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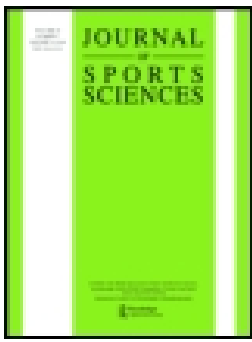
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ABSTRACT

In a group-serve-reception task, how does serve-reception become effective? We addressed "who" receives/passes the ball, what task-related variables predict action mode selection and whether the action mode selected was associated with reception efficacy. In 182 serve-receptions we tracked the ball and the receivers' heads with two video-cameras to generate 3D world-coordinates reconstructions. We defined receivers' reception-areas based on Voronoi diagrams (VD). Our analyses of the data showed that this approach was accurate in describing "who" receives the serve in 95.05% of the times. To predict action mode selection, we used variables related to: serve kinematics, receiver's movement and on-court positioning, the relation between receiver and his closest partner, and interactions between receiver-ball and receiver-target. Serve's higher initial velocities together with higher maximum height, as well as smaller longitudinal distances between receiver and target increased the chances for the use of the overhand pass. Conversely, decreasing alignment of the receiver with the ball and the target increased the chances of using the underhand-lateral pass. Finally, the use of the underhand-lateral pass was associated with lower quality receptions. Behavioural variability's relevance for serve-reception training is discussed.

Introduction

In top-level competition, mastering the key actions of the game gives a competitive edge that may determine winning or losing a match. In volleyball, one of such game actions is serve-reception (hereafter referred to as "reception"). However, although it is well established that serve-reception efficacy is a predictor of competitive success (Peña, Rodríguez-Guerra, Buscá, & Serra, 2013; Silva, Lacerda, & João, 2014), what leads to an effective serve-reception has not received much attention. In our view there are three key questions in that regard: "Who" of the candidate passers receives the ball? "How" the ball is passed (i.e., which action mode is selected)? And what is the outcome/efficacy of the reception?

According to the ecological dynamics framework, reaching a task goal emerges from the interaction of an individual with his/her environment (Araújo, Davids, & Hristovski, 2006). This approach describes how the player acts according to opportunities for action (*affordances*, Gibson, 1986) offered by the environment. Decision making is seen as an integral part of goal-directed behavior since decisions are grounded, i.e., expressed behaviorally through actions in performance contexts (Araújo et al., 2006). That is to say, they emerge at the ecological scale from the interaction of individual, environmental, and task constraints (see Newell, 1986; Newell & Jordan, 2007) over time towards the reaching of specific task goals (Araújo et al., 2006). Finally, the literature on interceptive actions within the ecological dynamics framework suggests

that the action mode selection (choosing one pass over the others available) is a way of adapting to changing task constraints to maintain performance levels (Barsingerhorn, Zaal, De Poel, & Pepping, 2013; Hristovski, Davids, Araújo, & Button, 2006). Therefore, when answering the questions raised with respect to volleyball reception, grounded in ecological dynamics, we must consider the ecological scale of analysis in the selection of the receiver that intercepts the serve, and in the selection of the type of pass used in that interception. Also, it allows the hypothesis formulation that whatever the action mode selected by the receiver, the reception efficacy is the same.

In top-level volleyball, the task of receiving the opponent's serve is usually undertaken by three of the six players on court (Ciuffarella et al., 2013). In contrast to other team ball sports, the target area defended by a team is the entire half-court. So, in the task of receiving the opponent's serve, the three receivers share the half-court space and are responsible for a given reception area. Based on the ecological dynamics framework, the definition of the three receivers' reception areas should take into account the particulars of each reception, and should be formulated at the ecological scale. One way to test this idea, is by using a spatial measure that decomposes the court into reception areas based on the relative positioning of the receivers on the half-court – the "Voronoi Diagram" (VD, see Fonseca et al., 2014). In this approach "who" receives the serve is the player closest to the approaching ball (arriving in his/her

dominant region, Fujimura & Sugihara, 2005). We hypothesize that this approach is an accurate descriptor of the receivers' bona fide reception areas.

Receiving a serve takes one second or less, and the receiver's movement initiation time takes around 0.3 seconds from server-ball contact (Benerink, Bootsma, & Zaal, 2015). Furthermore, we have previously reported that the receiver's initial position, defined as the distance to the net at server-ball contact, was the strongest predictor of reception efficacy and of the action mode selected to do so (Paulo, Zaal, Fonseca, & Araújo, 2016). Our first aim was to test the VD-approach as an adequate descriptor of "who" receives the serve. Given the severe time constraints of the reception task, and our previous research, we hypothesized that the receiver that contains initially (i.e., at server ball-contact) the reception interception-point in his reception area (dominant region) is the one that comes to receive the serve.

The next question was "how" the serve is passed. The selection of the pass used to receive a serve is constrained by the characteristics of the serve, the receiver's positioning and movement, and possibly by the receivers' on-court relationship (e.g., their relative positioning).

In top-level male volleyball, the serve action modes most commonly used are the "power-jump" and the "jump-float" serves (Ciuffarella et al., 2013). When compared to the jump-float serve, the power-jump serve produces higher ball velocities (Charalabos, Savvas, Sophia, & Theodoros, 2013; Huang & Hu, 2007; Moras et al., 2008), longer horizontal displacements, and greater heights of server-ball contact (Charalabos et al., 2013; Huang & Hu, 2007). If serving modes differ in their kinematic proprieties, that might influence the action mode the receivers select. In expert level male competitive context the use of the overhand pass against the power-jump serve is a rare occurrence (used 0.8% of the times; see Paulo, Davids, & Araújo, 2017). Besides serve mode and the mentioned kinematics there might be other relevant aspects of the serve that could play a role in action mode selection. Based on the literature, other relevant sources of constraint could be the serve's flight time (Benerink et al., 2015; Deprá & Brenzikofer, 2008), projection angle (Bartlett, 2007; Deprá & Brenzikofer, 2008), lateral displacement (Bartlett, 2007), and the serve's height when crossing the net (Deprá & Brenzikofer, 2008). The serve's maximum height and the time when it is reached could also be relevant features. There are potential differences in the serve's trajectory related to these variables that could be relevant for the type of pass used. Always having to pass the net, higher maximum heights that are reached sooner imply more descending and less parabolic serve trajectories, influencing the way the ball approaches the receivers' half-court.

