# Co-adaptation of ball reception to the serve constrains outcomes in elite competitive volleyball

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**Published version**

PAULO, Ana, DAVIDS, Keith and ARAUJO, Duarte (2017). Co-adaptation of ball reception to the serve constrains outcomes in elite competitive volleyball. International Journal of Sports Science and Coaching. (In Press)

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# Co-adaptation of ball reception to the serve constrains outcomes in elite competitive volleyball

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Paulo, A., Davids, K. & Araújo, D. (in press). Co-adaptation of ball reception to the serve constrains outcomes in elite competitive volleyball. International Journal of Sports Science and Coaching.

**Abstract**

How impactful is volleyball's 'serve-reception game'?  Its efficacy has been found to discriminate between winning and losing a match. But how does reception become (in)effective? Based on the theoretical rationale of ecological dynamics, we e hypothesized that skilled receivers in volleyball would not display  ready-made responses, but rather would co-adapt action modes  during serve-reception to deal with the specific, emergent constraints of service to achieve ttask goals. In order to examine this issue we investigated whether the co-adaptation of serve and reception action modes was a significant  predictor of set outcome in elite volleyball performance (win or loss), analysing the first and last sets of the 2014 World League Finals matches (897 game-sequences). The power-jump and jump-float were the serving modes observed and the overhand, underhand-lateral and underhand-frontal passes were the reception modes categorized. We found that the co-adaptation of serve and reception action modes predicted set outcome in the final set of a match. Receiving the jump-float serve with an overhand pass or underhand-lateral pass increased the odds of winning the final set by 200 per cent. Results suggested that, at an expert level, mastering the overhand pass and the underhand-lateral pass gives teams a competitive edge. Receivers showing flexibility in action mode selection improved a team's odds of successfully winning the final set of a match.

**Keywords**

Co-adaptation, Observational Analysis, Game analysis, Skill, Serve-reception, Action modes

## Introduction

Performance analysis in volleyball has focused on the efficacy of key game actions, mostly at an expert level of performance ( for reviews see Mesquita et al. [1] and [1]). Efficacy in performance of key game actions, such as the serve, attack, block, serve-reception (referred to as reception from this point on), has been associated with successful competitive performance in top-level male volleyball [2-4]. In a recent study, Silva et al.[4] assessed which game-related skills discriminated between winning and losing in competitive volleyball. They reinforced the importance to competitive outcomes, in top-level males, of the ‘serve-reception game’. They found that ‘serve points’ and ‘reception errors’ were two key variables that best discriminated between winning and losing a match. However, in their study, these game actions were assessed separately as if their performance was independent of each other, as isolated variables. In their study it was not clear whether there was an overlap between ‘serve points’ and ‘reception errors’ (as if these were the same occurrences). This overlap in the way that serve and reception efficacy are usually assessed (rating scales, e.g. [5]) leaves unclear the co-adaptive nature of the interactions between the receiver and server in emergence of performance outcomes (see also Afonso et al. [6]).

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According to Davids et al. [7] ‘expert performance in sport is predicated on an athlete’s capacity to functionally adapt his/her movements to the dynamics of complex performance environments’. They argued that skilled athletes are able to continuously co-adapt their actions to dynamic aspects of performance contexts including: surrounding information, and changing events, objects and actions of opponents. The co-adaptation capacity is not merely reactive, but interactive, in that changes in opponent positioning and tactical formations can lead to the emergence of affordances (opportunities for serving actions) for servers to probe possible defensive vulnerabilities in a receiving team. In turn receivers need to anticipate different service modes, (re)organising their actions accordingly. This results in continuous co-adaptive moves between opponents in sport which define competitive performance outcomes [7].

