NS: unsuccessful shot; D: diagonal; L: longitudinal; T: transverse; NM: no movement.

Analysing the kind of shot performed by players from each zone; from deep zone (Z1, Z4, Z7 and Z10) the most realized shot is Drop (> 40%) followed by Smash (≈ 40%); from middle zone (Z2, Z5, Z8 and Z11), Net is the most realized shot (≈ 40%) and from Net zone (Z3, Z6 and Z12) Lob is the most realized one (> 50%) except Z9, were Net is used by players (55.6%).

Taking into account previous players' footwork before hitting the shuttlecock, results showed that diagonal court movements are between 57% and 98.7% from deep and Net zones respectively, except Z9, were the most common footwork are longitudinal ones. From Z5 and Z8 (court centre), players hit the shuttlecock without executing previous movement (> 40% in both zones) and from Z2 and Z11 (lateral middle-court) transverse court movements are realized > 60% for both zones. In terms of distance covered by players, short footwork is commonly performed from Z4 to Z9, being diagonal court movements the most realized ones from the other zones (from Z1 to Z3 and from Z10 to Z12).

Table 2. Saturated model values.

Coefficients	**Estimate**	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	3.30E+00	1.93E-01	17.126	< 2e-16 ***
Unsuccessful	2.23E+00	2.03E-01	11.008	< 2e-16 ***
Zone Middle	-9.93E-01	3.70E-01	-2.683	0.007294 **
Zone Net	-2.76E+01	1.15E+05	0.000	0.999808
Drive	-2.60E+00	7.33E-01	-3.552	0.000383 ***
Drop	6.36E-01	2.38E-01	2.672	0.007536 **
Lob	-2.76E+01	1.15E+05	0.000	0.999808
Net	-2.76E+01	1.15E+05	0.000	0.999808
Smash	1.57E+00	2.12E-01	7.431	1.07e-13 ***
Unsuccessful: Zone Middle	-1.07E+00	4.15E-01	-2.569	0.010186 *
Unsuccessful: Zone Net	-2.23E+00	1.62E+05	0.000	0.999989
Unsuccessful: Drive	7.91E-01	7.52E-01	1.052	0.29294
Unsuccessful: Drop	2.83E-01	2.49E-01	1.133	0.257084
Unsuccessful: Lob	-2.23E+00	1.62E+05	0.000	0.999989
Unsuccessful: Net	-2.23E+00	1.62E+05	0.000	0.999989
Unsuccessful: Smash	-1.27E+00	2.27E-01	-5.58	2.41e-08 ***
Zone Middle: Drive	2.09E+00	8.97E-01	2.333	0.019628 *
Zone Net: Drive	2.60E+00	1.62E+05	0.000	0.999987
Zone Middle: Drop	-1.66E-01	4.68E-01	-0.355	0.722911
Zone Net: Drop	-6.36E-01	1.62E+05	0.000	0.999997
Zone Middle: Lob	2.96E+01	1.15E+05	0.000	0.999795
Zone Net: Lob	5.60E+01	1.62E+05	0.000	0.999725
Zone Middle: Net	2.96E+01	1.15E+05	0.000	0.999794
Zone Net: Net	5.71E+01	1.62E+05	0.000	0.999719
Zone Middle: Smash	-1.04E+00	4.51E-01	-2.307	0.021027 *
Zone Net: Smash	2.47E+01	1.15E+05	0.000	0.999829
Unsuccessful: Zone Middle: Drive	3.49E-01	9.38E-01	0.372	0.710163
Unsuccessful: Zone Net: Drive	-7.91E-01	2.30E+05	0.000	0.999997
Unsuccessful: Zone Middle: Drop	1.90E+00	5.08E-01	3.743	0.000182 ***
Unsuccessful: Zone Net: Drop	-2.83E-01	2.30E+05	0.000	0.999999
Unsuccessful: Zone Middle: Lob	3.13E+00	1.62E+05	0.000	0.999985
Unsuccessful: Zone Net: Lob	4.62E+00	2.30E+05	0.000	0.999984
Unsuccessful: Zone Middle: Net	3.46E+00	1.62E+05	0.000	0.999983
Unsuccessful: Zone Net: Net	3.26E+00	2.30E+05	0.000	0.999989
Unsuccessful: Zone Middle: Smash	-3.30E-01	5.77E-01	-0.573	0.566894
Unsuccessful: Zone Net: Smash	4.21E-01	1.62E+05	0.000	0.999998