With respect to the receivers positioning and movement, previously, in a passing task, Barsingerhorn et al. (2013) found larger longitudinal displacements of the receiver to be associated with using the underhand pass, whereas shorter longitudinal displacements were associated with the use of the overhand pass. Furthermore, in a serve-reception task, receiving positions at longer distances from the net, and movements away from the net, afforded the use of the underhand pass instead of the overhand pass (Paulo et al., 2016). However, Barsingerhorn et al. (2013) addressed the action mode selected without taking

into consideration the characteristics of the serve – the ball intercepted in the passing task was thrown, not served. On the other hand, in Paulo et al. (2016) only the jump-float serve was used, and the reception task was performed individually in restricted reception zones on-court. Thus, the implications of the difference in kinematics of the power-jump serve and the jump-float serve on action mode selection in reception remains unclear, particularly in tasks involving more than one receiver and when the entire half-court needs to be defended from the serve, circumstances we find in the competitive performance context. Paulo et al. (2016) also points out as potential relevant variables the receiver's lateral and longitudinal displacements, and his distance to target (lateral and longitudinal). Moreover, in accordance with Ureña, Santos, Martínez, Calvo, and Oña (2000), the receiver's lateral displacements relative to the target could also be of interest. In their study, the receiver having to move away laterally from the target was associated with a decrease in her availability to attack, affecting the offensive organization of the team. Given the group-level of the reception task, we hypothesized that the closest partner position and movement with respect to the receiver can also influence his action.

In the volleyball coaching literature, a reception using the underhand-frontal pass is the recommended technical approach (Dunphy & Wilde, 2014; Miller, 2005; Shondell, 2002) and indeed holding the gaze in a frontal position during the task leads to higher reception efficacy (Vickers & Adolphe, 1998). Therefore, another potential predictor-variable is the angle defined by the Receiver's Ball (lateral) Alignment (RBA) (see Figure 1(a)). Furthermore, as the target is also a relevant constraint and coaching literature recommends that the contact surface (forearms/hands) should be set toward the target (Dunphy & Wilde, 2014; Gozansky, 2001; Shondell, 2002) we also included the Ball-Receiver-Target (BRT) angle (see Figure 1(b)) in our analysis.

The second aim of this study was to establish predictor-variables for the action mode selected in reception. We hypothesized that such variables relate to the characteristics of the serve, to the receivers' on-court positioning and movement, and also to the relation between the receiver and his closest partner. Clarifying what is in the serve and in the receivers actions that leads to the selection of one action mode over the others is instrumental for future practice organization, allowing for the manipulation of relevant sources of constraint to promote one action mode over the others, or to robust the ability to adequately select the action mode (i.e., decision making) given the constraints present in this ever-changing task context.

Besides the underhand-frontal pass, two other action modes, the overhand and the underhand-lateral passes, have been mentioned in the coaching literature, but as last-resort options (Dunphy & Wilde, 2014; Shondell, 2002). Here we focused on expert receivers. These players have become progressively attuned to relevant affordances (Araújo & Davids, 2011) which allow them to consistently achieve the task goal. For expert receivers, 60 to 80% of serves are received successfully (see Afonso, Esteves, Araújo, Thomas, & Mesquita, 2012; Marcelino, Afonso, Cicero Moraes, & Mesquita, 2014; Palao, Manzanares, & Ortega, 2009). Another important feature of
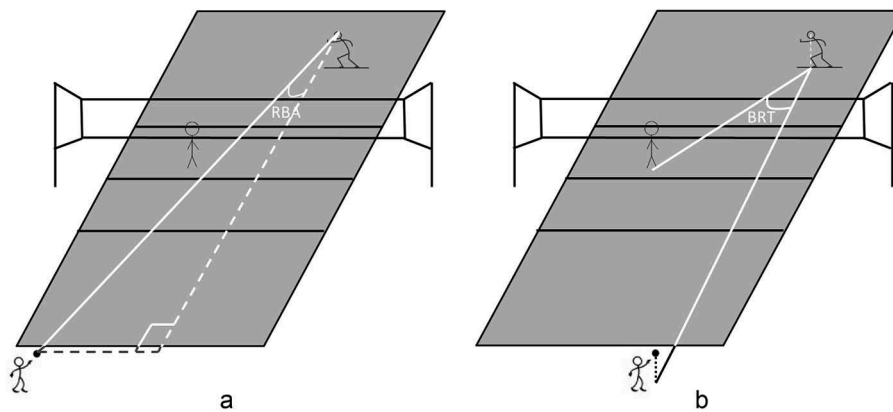
Figure 1. Illustration of (a) the Receiver's Ball (lateral) Alignment (RBA) Angle and of (b) the Ball-Receiver-Target (BRT) angle. In the BRT angle the ball and receiver's (head) coordinates were projected in the xy-plane.

expert performers is that they are able to transit functionally between motor solutions to achieve the same performance outcomes (Davids & Glazier, 2010; Seifert, Button, & Davids, 2013; Weast, Shockley, & Riley, 2011).Therefore, what leads to their selection of one action mode instead of another is important for volleyball serve-reception training. We previously showed that in expert-level competition using the overhand and underhand-lateral passes to receive jump-float serves significantly increased (by three times) the chances of winning the final set of a match (Paulo et al., 2017). Thus, if the action mode selection is an adaptation to the task demands, practice should not overemphasize the underhand-frontal pass, but should instead encourage the use of diverse action modes. Following this rationale, as a third and final aim, we hypothesized that the action mode selected in reception is not associated with reception efficacy. If so, the notion of action mode selection as a way to deal with task demands in order to remain effective is reinforced.