This idea, captured in volleyball, underlines why different service modes have different kinematic characteristics. For example, in comparison with the jump-float serve, the power jump serve displays higher values of ball velocity [8-10], horizontal displacement, and server -ball contact height [8, 9]. These variables express some of the performance constraints on a receiver's action modes. Intriguingly, in competition, Moras et al. [10] found no relationship between the speed of a serve and reception efficacy. These findings suggest that action mode selection is an expression of a performer's movement adaptations to satisfy changing task constraints to achieve a specific performance goal. For example, Barsingerhorn et al. [11], in a passing task, found that the underhand pass was used when larger longitudinal displacement of the passer were required, and the overhand pass was used closer to the initial position of the passer. Also, Hristovski et al. [12], in a heavy-bag-punching task in boxing, found that the probability of selection of a specific boxing action mode (jabs, hooks and uppercuts) was related to the scaled distance of a boxer to the target. These studies indicated that the action mode selected for reception expresses how a receiver solves the problems posed by the constraints presented by different serving modes. It is arguable that, the more adapted to a performance context, the more (technically) flexible a receiver in volleyball should be.

As Hughes and Bartlett [13] highlighted, for net and wall games, 'the effectiveness of a serve will always depend upon the returning skills of the opponent'. The coaching literature in volleyball portrays the power-jump serve as a powerful weapon to use [14]. At a male expert-level of performance it is the most commonly used serving mode [10, 15, 16], but when using this action,  a decrease in serving performance has been found in studies of elite volleyball competitors [17, 18], as opposed to lower-performance levels. . This decrease in serving performance has been related to the high skill level of receivers at the elite level. This finding indicates that, rather than a separate description of serve and reception actions, their interacting relations should be addressed. So the following questions remain:  How is the way the ball is received co-adapted to the service mode in elite competitive volleyball? Does the co-adaptation of ball reception to service mode predict successful performance outcomes? The aim of the present study was to address these questions in an observational analysis of elite competitive performance.

In addition to the power-jump serve, the literature suggests that, in elite male competitive volleyball, the jump-float and the float serve are the most commonly used serving actions modes [10, 15, 16]. In receiving the ball, the standard mode described in the coaching literature is the underhand-frontal pass [14, 19, 20]. However, some experienced coaches suggest that the underhand-lateral pass as a last-resource mode of action [14, 19]. Also, the overhand pass is proposed as an 'emergency' action mode [14] or as a useful action against the jump-float serve [19]. Due to their prominence in the extant literature, these three action modes were considered in the present study.

Marcelino et al. [21] identified the probability of winning each volleyball-set according to game location (home/away), and performance indicators (serve, reception, set, attack, dig and block) for top-level male performers. They found that, to win the first set, it was more important to take risks in attacking and blocking actions. On the other hand, to win the final set it was important to manage risk by improving performance in service reception. So, in addition to investigating how serve and reception action modes were co-adapted, as a significant predictor of set outcome, we also discriminated the service performance analysis for the initial and final sets. In doing so our goal was to understand how the process of  co-adaptation might have distinctly influenced these key points of interactions in competitive performance.

## Method

### Sample

To access elite level behaviours, we analysed competitive performance in the 2014 World League Finals, sampling all the matches played (n=10). Two sets (first and last) from each match were included in the analysis, resulting in a sample of 897 game sequences from this elite level competition. The analysis was performed from the perspective of the receiving team, i.e. when the team was in the side-out phase. There were six teams represented in the observed matches: Brazil (4 matches, 186 game sequences, 20.74% of the total sample), USA (4 matches, 182 game sequences, 20.29% of the total sample), Iran (4 matches, 177 game sequences, 19.73% of the total sample), Italy (4 matches, 174 game sequences, 19.4% of the total sample), Russia (2 matches, 81 game sequences, 9.03% of the total sample), and Australia (2 matches, 97 game sequences, 10.81% of the total sample).

In one of the matches, Iran vs. Russia, the last set corresponded to a fifth set, so it was played up to 15 points, not 25 as the rest of the set sample. Importantly, points played per type of set (First set 45.40 ± 6.38 points; Last set 44.30 ± 8.26 points; mean ± SD) were found not to be statistically different in the two types of set considered ($t_{(18)} = 0.33$, $p = 0.74$, $CI_{95\%} = -5.83, 8.03$).

This study was approved by the Ethics Committee of the Faculty of Human Kinetics, University of Lisbon (Nb. 7/2014)

## Instruments

An observational design was chosen for this study. The matches visualized were available on the Fédération Internationale de Volleyball Web TV Channel (http://www.laola1.tv/en-at/fivb-world-league/95.html) and data analysis took place during August, 2015. Since the footage was of TV broadcasts, several views of the court were presented, but the most recurrent one was perpendicular to the court's longitudinal axis.