*Significant codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.*

When considering kind of shots and footwork in terms of efficacy, Z8 is the most successful zone (15.7% of shots carried out from this zone ends in point for the player who performs it) and also it is the most frequent zone for hitting the shuttlecock, followed by Z10 (14.6%). On the contrary, the most unsuccessful zone is Z8 (16.0%) followed by Z5 (15.9%).

The log-linear analysis results are always fitted because all variables are checked with all categories, as being a saturated model. As it can be observed in Table 2, the model seems to be quite accurate due to highly significant coefficients and p values close to 0. Consequently, observed and predicted data by the model are very similar. Besides, Table 2 shows the observed situations that contribute in a significant way to the model adjustment (Pr value ≤ 0.05).

The log-linear models were performed to check residual deviation. As a general rule, it is suggested that the result is close to the degrees of freedom value. In this case, the residual deviation value is 5.5781e-10 and degrees of freedom are 0, therefore, values are really to close each other. It is also important to have into consideration the lambda parameter value (λ), whereby to identify the most favourable condition (positive) and the least favourable one (negative). These parameters are characterized by the sum of all values λ (one per category in each variable) has to be equal to 0. Our λ values are as follows:

Successful and unsuccessful λ results (-0.9513385 and 0.9513385 respectively) indicate that players perform more unsuccessful than successful shots. That was expected because every shot that does not end in a winner point was methodologically considered as an unsuccessful one. Deep (-0.1170750), middle 0.2554492 and Net (-0.1383743) λ zones values allow us to check that middle zone is the most stressed court zone independently of shot result.

Clear (-0.6202677), Drive (-1.6972408), Drop (0.6597978), Lob (0.8354362), Net (0.9803817) and Smash (-0.1581072) λ shot values let us point out that the most successful shots are Net, Lob and Drop in this order.

Finally, log-linear results can be presented as a mosaic graph (Figure 2). In order to perform a good interpretation of the graph information, it must be taken into account that, the region size indicates the signification value (the largest region shape, the highest significant value). A zone in blue shows positive significance, a zone in red designates negative significance and a zone in grey specifies non-significant results.

According to the explanation given above, mosaic could be interpreted as follows:

In terms of unsuccessful shots and court zones; Smash shot has the lowest effectiveness tax from deep zone but it has a little bit of success (slight red line) from middle zone; Net shot shows a really low effectiveness from middle and Net zone. In addition, Lob shot is really unsuccessful from Net zone and Drop and Clear shots show large unsuccessful from deep zone.

On the contrary, when observing court zones and successful shots it can be stated that the most successful zone for Smash is also deep zone due to the amount of this kind of shot performed from that court area. The Net shot is a successfully shot when it is performed from Net zone, while deep zone is the most successful court zone to execute a Clear shot.