Methods

Sample

The participants were 14 male right-handed expert volleyball players aged 25 ± 6 years [mean ± standard deviation] and with 14 ± 5 years of practice, who were members of the Portuguese national team. Eight players served, and two set the balls received. The remaining four players were expert receivers (including one libero – defence specialist) and therefore only they performed the receiving task. The study was approved by the Ethics Committee of the Faculdade de Motricidade Humana at the Universidade de Lisboa (Nb. 7/2014).

Experimental task

On one side of the court, eight servers were distributed along the final line and took turns on serving. On the opposite court, three receivers were inside one half-court, while the fourth receiver waited outside the court for his turn to receive. After receiving the ball twice, an on-court receiver was replaced by

the receiver outside the court. The libero never received on the left-side of the court, just as in performance environments. One setter was the target-reference for the receivers (see Supplemental material Figure 1). His actions were also considered in the assessment of reception efficacy (see variables description). The servers were instructed to serve with the aim of scoring a direct point (i.e., cause a serve-reception error) such as to challenge the receiver's response. The receivers were instructed to try to pass the ball to the setter in the best way possible. The session lasted around 40 minutes in total, resulting in a sample of 182 trials. These trials comprise all the trials where a ball served passed the net into the opponent's court and was contacted by one of the receivers. Therefore, all the serve errors (balls against the net or that landed off court's bounds) and the serve "aces" (balls that contacted the receivers' half-court directly) were not included in the sample.

3D reconstruction

Two cameras were used to record the serves and their receptions at a frame rate of 25 Hz. The positions of the ball and of each receiver's head were determined from the recorded videos. Next, Labbio62.15 software [an updated version of TACTO (Serrano & Fernandes, 2011)] was used to determine 2D camera coordinates. 3D world coordinates were then computed from the 2D camera coordinates, using DLT algorithms programmed in MATLAB R2009a (Reinschmidt, 1994a, 1994b). The measurement volume was calibrated using 42 reference points (spanning a 9x18x3m volume) and the video recordings were synchronized based on the frame in which the server contacted the ball.

To estimate the error associated with the process of attaining 3D coordinates, the 2D coordinates of the digitized calibration points were inserted into a 3D reconstruction MATLAB program, and the resulting coordinates (x, y and z) were compared to the real (known) ones. The median error was 8 cm with an interquartile range (IQR) of 7 cm and a maximum error of 24 cm. To frame this error magnitude in the task space (i.e., the volleyball court), the mean error is 0.39% of the court

length and 0.78% of its width, and the maximum error is 1.33% of the court length and 2.67% of its width.

Intra-observer reliability was calculated based on the repeated digitalization (twice, 15 days apart) of three different trajectories: i) the trajectory of the ball in a power-jump serve, ii) the trajectory of the ball in a jump-float serve, and iii) the trajectory of the receiver's head. The selected trajectories came from three different trials. First, in the raw 2D digitized sets of coordinates of the two cameras (N = 6) the Variation Accounted For (VAF; see Duarte et al., 2010; Moorhouse & Granata, 2007) in x and y coordinates (VAF$_x$ = 99.99 ± 0.0001%; VAF$_y$ = 99.99 ± 0.001%) was calculated as a reliability procedure. Second, after reconstructing the 3D sets of coordinates of each of the three trajectories, we calculated the VAF for the reconstructed 3D x, y and z coordinates (VAF$_x$ = 100 ± 0.002%; VAF$_y$ = 99.99 ± 0.01%; VAF$_z$ = 99.97 ± 0.04%).

Since footage from two cameras was used for the 3D reconstruction, an additional error is expected from discrepancies in the synchronization of the cameras, which was not estimated. The reconstructed 3D positions of the ball and of the receiver were used for computing velocities and other variables (detailed below).

Variables

Two factors were manipulated: the serving mode (*jump-float serve* and *power-jump serve*, see USA Volleyball, 2009) and the on-court relative positioning of the receivers – *R1*, when the receiver was positioned on the right-side of the court (receiver's perspective), *R5*, when the receiver was positioned on the left-side of the court, and *R6*, when the receiver was in-between the other two receivers (see Supplemental material Figure 1).

For our first aim we defined the reception areas according to the VD-approach at the initial frame of each sequence (when the server contacts the ball). The receivers' reception areas (dominant regions) were computed according to the following procedures (Lopes, Fonseca, Lese, & Baca, 2015):

(1) The coordinates of the three receivers within the reception area (half-court) were considered.
(2) A grid of 0.1 × 0.1 m^2 squares was superimposed over the reception area.
(3) Each square in the grid was associated to the nearest receiver considering the distance to its coordinate.
(4) The Voronoi area of a receiver was given by the sum of the squares closer to him than to all other receivers.
(5) The percentage of Voronoi area of each receiver was calculated by dividing each Voronoi area by the total area.

The dichotomous variable *VD-approach accuracy* was computed. This variable coded *Yes* for when the receiver's initial reception area (his dominant region) contained the receiver-ball interception point, and *No* for when it did not. The receiver-ball interception point was considered the last coordinate of the ball's trajectory projected on the court plane ($z = 0$).

For predicting the action mode selected in reception we considered eight serve-related variables: flight time, initial velocity, maximum height, time at maximum height, displacement (lateral and longitudinal), height at server contact, and height at net crossing.

As receiver-related variables we considered: receiver's initial position (distance from the net at server ball-contact), lateral and longitudinal displacement, backward-forward displacement (dichotomous variable with the categories *back* and *front* coding displacements to the back or to the front of the court, respectively, from the receiver's initial position), distance to target (lateral and longitudinal), and distance to closest partner (lateral and longitudinal). The target was defined as the centre point of the "excellent setting zone" (Afonso et al., 2012; Paulo et al., 2016). The lateral displacements relative to the target was defined in two categories *away* or *closer*, representing displacements, from the initial position of the receiver to a position further away or closer to the target, respectively. Similarly, two categories were defined for each of the following variables: lateral displacement (*away* and *closer*), longitudinal displacements (*back* and *front*) and position of the receiver (*behind* and *in front*). These variables were computed from the ball and the receiver's coordinates.

We computed two angles as additional predictor variables: the Receiver's Ball (lateral) Alignment (RBA) (see Figure 1(a)) and the Ball-Receiver-Target (BRT) angle (see Figure 1(b)). Their values were obtained for three instances: (i) server-ball contact, (ii) when the ball crossed the net, and (iii) receiver-ball interception. We also calculated how these angles values changed over time. We subtracted to the angle's value at the receiver-ball interception (*final* instant) the angle's value at server-ball contact (initial instant) – variable *Final-Initial change*; and the angle's value when the ball crossed the net (*net* instant) – variable *Final-Net change*.

We considered three action modes: the *overhand pass*, the *underhand-lateral pass*, and the *underhand-frontal pass* (Dunphy & Wilde, 2014). In distinguishing the lateral from the frontal underhand passes, the criterion used was the ball-contact being between the legs (*frontal*) or not (*lateral*), taking the frontal plane as reference. For reception efficacy, we used three categories (see Paulo et al., 2016): *error*, when the receiver's pass does not allow setting or restricts the setting options to one; *out*, when the setter has to set outside the excellent setting zone, or in the setting zone, but with restricted setting options; and, *effective*, when the reception allows setting in the excellent setting zone with all setting options available.

Analysis

In the present work we formulated three hypotheses.

First hypothesis
We analysed the accuracy of the VD-approach in selecting the player that receives the serve for every trial. For this, we obtained the frequency and percentage of the *Yes* and *No* categories of the *VD-approach accuracy* variable.

Second hypothesis
We first characterized the potential predictor-variables considered for modelling the action mode selected in reception. The overall values and inferential statistics were computed considering the serve mode effect and the receiver's on-court

Table 1. Multinomial logistic regression analysis of the action mode in 182 receptions.

			ß (S.E.)	χ²	p	Exp(ß)	Exp(ß) 95% CI Lower bound	Exp(ß) 95% CI Upper bound
OV instead of UF	Serve	Initial velocity (m.s⁻¹)	2.360 (0.637)	13.710	<0.001	10.588	3.036	36.924
		Time at max height (s)	0.056 (0.015)	15.062	<0.001	1.058	1.028	1.089
	Receiver	Longitudinal target distance (dm)	−0.460 (0.131)	12.340	<0.001	0.632	0.489	0.816
		Partner longitudinal-change (Away)	−0.036 (0.962)	0.001	0.970	0.964	0.146	6.358
	BRT angle	Net (º)	0.148 (0.045)	11.004	0.001	1.160	1.063	1.266
		Final-Initial Change (º)	−0.025 (0.024)	1.095	0.295	0.975	0.931	1.022
	RBA angle	Final-Net Change (º)	−0.054 (0.036)	2.248	0.134	0.947	0.882	1.017
Constant			−41.018 (11.387)	12.975	<0.001			
UL instead of UF	Serve	Initial velocity (m.s⁻¹)	0.435 (0.205)	4.513	0.034	1.546	1.034	2.310
		Time at max height (s)	0.011 (0.005)	4.244	0.039	1.011	1.001	1.021
	Receiver	Longitudinal target distance (dm)	−0.036 (0.043)	0.707	0.401	0.964	0.886	1.050
		Partner longitudinal-change (Away)	1.341 (0.530)	6.409	0.011	3.823	1.354	10.797
	BRT angle	Net (º)	0.030 (0.021)	1.940	0.164	1.030	0.988	1.074
		Final-Initial Change (º)	0.042 (0.011)	14.049	<0.001	1.043	1.020	1.067
	RBA angle	Final-Net Change (º)	0.077 (0.015)	25.357	<0.001	1.080	1.048	1.113
Constant			−12.766 (4.473)	8.144	0.004			
UL instead of OV	Serve	Initial velocity (m.s⁻¹)	−1.924 (0.650)	8.757	0.003	0.146	0.041	0.522
		Time at max height (s)	−0.046 (0.015)	9.378	0.002	0.955	0.928	0.984
	Receiver	Longitudinal target distance (dm)	0.423 (0.135)	9.887	0.002	1.527	1.173	1.987
		Partner longitudinal-change (Away)	1.377 (1.041)	1.750	0.186	3.965	0.515	30.508
	BRT angle	Net (º)	−0.119 (0.047)	6.273	0.012	0.888	0.809	0.975
		Final-Initial Change (º)	0.067 (0.025)	7.534	0.006	1.070	1.019	1.123
	RBA angle	Final-Net Change (º)	0.132 (0.038)	12.198	<0.001	1.141	1.059	1.228
Constant			28.253 (11.791)	5.741	0.017			

OV: overhand pass; UL: underhand-lateral pass; UF: underhand-frontal pass; CI: confidence interval
For partner longitudinal-change, the category in the model is presented in brackets.
Significance level was set at 0.05.

relative positioning (see Supplemental material Table 1). We used multinomial logistic regression (IBM SPSS Statistics 22) to build a predictive model for the action mode selected in reception. We resorted to a main-effects backward-stepwise method. In logistic regression, $Exp(ß_i)$ represents the odds-ratio of success versus failure (categories of the model's dependent variable, in the present case, for e.g., the prediction of the use of the overhand pass instead of the underhand-frontal pass) when variable X_i (a predictor-variable on the model) increases by one unit with respect to the odds-ratio of success versus failure when X_i stays constant. Since distance, displacements, and heights measures did not reach one meter, they were entered in the model in decimetres (due to modelling sensitivity) and hence the odds ratio calculated for these variables refer to a unit change of 0.1 meters. Initially all potential predictor-variables were entered. The criteria for inclusion in the model was the Likelihood ratio test, with an entry probability set at 0.05, and the exclusion criteria was the Wald test, with a removal probability of 0.05.

To analyse the model we considered the: i) quality of the adjusted model; ii) classification improvement to classification by chance of the model); iii) goodness-of-fit criteria (Hosmer and Lemeshow Test, for the action-mode-selected model); and iv) the significance of the Wald statistics, the odds-ratio values of the predictors, and their effect size interpretation. We set the significance level at 0.05. We evaluated the odds-ratio effect size using values 1.52 (small), 2.74 (medium), and 4.72 (large) as evaluation criteria in accordance with (H. N. Chen, Cohen, & Chen, 2010), for a 0.05 significance level.

Third hypothesis

We tested the association of the type of pass used with the efficacy of the reception. For this we used Chi-square statistics and assessed the effect size by using Cramer's V. The assumptions for test use were satisfied (there were no expected cell counts of zero, and there was only one cell with an expected count below five – 11.11%).

Results

Selection of "who" receives the serve

To test the first hypothesis, we assessed the accuracy of the VD-approach in selecting "who" receives the serve. We examined whether the receiver's initial assigned area (dominant region) contained the receiver-ball contact point (*Yes* category of the variables *VD-approach accuracy*). This was the case in 95.05% of the times (173 out of 182 cases).

"How" the serve is received

For the second hypothesis, a backward-stepwise-for-main-effects logistic regression analysis was performed to assess the prediction membership for the action mode (overhand, underhand-lateral, and underhand-frontal pass). All predictor-variables were initially introduced in the model (see Supplemental material Table 1). However, as the power-jump serve was never intercepted with an overhand pass, the only manipulated factor included in the model was the receiver's on-court position
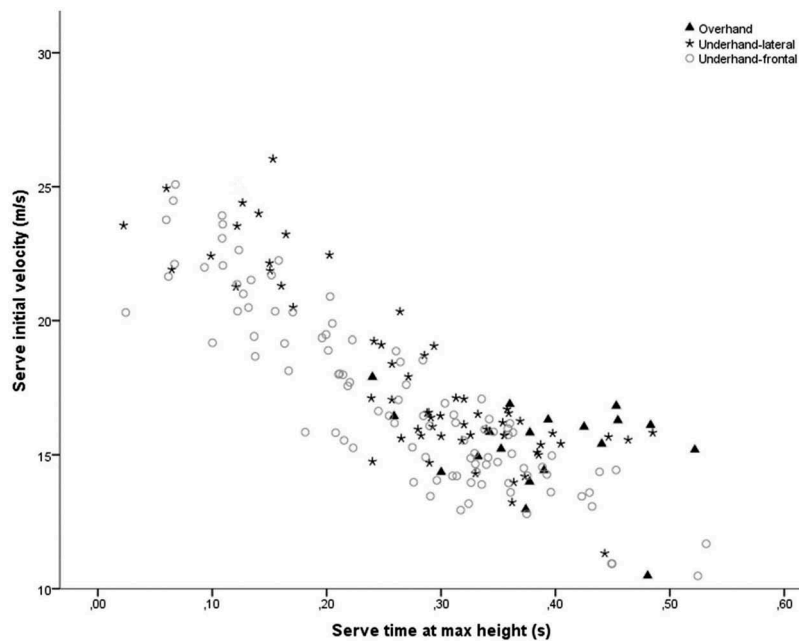
Figure 2. Depiction of the relation between serve initial velocity with the time the serve reaches its maximum height for every trial (N = 181). Cases are labelled by type of pass predicted in the model: overhand pass (N = 20), underhand-lateral pass (N = 61), and underhand-frontal pass (N = 100).

variable. After removal of one outlier, data from 181 receptions was available for analysis: 19 overhand (10.5%), 66 underhand-lateral (36.5%), and 96 underhand-frontal passes (53%). Seven predictor-variables were included in the final model (see Table 1). The model performed significantly better than a constant-only model ($G^2_{(14,N=181)}$ = 194.893, p < 0.001) with a fit not significantly different from a well-calibrated (hypothetical) model (Hosmer and Lewenshow test: $\chi^2_{(346,N=181)}$ = 195.270, p = 1), resulting in a Nagelkerke r^2 of 0.78. The model correctly classified 85.6% of the trials (increase of 43.08% to correct classification by chance).

There was a correct classification of 17 out of 19 overhand passes (89.5%), 53 out of 66 underhand-lateral passes (80.3%) and 85 out of 96 underhand-frontal passes (88.5%).

The only predictor-variables that significantly discriminated the selection of the three action modes were the serve's initial velocity and the time it reached its maximum height (see Table 1 and Figure 2). Higher initial velocities and maximum height reached later increased the odds of the overhand pass occurring instead of the other two types of pass, and also increased the odds for the underhand-lateral pass use instead
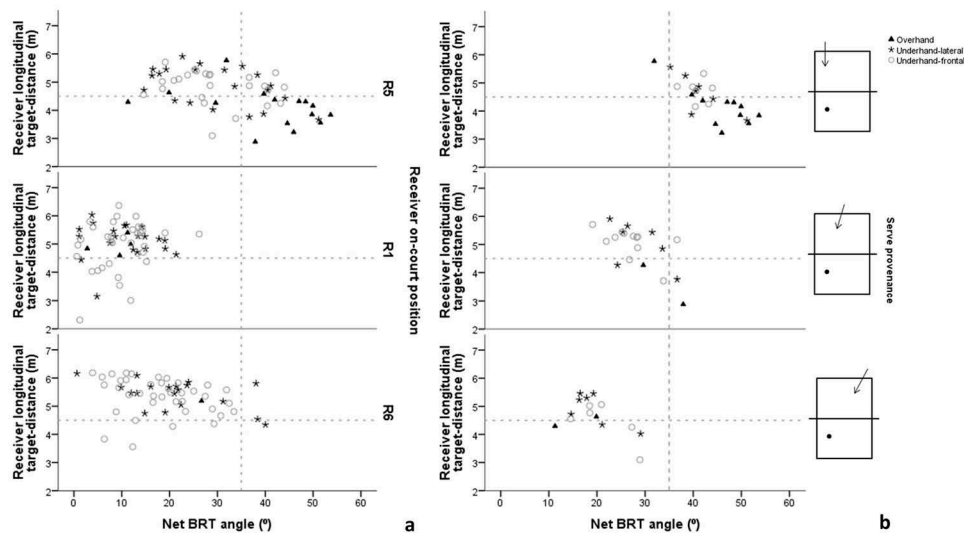

Figure 3. Relation of receiver longitudinal target-distance with the BRT angle's values at the serve net-crossing. (a) Depiction of this relation for every trial (N = 181), panelled by the receiver on-court position – R5 (N = 61), R1 (N = 61), and R6 (N = 59). (b) Depiction of this relation only for the cases where R5 was the receiver (N = 61), panelled by serve provenance – from in front of R5 (N = 25); from a mid-court position (N = 21), and from a cross-court position (N = 15). Reference lines were added to the x axis (at 35º) and the y axis (at 4.5m). Cases are labelled by the type of pass predicted by the model: overhand pass ((a) N = 20; (b) N = 15), underhand lateral pass ((a) N = 61; (b) N = 21), and underhand-frontal pass ((a) N = 100; (b) N = 25).

of the underhand-frontal pass. Nonetheless, the overhand passes were not predicted for serves with an initial velocity higher than 18 meters per second.

When the receiver was positioned longitudinally closer to the target at the moment of ball interception, the chances of occurrence of an overhand pass increased with respect to the other two action modes. Furthermore, larger values of BRT angle at the moment the ball crossed the net were also associated with increased chances for an overhand pass use instead of both the underhand passes (see Figure 3). Both the longitudinal distance to the target and the net-BRT angle of the receiver significantly changed according to the receiver's on-court position (see Supplemental material Table 1). On average, the receivers in R5 had smaller longitudinal distances to the target and larger net-BRT angles. Net-BRT angles above 35º were only observed in the R5 on-court position. Above this value our model tends to predict the overhand pass, particularly when the receiver's longitudinal distance to the target is less than 4.5 m (see Figure 3(a)). The BRT-angle definition depends on the position of the ball, the receiver, and the target. Figure 3(b) shows for the R5 on-court position, that net-BRT angles decrease the more diagonal the serve provenance is. There BRT angle's values above 35º tend to emerge when the receiver is directly facing the approaching ball.

The change in BRT angle from initial-to-final values, and the change in RBA angle from net-to-final values were the most significant predictors for underhand-lateral pass, significantly predicting it instead of the other two action modes (see Table 1). Figure 4 shows the relationship between these variables on a trial-by-trial basis for every action mode as predicted by our model for the on-court positions of the receiver (R5, R6, and R1). For the three on-court positions, the increase of both angles values lead to the prediction of the underhand-lateral pass. In the positions R6 and R1 the maintenance or decrease of both angles values lead to the prediction of the underhand-frontal pass. This was also the case for R5, but here the overhand pass was also predicted in these circumstances. Note that in R5 the increase of one of the angles and the decrease or maintenance of the values of the other allowed the prediction of both the underhand-lateral and the underhand-frontal passes.

Table 2. Type of pass association with reception efficacy.

		Error	Out	Effective	Total
Overhand	N	1	6	13	20
	% Pass	5%	30%	65%	100%
	% Efficacy	2.4%	17.6%	12.1%	11%
	% Total	0.5%	3.3%	7.1%	11%
UL	N	22	15	29	66
	% Pass	33.3%	22.7%	43.9%	100%
	% Efficacy	53.7%	44.1%	27.1%	36.3%
	% Total	12.1%	8.2%	15.9%	36.3%
UF	N	18	13	65	96
	% Pass	18.8%	13.5%	67.7%	100%
	% Efficacy	43.9%	38.2%	60.7%	52.7%
	% Total	9.9%	7.1%	35.7%	52.7%
Total	N	41	34	107	182
	% Pass	22.5%	18.7%	58.8%	100%
	% Efficacy	100%	100%	100%	100%
	% Total	22.5%	18.7%	58.8%	100%

OV: overhand pass; UL: underhand-lateral pass; UF: underhand-frontal pass. Significance level was set at 0.05.

Finally, moving away longitudinally from his closest partner significantly increased the receiver's probability of using the underhand-lateral pass, instead of the underhand-frontal pass.

Action mode selection and reception efficacy

A Chi-square test was used to test the association of the type of pass used and the efficacy of reception. There was a statistical significant association with a weak effect size between the type of pass used and the efficacy of the reception ($\chi^2_{(4,N=182)} = 13.970$, $P < 0.007$, $V_{Cramer} = 0.20$).

The majority of the receptions was effective ($N = 107$, 58.8%). Looking into each of the passes, for both the overhand ($N = 13$; 65%) and the underhand-frontal passes ($N = 65$; 67.7%) also the majority of the receptions was effective. For the underhand-lateral passes, the effective reception was the most frequent ($N = 29$; 43.9%), but not a majority (see Table 2).

On the other hand, the majority of the error receptions occurred when using the underhand-lateral pass ($N = 22$; 53.7%), followed by the underhand-frontal pass ($N = 18$; 43.9%). There was only one reception error when using the overhand pass (5%). The underhand-frontal pass was used in
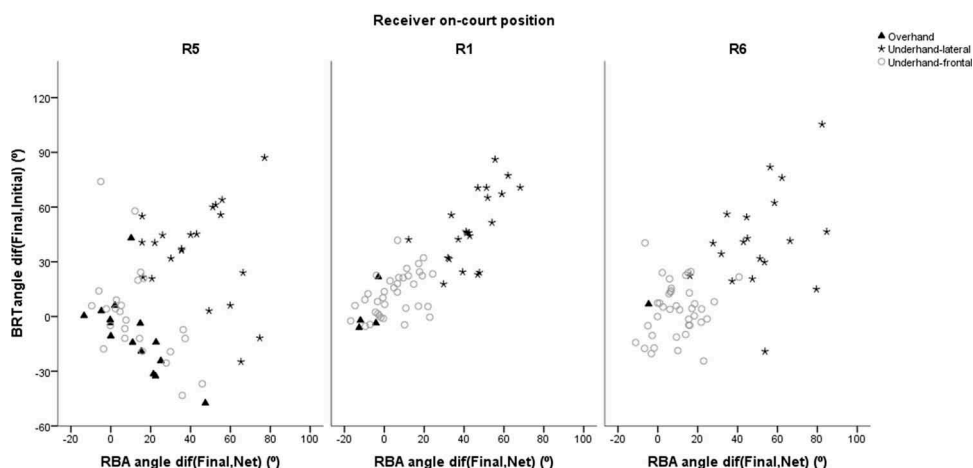

Figure 4. Depiction of the relation between the change from initial to final values of the BRT angle and the change from net to final values of the RBA angle for every trial (N = 181), panelled by the receiver's on-court position – R5 (N= 61), R1 (N = 61), and R6 (N = 59). Cases are labelled by the type of pass the model predicted: overhand (N = 20), underhand-lateral (N = 61), and underhand-frontal (N = 100) passes.

the majority of the effective receptions (N = 65; 60.7%), and it was also the most frequent type of pass (N = 96; 52.7%), followed by the underhand-lateral pass (N = 66; 36.3%), and finally by the overhand pass (N = 20; 11%, see Table 2).

Discussion

The aim of this study was to understand how a reception becomes effective. First we focused on how the receiver is selected at the ecological scale among three receivers in a top-level volleyball team. Next, we tested predictor-variables for the action mode selected to receive a serve, including variables related to the serve, the receiver, and to his relationship with the other receivers. Finally, we asked whether the action mode selected in reception was associated with reception efficacy, which, if not, would suggest that action mode selection is a way of adjusting to changing task constraints in order to achieve a successful reception.

Selection of "who" receives the serve

In the selection of "who" receives the serve we hypothesized that a VD-approach would accurately define the receivers' reception areas, and therefore adequately inform on "who" comes to receive the serve. We confirmed our hypothesis. The relevance of this finding is two-fold. First, it reinforces the ecological dynamics framework by demonstrating that an ecological scale of analysis is suited for understanding the emergent behaviour in a reception. Secondly, it contributes to reception training in volleyball by defining the receivers' reception areas (dominant regions) in an accurate and context-dependent way. Having confirmed the merits of having the VD as a base to define receivers' reception areas, the next step relates to how we can make this approach available to coaches in the gym. The technological advancements of today allow diverse possibilities: the conception of apps that allow manipulation of players position on court to visually inform the coaches and the players of their areas of responsibility; the use of virtual reality to allow players to act while having their reception areas highlighted; the incorporation of *smart floors* on the gyms where the reception areas could be highlighted through led-lights online.

"How" the serve is received

We developed a significant model for predicting the action mode selected to receive a serve, which included predictor-variables related to serve kinematics, the receiver's relationship with the ball and the target, and with his closest partner in reception. These predictor-variables had a different impact on the prediction of the different action modes.

Higher serve velocity significantly contributed to the prediction of the overhand pass instead of the other two action modes, and also to the prediction of the underhand-lateral pass instead of the underhand frontal pass. The overhand pass availability was bounded within initial serve velocities between 10 to 18 m.s^{-1}, which explains why it did not emerge against the power-jump serve (initial velocity: 20.27 ± 2.94 m.s^{-1}, see Supplemental material Table 1). These results are consistent with previous

studies in competitive settings (Palao et al., 2009; Paulo et al., 2017). Within the 10 to 18 m.s^{-1} serve-velocity interval, higher initial serve velocities were associated with the use of the overhand pass when maximum height was reached later. Serve-reception is a highly time-constrained task; the ball reaches the receiver in less than a second (see Supplemental material Table 1), and he initiates movement in around 0.3s from server's ball-contact (Benerink et al., 2015). Given the constraint of the net (net-height for male senior level is 2.43m) the closer the receiver is to the net the sooner he will be able to intercept the serve, and the higher the ball will be at interception, especially in serves with later time at maximum height, i.e., with a more parabolic trajectory. This prompted the use of the overhand pass under those circumstances.

Previous research (Paulo et al., 2016) reported that receptions in the R5 position (instead of R1) and closer to the net increased the chances of using the overhand pass. Our results expanded those findings by revealing that other task constraints, such as serve characteristics and receiver's position relative to target, also affect action mode selection. First the overhand pass was never used against the power-jump serve. Second, the receivers' on-court positions determined a particular range of BRT angles that are significantly different at initial and net values (see Supplemental material Table 2). For instance, when the ball crossed the net, only the receiver in R5 had BRT values above 35º, and in these circumstances the overhand pass tended to be predicted, particularly when the receiver was longitudinally closer to the target at ball interception (see Figure 3(a)). The receivers in R5 contacted the ball longitudinally closer to the target than when in R1 or R6 (see Supplemental material Table 2). In competition, the receiver in R5 is usually a front-row attacking-receiver (in five out of the six possible rotations, [see for further detail FIVB (2014)]), which means his subsequent attacking action will take place near the net. So the subsequent attacking action might have acted as an additional constraint on the receiver that prompted him to position himself closer to the net (see also Paulo et al., 2016), even though the task had no incentive on that regard. This positioning of the receiver increased the chances of the use of the overhand pass.

The most significant predictor-variables for the underhand-lateral pass were those reflecting the interactions between ball, receiver, and target over time (i.e., changes in the BRT angle from initial-to-final position and changes in the RBA angle from net-to-final position). The receiver aims at the target at ball-interception to ensure a successful reception (Dearing, 2003). As coaching literature suggests, the interception platform must be oriented toward the target (Dunphy & Wilde, 2014; Gozansky, 2001; Shondell, 2002). The reception is performed with the forearms/hands, so the target-alignment can be obtained through action mode selection by either using the overhand or underhand-frontal pass when maintaining or decreasing the values of the RBA/BRT angles, or by increasing their values when using the underhand-lateral pass. Indeed, both the underhand-frontal and the underhand-lateral passes were predicted by the model in R5 when one of the angles increased and the other decreased or maintained its values (see Figure 4). This result show two possible

strategies used by the receiver in R5. It may result from a change from "facing the net" to "facing the target" of the receiver's interception platform: using the underhand-frontal pass when maintaining or decreasing the RBA angle and increasing the BRT angle, and using the underhand-lateral pass when increasing the RBA angle and maintaining or decreasing the BRT angle. Thus, as R5 is the laterally furthest on-court position from the target (see Supplemental material Table 2), an extended array of occurrences were observed as a response to the unique challenges afforded by the receiver in this position.

These findings reinforce the suitability of this ecological scale of analysis, as well as of the ecological dynamics framework, to explain the process of action mode selection in reception (Araújo et al., 2006). Several sources of constraint influence the perception-action coupling of the receiver (Shaw, 2001), thereby establishing a particular field of affordances in each reception that limits or expands the receiver's selection of action modes for achieving the task goal (see Rietveld & Kiverstein, 2014).

A reception can occur in diverse circumstances (see above); although we have confirmed that the underhand-frontal pass is more often used, we also show that the overhand and the underhand-lateral passes are also used and have increased chances to be used under some circumstances.

Action mode selection and reception efficacy

Contrary to our hypothesis, though weakly, the pass used to receive the serve was associated with reception efficacy. The majority of the error receptions occurred when the underhand-lateral pass was used. This result is in line with the view that the underhand-lateral pass is a last resource (Dunphy & Wilde, 2014; Shondell, 2002). But we found that not to be the case of the overhand pass. When using the overhand pass the majority of the receptions were effective, just as for the underhand-frontal pass. This, on the other hand, supports the view that the overhand pass is selected in a given spectrum of task constraints in order to maintain performance levels.

Holding the gaze in a frontal position during the task toward the incoming ball is associated with higher reception efficacy (Vickers & Adolphe, 1998). In our study, this notion is associated with the receiver's re-positioning to maintain or decrease the RBA angle to values near zero (to avoid using an underhand-lateral pass). Again these results are consistent with the underhand-lateral pass "last resource" view. However, in top-level competition settings we showed that using the underhand-lateral pass to receive a jump-float serve significantly increased the chances of winning the match's final set (Paulo et al., 2017). In competitive settings there are several constraints to the receivers' on-court position and to the size of their reception area – e.g., volleyball rotation rule or the following attacking action. In that sense, given the short time the receiver has to act on the ball, there are situations where receiving the serve might imply the use of the underhand lateral pass, and mastering it might give expert teams a competitive edge. Those constraints were not present here, leaving open the question of the relevance of mastering this action mode to adapt to task demands in that case. Nonetheless, the results on the overhand pass allow us to advocate for an adaptive approach to reception training, where the selection of the action mode is not predefined, but an adaptation to task demands. This approach can be helpful for developing the action capabilities of the players and consequently for improving their performance.

Overall, these results can be the starting point for research addressing the impact of training programs focused on action mode selection as a way of dealing with the inherent variability of task constraints. As it has been shown (Hristovski et al., 2006), action mode selection is not "black or white"; there are performance regions, particularly in complex tasks such as the one exemplified here, which allow the emergence of several action modes. By exploring such regions, the performer becomes more attuned to relevant sources of constraint, thus expanding his/her action capabilities, bettering his decision making, and ultimately improving his/her performance (i.e., achieving the task goal). This approach contradicts current views on volleyball coaching literature (e.g., Hebert, 2014), where an ideal reception mode – the underhand-frontal pass) is promoted.

Conclusions

Reception efficacy is particularly relevant in competitive volleyball. Our study aimed to increase current understanding of the variables and constraint sources affecting reception. Voronoi diagrams were highly accurate in predicting at server ball-contact the player who comes to receive the serve. Furthermore, we were able to obtain a significant seven-predictor model for the action mode selected in reception. The predictors were related to the characteristics of the serve, the receiver's positioning and movement, and the receivers' on-court relative positioning. These findings give important insights into our understanding of the factors underlying the selection of a given action mode, and they contribute to volleyball reception training.

The type of pass used was associated with reception efficacy. The majority of the overhand and underhand-frontal passes were effective. On the other hand, the majority of the error receptions occurred when the underhand-lateral pass was used. Our results partially support the assumption of action mode selection as a way to maintain performance levels against changing task constraints. Further research is needed on verifying that assumption.

Disclosure statement

No potential conflict of interest was reported by the authors.

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