We visualized the videos on one computer and inputted the data on another, in an Excel 2010 sheet. In this sheet each line corresponded to a game sequence played, and the columns corresponded to the variables notated. The latter were notated by the numbers assigned to each category depicted in Table 1. We later exported the data to SPSS Statistics 21 package for statistical analysis.

One observer, the first author, performed the analysis of the full sample. She is a level III credited Portuguese coach, with a degree in sport and physical education – specialized in volleyball training. Also, she has a Masters level degree in high performance training – specialized in volleyball training and competed internationally as an athlete for 12 years in the Portuguese national team. These skills and experiences qualified her as an expert observer in volleyball. A second expert observer was available to perform reliability checks. This observer had identical skills to those described for the first observer.

For the observation reliability procedures two sets were analysed (10% of the sample). Intra – Kappa = 0.93, and inter-observer (two observers) – Kappa = 0.85, fidelity satisfied the minimum of 0.75 established in the literature [22].. The reliability procedures were initiated with a meeting aimed at normalizing the notation of the variables in the study. One week after this meeting, the inter-observer's reliability rating took place. Since the Kappa value was satisfactory, the observation of the full sample took place. The intra-observer reliability procedure took place two weeks after the observation period.

## Variables

Each rally played was notated with regard to the team in the side-out phase (i.e. the team receiving the serve). Given that we already knew before the notation which of the teams won/lost the set, we also notated that information (e.g. the team in the side-out phase was the one that lost the set). In the Excel sheet used for recording the data, each line of record corresponded to a rally played, and each columns to the variables presented in Table 1. After the data set was introduced to SPSS Statistics 21, we used the software’s ‘Compute variable’ command to generate the variable Co-adaptation of serve and reception action modes, whose categories express the co-adaptation, in each rally, of the action modes used in the serve and in reception.

[insert Table 1.]

## Analysis

To verify the relevance of considering the co-adaptation of serve and reception modes as a predictor of set outcome, we preliminarily analysed the association between serve and reception action modes and the efficacy of these game actions (Supplemental online material Table 1 and 2), the association between serve and reception action modes (Supplemental online material Table 3), and the association between the co-adaptation of serve and reception action modes with reception efficacy (Supplemental online material Table 4). For the associations tested we used Chi-square statistics and assessed their effect sizes by using Cramer's V. In the four Chi-square analyses, the assumptions for test use were satisfied (there were no expected cell counts of zero, and the maximum of cells with an expected count below five was 17%). We found that the action modes used in serve and in reception were closely associated and correlated with performance efficacy. Importantly we found that the co-adaptation of serve and reception action modes was associated with reception efficacy, a finding which supported the study's aim, leading us to use this variable as predictor of set outcome.

We used (SPSS Statistics 21) Binary Logistic Regression to test the co-adaptation of serve and reception action modes as a predictor of set outcome. We tested it as predictor of winning or losing the set for the full sample, and for the first and last sets, independently. In the definition of the reference category for the co-adaptation of serve and reception action modes we took two steps. First, we defined as the reference category the co-adaptation of the power-jump serve with the underhand-frontal pass since it was the most frequent co-adaptation (34%, see Supplemental material Table 4). However, we did not want to omit any relevant information, so we additionally ran the analysis five more times, with one of the other co-adaptation categories included in the model as the reference category on each occasion. This procedure led to no new significant information emerging, so the model obtained in the first step was the only one included in the results section. The models' ability to predict known results was depicted by: i) the quality of the adjusted model obtained; ii) classification capacity of the model of known results; iii) the odds-ratio value of the predictor, and its interpretation as an effect size. Also, the assessment of the discriminant power of the model was additionally confirmed by a Receiver Operating Characteristics (ROC) curve. The odds-ratio effect size was evaluated using values 1.52 (small), 2.74 (medium), and 4.72 (large) as criteria with accordance to Chen et al. [23] for the .05 significance level we set.

Having obtained a statistically significant model for the final set, but not for the full sample and the first set, we explored by means of a contingency table and Chi-squared tests the association of the co-adaptation of serve and reception action modes and the set result for the full sample and for the first and final set.

## Results

To arrive at a model for set outcome, we tested the co-adaptation of serve and reception action modes as a predictor. Because of the inter-related nature of the predictor variable, serve errors were removed from the sample (n = 153), leaving 744 cases. The coupling of power-jump serve and overhand pass was removed from the model, due to its small count (3 cases), leaving 741 cases for analysis. From these cases, 404 (54.5%) pertained to the sets lost by the receiving team and 337 (45.5%) to sets won by the receiving team. The tested model did not perform significantly better than a constant-only model ($G^2_{(6, n = 741)} = 6.180$, $p = 0.403$). We next used the co-adaptation of serve and reception action modes as predictor of the first and last sets' outcome separately.

### First set

We removed error serves (n = 75) and, due to small counts, the couplings of jump-float serve with no-contact (1 case) and of power-jump serve with the overhand pass (2 cases), leaving 376 cases for analysis. Of those cases 207 (55.1%) pertained to lost sets and 169 (44.9%) to won sets. Again, the tested model did not perform significantly better than a constant-only model ($G^2_{(5,n = 379)} = 5.289$, $p = 0.382$).

### Last set

We tested the co-adaptation of serve and reception action modes as a predictor of the final set outcome. We removed error serves (n = 78) and the co-adaptation of the jump-float serve with no-contact (1 case) and of the power-jump serve with the overhand pass (1 case), due to small counts. There were 363 cases available for analysis, 196 (53.9%) pertained to lost sets and 167 (46.1%) to won sets.

The model performed significantly better than a constant-only model ($G^2_{(5,n = 363)} = 17.136$, $p = 0.004$). It correctly classified 59.8% of the cases. The model's overall increase to correct classification by chance was 5.8%. Given these results, in order to rely on the predictive capacity of the model, we also tested its discriminant power (between won and lost sets) with a ROC curve (Figure 1), and its classification capacity was confirmed (ROC c = 0.621; $p < 0.001$; 95% CI [0.563, 0.679]).

[insert Figure 1.]

The odds of winning the set significantly increased when the receivers co-adapted to the jump-float serve by using one of the following: the overhand pass (medium effect size), the underhand-lateral pass (medium effect size) and the underhand-frontal pass (small effect size), as opposed to the reference category – the co-adaptation of the power-jump serve with the underhand-frontal pass (see Table 2).

[insert Table 2.]

Table 3 presents the contingency data for the association of the co-adaptation of serve and reception action modes and the set result for the full sample, the first, and the final set. The co-adaptation of serve and reception action modes was significantly associated with set result for the final set, but not for the full sample and the first set. This difference, underlying the results of the previously presented logistic regressions, relates to the change in the final set of the frequency values of the co-adaptation of the jump-float serve with the overhand pass and with the underhand-lateral pass, and also the co-adaptation of the power-jump serve with the underhand-frontal pass. In the final set the co-adaptation of the jump-float serve with the overhand and the underhand-lateral pass was more frequently associated with successful performance (i.e. in sets that were won, compared to those lost). The inverse occurred in the first set. For the full sample, the co-adaptation of the jump-float serve with the overhand and the underhand-lateral pass was also more frequent in sets won, but the asymmetry in the (won-loss) proportions was more marked in the final set. In contrast, in the final set, the frequencies of the co-adaptation of the power-jump serve with the underhand-frontal pass were higher for lost sets than for those won. As with previous co-adaptations, in the first set these frequencies were inversed. In the full sample, like in the final set, the frequency of the co-adaptation of the power-jump serve with the underhand-frontal pass was higher in lost sets, but as for previous co-adaptations, the asymmetry in (won-loss) proportions was more marked in the final set.

[insert Table 3.]

## Discussion

Our observational analysis in expert male volleyball competition showed that the co-adaptation of serve and reception action modes predicted set outcome in the last set of the match. Marcelino et al. [21] had already reported that, in a volleyball match the sets are different in terms of game-action performance. They suggested that, in the last set, it is important to pay close attention to performance in reception. The data in the present study complemented those reported by Marcelino et al. [21] suggesting that, when receiving the jump-float serve, the odds of winning the final set increased by using the overhand pass and the underhand-lateral pass. Though not able to predict the set result for the full sample, data in Table 3 suggest that, in the full sample, the tendency of the distribution expressed in the model for the final set was present, though with (won-loss) proportions more evenly spread. Future studies should go beyond the first and final set to samplethe full match in order to confirm the trend expressed in the results of the present study.

Given the constraints of the jump-float serve, our findings suggest that mastering reception modes, other than the traditionally-standard mode – the underhand-frontal pass [14, 19, 20], affords teams an adaptive advantage in competition. The overhand pass has also been proposed in the volleyball coaching literature [19] as an adequate mode of action when facing the jump-float serve. It has also been found to increase the odds of a more effective service reception in competitive performance [24]. What was novel in our results was the finding that the use of the underhand-lateral pass also increases the odds of winning the final set of a match. This is a somewhat surprising finding, given that the coaching literature labels it as a last resource action mode [14, 19]. To our understanding, these findings indicate how an expert receiver co-adapts to the type of serve used by an opponent by detecting information that guides him/her to select a functional action mode, not a pre-determined one, increasing the team's odds of successful performance (winning the set).

In the coaching literature, the power-jump serve is seen as a powerful weapon [14], and its coupling with no-contact reception situations (i.e., when a server serves the ball directly onto the opposition court, without receivers touching the ball) increased the odds of losing the final set. However, this relationship was the least impactful in the model (see Table 2). Several studies have shown that the power-jump serve animates the ball with significantly higher velocities than the jump-float serve e.g. [8, 10] and more frequently results in  points being directly won [10, 15, 16, 25]. But in a recent study of the efficacy of different serve modes, Garcia-de-Alcaraz et al. [25] highlighted the higher point-to-error ratio (greater number of errors for every scored point, and consequently, lower efficiency) of the power-jump serve as opposed to the jump-float serve, questioning the frequent use of the power-jump serve in expert level performance. We found that in a final set of an expert-level match the power-jump serve advantage was neutralized by use of the underhand-frontal pass in reception. The results of the present study (see online supplemental material Table 1) indicated that use of the jump-float serve has increased in top-level male volleyball. At this top level its use-percentage was almost 20% higher than that reported in previous studies [10, 15, 16]. Its increase in frequency of use reinforces the relevance of the present study's findings. The data suggest that, to win the final set (i.e. the match), in top-level male volleyball, receivers should master and use the overhand and the underhand-lateral passes when receiving the jump-float serve. In practice, flexibility in action mode selection should be prioritized in training, since it provides a competitive edge. The two service reception modes should be seen as fundamental to successful performance and be routinely practiced by top-level teams, along with the underhand-frontal pass.

Our regression model, though significantly different from a constant-only model, increased in predictive value by 5.8% compared to chance. There may be underlying constraints, other than the service action modes per se, that may be more informative with regards to the emergent behaviours of reception. Each instance of reception has ecological constraints related to the receiver (e.g. height or posture, on-court positioning, and role within the team – libero/attacker-receiver), the task (intercept a fly ball – e.g. ball velocity and displacement, while collaborating with others – service reception tactical system) and the performance environment (e.g. final set) that uniquely interact leading to a given performance outcome (action mode selection or reception efficacy). This issue could be considered in future studies supported by a constraints-led approach to performance [26, 27]. Constraints can limit or expand the possible action modes used by the receiver. Moreover, constraints manipulation in practice attunes players to use better information to guide their actions [28]. As this study showed, the receiver can use the underhand-frontal pass successfully as prescribed by the coaching literature. But the action mode used needs to be co-adapted to the specific constraints that emerge during performance, as illustrated by the use of the overhand pass and the underhand-lateral pass in our study. The receivers showing flexibility in action mode selection significantly improved their team's odds of performance success (winning the final set – i.e. the match).

**Acknowledgements**

The authors wish to thank Francisca Esteves for her availability to perform the analysis that allowed the inter-observer reliability procedures.

This work was supported by the Portuguese Foundation for Science and Technology under Grant SFRH/BD/68692/2010 awarded to the first author.

The authors declare no conflict of interest.

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**Figures**

**Figure 1.** ROC curve representation of the co-adaptation of serve and reception action modes discriminative power between won and lost sets. Sensitivity = 1 if model selects all wins; 1-Specificity = 1 if model selects only wins.