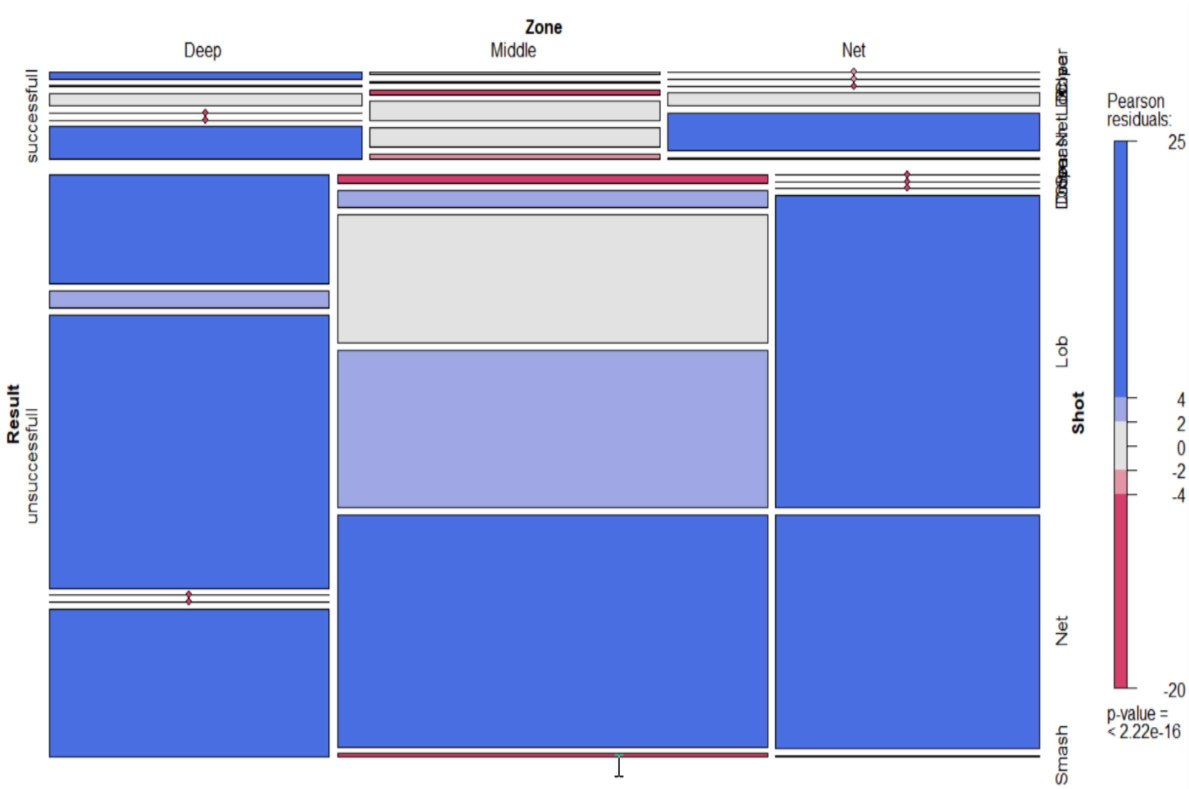

Figure 2. Saturated model mosaic.

DISCUSSION

The main purpose was to analyse frequency and effectiveness of different kind of shots and players' footwork performed by single men badminton players on Jakarta 2015 World Championship depending on court zone.

Firstly, it is important to mention that badminton stressed court zones has not been analysed previously, so these results could not be compared with other studies due to the absence of related information.

From a tactical point of view, Z5 and Z8 highest shot frequency results could be explained because those court areas correspond to the usual waiting areas where the players are placed to hit the shuttlecock back to the opponent as Gibbs (1988) proposed on his work. Staying on the middle of the court allow players to be in equidistance from every corner, so it is assumed that waiting on Z5 (15.4%) or Z8 (16.0%) could have better performance. Nowadays, it seems that players hit the shuttlecock against the opponents' body as a new role strategy, avoiding corners and narrowing the court. Therefore, players are reducing opponent technical skills options for hit the shuttlecock waiting and with time enough to select the zone where the opponent could have fewer options to do the necessary footwork. In this scenario, players have to hit it back from the defensive position defined by Gibbs (1988), giving the offensive chance of the point to the opponent, which could end in a point for the other player.

In a fatigued state, players start to widen the court with deeper and longer shots. That is reasonable when Z10 is the left corner and have 11.8% of the shots made from. This is more related to Gibbs theory when players are on a defensive position in the middle of the court. On the contrary, the less stressed zones are

Z4 (4.9%) and Z7 and Z11 (5.4% both). It fits with a logical game pattern, avoiding throwing the shuttlecock over opponent's head, which could become in a Smash (or other offensive shot) by the opponent and a loss of the point.

From the deepest area of the court, the most realized shots are Drop and Smash (≈ 40%). This kind of shots are considered by Cabello (2000) and overhead and offensives kind of shots and performed from a similar waiting court position and being a feinted movement looking for surprise the opponent player. From the centre of the court Net shows higher results. We hypothesized that as on Net classification are included defensive Net, this increase values for the middle of the court shots. In addition, from the Net zone is commonly used Lob unless from Z9 where Net is the most common shot performed. That is possible because, as above mentioned, badminton strategy has changed to a straighter to opponents' body hitting in order to restrict hitting back options and avoid the most technical racquet handwork on the Net zone. Thus, players raise up shuttlecock instead to keep on Net zone.

Previous footwork performed before hitting the shuttlecock has been analysed by these researchers in order to know the most realized one. The way we have analysed is taking into account the zone were player is situated when the opponent hit the shuttlecock, to the zone were the observer player hits back following Valldecabres et al. (2017). They found diagonal movements as the most realized ones during a final world championship and are in line with our findings where diagonal movements are commonly used from bottom and Net zones (except Z9 where longitudinal is the most performed footwork). Analysing these results, we have found sense because, as we have stated above, one of the players' strategy is throws the shuttlecock to the opponents' farthest corner so, when the opponent is in a Net or bottom zone, has to perform fast and suddenly footwork from one to another place. From Z5 and Z8 is up of 40% frequent no previous movement for hit the shuttlecock, which support our theory that is common nowadays throw the shuttlecock to the opponent's body when is waiting from Z5 and Z8. From Z2 and Z11 transverse footwork shows higher values (> 60% in both zones) which should be due for the action for hit and back to the defensive position in the middle of the court. When talking about distance covered by players previous hit the shuttlecock, it is more used short from the centre of the court (Z4 to Z9) supporting the theory that players throw the shuttlecock to the opponent's body and this have no chance to perform footwork before hitting the shuttlecock. From the rest of the court zones, large is the most common footwork before hitting, supporting the old theory of throwing to the farthest corner to the other player. NM is not the most used one but shows similar values to short in Z5 (41.2% & 47.6%) and Z8 (47.1% & 48.2%) which is in line with previous statements about new badminton strategies to throw the shuttlecock where the opponent is waiting (defensive position) looking for impact the shuttlecock on the contrary's body.

Analysing zones taking into account the action success, it has to be highlighted that Z8 is the most successful zone (15.7% of shots ends in point for the observer player) followed by Z5 (15.9%). This could be due because is at the same time, the most stressed zone and more than 15% of the shots are performed from these zones. At the same time, players are aware that have to have good handwork from these court zones due to the new paradigm of throwing shuttlecock to the opponent's body.

The log-linear analysis carried for all variables with 2x3 contingency tables (successful-unsuccessful and Net, middle and deep court zone) for all variables out has shown that Net, Lob and Drop are the most successful shots, regardless of the court zone from which they are made. These findings are similar to those pointed out by Valldecabres et al. (2017) except for the Smash shot. That is possible because they had analysed just final round for men and women, so players shot patter could differ from the first rounds Championship.

When analysing shots depending on the court zone where has been performed, Smash is more effective shot from middle than deep zone. This is possible that a major number of shots are made from Z10 looking for the around-the-head shot, which is difficult to perform an accurate Smash from this position. In addition, Net shot also shows really lower effectiveness values from middle and Net zone at the same time that is a successful short from Net zone, which could be explained by the huge amount of shots performed by both zones, so, as many shots performed from the same court zone, higher odds to get bot, success and unsuccessful results. Furthermore, Lob could not be considered a successful shot when performing from Net zone as well as Drop and Clear are really successful shots when made from deep zone. This could not have been discussed with other manuscript because from this researchers' knowledge, no previous work taking into account different court zones has been performed for badminton.

CONCLUSIONS

Different technical-tactical patterns are used for players depending on court position, which could be used by opponents to hit the shuttlecock to the less successful zone. In addition, badminton internal locus is shifting from hit the shuttlecock to the furthest zone of the opponent's court to the other player body, making very hard to hit it back the shuttlecock. Trainers and players could take into account this information for training specifically successful shots and zones and avoid the less successful ones in order to planning better for win championships.

AUTHOR CONTRIBUTIONS

RV registered data, reviewed literature and wrote the manuscript. CAC developed the project, wrote the manuscript and was responsible for performing analysis and methods. JLLosada performed statistical analysis sections. AMdB developed the project, wrote the manuscript, translated and drafted the manuscript. All authors approved the final submitted version of the manuscript.

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DISCLOSURE STATEMENT

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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