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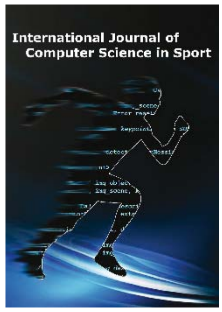

Bayesian Analysis of Skills Importance in World Champions Men's Volleyball across Ages

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Abstract

In volleyball, due to the sequential structure of the game, each outcome results from events that follow consistent consecutive patterns: pass–set–attack–outcome, serve–outcome and block–dig–set–counter attack–outcome. There are three possible outcomes: point won, point lost, and rally continuation. With the aim of quantifying the importance of volleyball skills, data of world champions of the male International Volleyball Federation tournaments for three age categories (Youth, Juniors and Men) were used to construct a transition matrix between subsequent moves and skills within the game. A Dirichlet-Multinomial Bayesian model was used to estimate the transition probabilities between the subsequent moves along with the marginal probability of success of each skill in the complex. The prior distribution of each transition probabilities between moves/skills was elicited to incorporate experts' opinion. For the final evaluation of the skills a simple Monte Carlo scheme was applied to obtain a random sample from the posterior distribution. The findings of the study indicate that the relative importance of volleyball skills is robust across world champions of different age categories. Slight variations are observed on specific skills. A new index (Quantile Mid-range Ratio) is proposed for highlighting skills that are valuable for team's gameplay.

KEYWORDS: PERFORMANCE ANALYSIS, MARKOV CHAIN, TRANSITION MATRIX, MULTINOMIAL DITSRIBUTION, JUNIORS

Introduction

In volleyball, the points scored by a team are primarily based on the successful execution of the skills of the game. Volleyball has three scoring skills (serve, attack, and block) and three non-scoring skills (pass, set, and dig). For each team, a maximum of three contacts of the ball is allowed before the ball crosses the net to the opponent's court (a block does not count as a touch). Typically, teams exhaust all three contacts. Due to the sequential structure of the game, each outcome results from events that follow three consistent consecutive patterns (Miskin, Fellingham, & Florence, 2010): (1) pass–set–attack 1–outcome, (2) serve–outcome, and (3) block–dig–set–counterattack or attack 2–outcome. The outcome is a consequence of one of three possibilities: (1) point won, (2) point lost, or (3) the rally continues with the ball on the opponent's side.

Quantitative analysis of volleyball data has been focused on the analysis of skill-specific isolated touches of the ball and do not offer any insight for the sequence or the interaction between skills and moves leading to a winning point (Araujo, Mesquita, & Marcelino, 2009; Marcelino, Mesquita, & Sampaio, 2009). Such analysis has been performed for tournament, season, game or set data and even for sets depending on the point difference between the two teams (Drikos & Vagenas, 2011). Conversely, research concerning the importance of skills and their execution level on the final outcome of a single rally is rather limited. Only the studies of Florence, Fellingham, Vehrs, and Mortensen (2008) and Miskin et al. (2010) have attempted to account for the interaction of volleyball skills within a single rally using data from a women's team. Research so far has investigated, almost exclusively, the top age category of each gender (Alfonso, Esteves, Araujo, Thomas, & Mesquita, 2012; Kountouris, Drikos, Aggelonidis, Laios, & Kyprianou, 2015; Zetou, Tsigilis, Moustakidis, & Komninakidou, 2006) with the exception of the articles of Costa, Caetano, Ferreira, Alfonso, and Costa (2011) and Garcia de Alcaraz, Ortega, and Palao (2015) which examined possible determinants of the attack effectiveness for youth male volleyball teams and across ages, respectively.

The aim of the current study was to estimate the importance of detailed skills and skill sequences within each rally and to compare results across the World champions' teams of the three male age categories (youth-U19, juniors–U21 and men). For volleyball practitioners (coaches and managers) it is meaningful to know the value of each skill in isolation in order to allocate training time efficiently, especially when it is limited, and to select players with proper technical characteristics when forming a team.

Methods

Data and Variables

All recorded data refer to the performance of the winning team from the latest world championships of national teams in all age categories (U19, U21 and men) for male volleyball. To be more specific, we consider all the rallies (N=2111) for Poland in Men, winner for 2014 and for Russia, winner for 2013 both in U21 (N=1327) and in U19 (N=1116).

Moreover, only the actions of the team under study are recorded and analyzed. The data for the observed team was collected by using the Data Volley software, a specialized digital recording tool (Data Project, 2000). Attack, block, dig and free ball skills were categorized into two sequences (1 & 2). Setting for the attack, either after serve's pass or after the defense is divided according to the position of the court and the type of setting.

Five possible positions of attack (left front side, middle front & middle back side, right front & right back side) and two types of attack (quick and high) are included. Types of setting for all positions of attack are categorized as follows (with merge of categories proposed by Afonso and Mesquita (2007): Quick (fast) setting when the attacker jumps during or slightly after the set, possibly taking one step after the set and high (slow) setting when the attacker takes more than two steps or waits after the set to start his approach. Also, the attack in the second contact from the setter and the attack out of the system are classified as attacking moves. A direct attack is defined as the case when the ball is driven directly from the opponent's court (direct attack of an overpass). A setting error records the case where the recorded team makes an unforced error during the second touch.

For the serve, jump and float, and for a pass against jump or against float serve, a six-level ordinal tactical scale is employed with the value of one indicating a poorly performed skill and the maximum value corresponding to the optimally performed skill (Rocha & Barbanti, 2006).

For the block, either after serve or after the attack, a three-level ordinal scale is used (Palao, