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

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1 **Abstract**

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

16

17 **Keywords**

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

19 Introduction

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

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

Comment [KD1]: additional ref needed here?

42 This idea, captured in volleyball, underlines why different service modes have different
43 kinematic characteristics. For example, in comparison with the jump-float serve, the power jump serve
44 displays higher values of ball velocity⁸⁻¹⁰, horizontal displacement, and server-ball contact height^{8,9}.
45 These variables express some of the performance constraints on a receiver's action modes. Intriguingly,
46 in competition, Moras et al.¹⁰ found no relationship between the speed of a serve and reception efficacy.
47 These findings suggest that action mode selection is an expression of a performer's movement
48 adaptations to satisfy changing task constraints to achieve a specific performance goal. For example,
49 Barsingerhorn et al.¹¹, in a passing task, found that the underhand pass was used when larger longitudinal
50 displacement of the passer were required, and the overhand pass was used closer to the initial position of
51 the passer. Also, Hristovski et al.¹², in a heavy-bag-punching task in boxing, found that the probability of
52 selection of a specific boxing action mode (jabs, hooks and uppercuts) was related to the scaled distance
53 of a boxer to the target. These studies indicated that the action mode selected for reception expresses how
54 a receiver solves the problems posed by the constraints presented by different serving modes. It is
55 arguable that, the more adapted to a performance context, the more (technically) flexible a receiver in
56 volleyball should be.

57 As Hughes and Bartlett¹³ highlighted, for net and wall games, 'the effectiveness of a serve will
58 always depend upon the returning skills of the opponent'. The coaching literature in volleyball portrays
59 the power-jump serve as a powerful weapon to use¹⁴. At a male expert-level of performance it is the most
60 commonly used serving mode^{10,15,16}, but when using this action, a decrease in serving performance has
61 been found in studies of elite volleyball competitors^{17,18}, as opposed to lower-performance levels. . This
62 decrease in serving performance has been related to the high skill level of receivers at the elite level. This
63 finding indicates that, rather than a separate description of serve and reception actions, their interacting
64 relations should be addressed. So the following questions remain: How is the way the ball is received co-
65 adapted to the service mode in elite competitive volleyball? Does the co-adaptation of ball reception to

66 service mode predict successful performance outcomes? The aim of the present study was to address
67 these questions in an observational analysis of elite competitive performance.

68 In addition to the power-jump serve, the literature suggests that, in elite male competitive
69 volleyball, the jump-float and the float serve are the most commonly used serving actions modes^{10, 15, 16}.
70 In receiving the ball, the standard mode described in the coaching literature is the underhand-frontal pass
71^{14, 19, 20}. However, some experienced coaches suggest that the underhand-lateral pass as a last-resource
72 mode of action^{14, 19}. Also, the overhand pass is proposed as an ‘emergency’ action mode¹⁴ or as a useful
73 action against the jump-float serve¹⁹. Due to their prominence in the extant literature, these three action
74 modes were considered in the present study.

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

84

85 **Method**

86

87 *Sample*

88 To access elite level behaviours, we analysed competitive performance in the 2014 World
89 League Finals, sampling all the matches played (n=10). Two sets (first and last) from each match were

90 included in the analysis, resulting in a sample of 897 game sequences from this elite level competition.
91 The analysis was performed from the perspective of the receiving team, i.e. when the team was in the
92 *side-out phase*. There were six teams represented in the observed matches: Brazil (4 matches, 186 game
93 sequences, 20.74% of the total sample), USA (4 matches, 182 game sequences, 20.29% of the total
94 sample), Iran (4 matches, 177 game sequences, 19.73% of the total sample), Italy (4 matches, 174 game
95 sequences, 19.4% of the total sample), Russia (2 matches, 81 game sequences, 9.03% of the total sample),
96 and Australia (2 matches, 97 game sequences, 10.81% of the total sample).

97 In one of the matches, Iran vs. Russia, the last set corresponded to a fifth set, so it was played up
98 to 15 points, not 25 as the rest of the set sample. Importantly, points played per type of set (First set 45.40
99 ± 6.38 points; Last set 44.30 ± 8.26 points; mean \pm SD) were found not to be statistically different in the
100 two types of set considered ($t_{(18)} = 0.33$, $p = 0.74$, $CI_{95\%} = -5.83, 8.03$).

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

103

104 *Instruments*

105 An observational design was chosen for this study. The matches visualized were available on the
106 Fédération Internationale de Volleyball Web TV Channel ([http://www.laola1.tv/en-at/fivb-world-](http://www.laola1.tv/en-at/fivb-world-league/95.html)
107 [league/95.html](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
108 broadcasts, several views of the court were presented, but the most recurrent one was perpendicular to the
109 court's longitudinal axis.

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

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

121 For the observation reliability procedures two sets were analysed (10% of the sample). Intra –
122 Kappa = 0.93, and inter-observer (two observers) – Kappa = 0.85, fidelity satisfied the minimum of 0.75
123 established in the literature²². The reliability procedures were initiated with a meeting aimed at
124 normalizing the notation of the variables in the study. One week after this meeting, the inter-observer's
125 reliability rating took place. Since the Kappa value was satisfactory, the observation of the full sample
126 took place. The intra-observer reliability procedure took place two weeks after the observation period.

127

128 *Variables*

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

137

138

[insert Table 1.]

139

140 *Analysis*

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

153 We used (SPSS Statistics 21) Binary Logistic Regression to test the co-adaptation of serve and
154 reception action modes as a predictor of set outcome. We tested it as predictor of winning or losing the set
155 for the full sample, and for the first and last sets, independently. In the definition of the reference category
156 for the co-adaptation of serve and reception action modes we took two steps. First, we defined as the
157 reference category the co-adaptation of the power-jump serve with the underhand-frontal pass since it was
158 the most frequent co-adaptation (34%, see Supplemental material Table 4). However, we did not want to
159 omit any relevant information, so we additionally ran the analysis five more times, with one of the other
160 co-adaptation categories included in the model as the reference category on each occasion. This procedure
161 led to no new significant information emerging, so the model obtained in the first step was the only one

162 included in the results section. The models' ability to predict known results was depicted by: i) the quality
163 of the adjusted model obtained; ii) classification capacity of the model of known results; iii) the odds-
164 ratio value of the predictor, and its interpretation as an effect size. Also, the assessment of the
165 discriminant power of the model was additionally confirmed by a Receiver Operating Characteristics
166 (ROC) curve. The odds-ratio effect size was evaluated using values 1.52 (small), 2.74 (medium), and 4.72
167 (large) as criteria with accordance to Chen et al.²³ for the .05 significance level we set.

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

172

173 **Results**

174 To arrive at a model for set outcome, we tested the co-adaptation of serve and reception action
175 modes as a predictor. Because of the inter-related nature of the predictor variable, serve errors were
176 removed from the sample (n = 153), leaving 744 cases. The coupling of power-jump serve and overhand
177 pass was removed from the model, due to its small count (3 cases), leaving 741 cases for analysis. From
178 these cases, 404 (54.5%) pertained to the sets lost by the receiving team and 337 (45.5%) to sets won by
179 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
180 predictor of the first and last sets' outcome separately.

182

183 *First set*

184 We removed error serves (n = 75) and, due to small counts, the couplings of jump-float serve
185 with no-contact (1 case) and of power-jump serve with the overhand pass (2 cases), leaving 376 cases for

186 analysis. Of those cases 207 (55.1%) pertained to lost sets and 169 (44.9%) to won sets. Again, the tested
187 model did not perform significantly better than a constant-only model ($G^2_{(5, n = 379)} = 5.289, p = 0.382$).

188

189 *Last set*

190 We tested the co-adaptation of serve and reception action modes as a predictor of the final set
191 outcome. We removed error serves ($n = 78$) and the co-adaptation of the jump-float serve with no-contact
192 (1 case) and of the power-jump serve with the overhand pass (1 case), due to small counts. There were
193 363 cases available for analysis, 196 (53.9%) pertained to lost sets and 167 (46.1%) to won sets.

194 The model performed significantly better than a constant-only model ($G^2_{(5, n = 363)} = 17.136, p =$
195 0.004). It correctly classified 59.8% of the cases. The model's overall increase to correct classification by
196 chance was 5.8%. Given these results, in order to rely on the predictive capacity of the model, we also
197 tested its discriminant power (between won and lost sets) with a ROC curve (Figure 1), and its
198 classification capacity was confirmed (ROC $c = 0.621$; $p < 0.001$; 95% CI [0.563, 0.679]).

199

200 [insert Figure 1.]

201

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

206

207 [insert Table 2.]

208 Table 3 presents the contingency data for the association of the co-adaptation of serve and
209 reception action modes and the set result for the full sample, the first, and the final set. The co-adaptation

210 of serve and reception action modes was significantly associated with set result for the final set, but not
211 for the full sample and the first set. This difference, underlying the results of the previously presented
212 logistic regressions, relates to the change in the final set of the frequency values of the co-adaptation of
213 the jump-float serve with the overhand pass and with the underhand-lateral pass, and also the co-
214 adaptation of the power-jump serve with the underhand-frontal pass. In the final set the co-adaptation of
215 the jump-float serve with the overhand and the underhand-lateral pass was more frequently associated
216 with successful performance (i.e. in sets that were won, compared to those lost). The inverse occurred in
217 the first set. For the full sample, the co-adaptation of the jump-float serve with the overhand and the
218 underhand-lateral pass was also more frequent in sets won, but the asymmetry in the (won-loss)
219 proportions was more marked in the final set. In contrast, in the final set, the frequencies of the co-
220 adaptation of the power-jump serve with the underhand-frontal pass were higher for lost sets than for
221 those won. As with previous co-adaptations, in the first set these frequencies were inverted. In the full
222 sample, like in the final set, the frequency of the co-adaptation of the power-jump serve with the
223 underhand-frontal pass was higher in lost sets, but as for previous co-adaptations, the asymmetry in
224 (won-loss) proportions was more marked in the final set.

225

226 [insert Table 3.]

227

228 **Discussion**

229 Our observational analysis in expert male volleyball competition showed that the co-adaptation
230 of serve and reception action modes predicted set outcome in the last set of the match. Marcelino et al.²¹
231 had already reported that, in a volleyball match the sets are different in terms of game-action
232 performance. They suggested that, in the last set, it is important to pay close attention to performance in
233 reception. The data in the present study complemented those reported by Marcelino et al.²¹ suggesting

234 that, when receiving the jump-float serve, the odds of winning the final set increased by using the
235 overhand pass and the underhand-lateral pass. Though not able to predict the set result for the full sample,
236 data in Table 3 suggest that, in the full sample, the tendency of the distribution expressed in the model for
237 the final set was present, though with (won-loss) proportions more evenly spread. Future studies should
238 go beyond the first and final set to sample the full match in order to confirm the trend expressed in the
239 results of the present study.

240 Given the constraints of the jump-float serve, our findings suggest that mastering reception
241 modes, other than the traditionally-standard mode – the underhand-frontal pass^{14, 19, 20}, affords teams an
242 adaptive advantage in competition. The overhand pass has also been proposed in the volleyball coaching
243 literature¹⁹ as an adequate mode of action when facing the jump-float serve. It has also been found to
244 increase the odds of a more effective service reception in competitive performance²⁴. What was novel in
245 our results was the finding that the use of the underhand-lateral pass also increases the odds of winning
246 the final set of a match. This is a somewhat surprising finding, given that the coaching literature labels it
247 as a last resource action mode^{14, 19}. To our understanding, these findings indicate how an expert receiver
248 co-adapts to the type of serve used by an opponent by detecting information that guides him/her to select
249 a functional action mode, not a pre-determined one, increasing the team's odds of successful performance
250 (winning the set).

251 In the coaching literature, the power-jump serve is seen as a powerful weapon¹⁴, and its
252 coupling with no-contact reception situations (i.e., when a server serves the ball directly onto the
253 opposition court, without receivers touching the ball) increased the odds of losing the final set. However,
254 this relationship was the least impactful in the model (see Table 2). Several studies have shown that the
255 power-jump serve animates the ball with significantly higher velocities than the jump-float serve e.g.^{8, 10}
256 and more frequently results in points being directly won^{10, 15, 16, 25}. But in a recent study of the efficacy of
257 different serve modes, Garcia-de-Alcaraz et al.²⁵ highlighted the higher point-to-error ratio (greater

258 number of errors for every scored point, and consequently, lower efficiency) of the power-jump serve as
259 opposed to the jump-float serve, questioning the frequent use of the power-jump serve in expert level
260 performance. We found that in a final set of an expert-level match the power-jump serve advantage was
261 neutralized by use of the underhand-frontal pass in reception. The results of the present study (see online
262 supplemental material Table 1) indicated that use of the jump-float serve has increased in top-level male
263 volleyball. At this top level its use-percentage was almost 20% higher than that reported in previous
264 studies^{10, 15, 16}. Its increase in frequency of use reinforces the relevance of the present study's findings.
265 The data suggest that, to win the final set (i.e. the match), in top-level male volleyball, receivers should
266 master and use the overhand and the underhand-lateral passes when receiving the jump-float serve. In
267 practice, flexibility in action mode selection should be prioritized in training, since it provides a
268 competitive edge. The two service reception modes should be seen as fundamental to successful
269 performance and be routinely practiced by top-level teams, along with the underhand-frontal pass.

270 Our regression model, though significantly different from a constant-only model, increased in
271 predictive value by 5.8% compared to chance. There may be underlying constraints, other than the service
272 action modes per se, that may be more informative with regards to the emergent behaviours of reception.
273 Each instance of reception has ecological constraints related to the receiver (e.g. height or posture, on-
274 court positioning, and role within the team – libero/attacker-receiver), the task (intercept a fly ball – e.g.
275 ball velocity and displacement, while collaborating with others – service reception tactical system) and
276 the performance environment (e.g. final set) that uniquely interact leading to a given performance
277 outcome (action mode selection or reception efficacy). This issue could be considered in future studies
278 supported by a constraints-led approach to performance^{26, 27}. Constraints can limit or expand the possible
279 action modes used by the receiver. Moreover, constraints manipulation in practice attunes players to use
280 better information to guide their actions²⁸. As this study showed, the receiver can use the underhand-
281 frontal pass successfully as prescribed by the coaching literature. But the action mode used needs to be

282 co-adapted to the specific constraints that emerge during performance, as illustrated by the use of the
283 overhand pass and the underhand-lateral pass in our study. The receivers showing flexibility in action
284 mode selection significantly improved their team's odds of performance success (winning the final set –
285 i.e. the match).

286

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293

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364 **Figures**

365

366 **Figure 1.** ROC curve representation of the co-adaptation of serve and reception action modes
367 discriminative power between won and lost sets. Sensitivity = 1 if model selects all wins; 1-Specificity =
368 1 if model selects only wins.

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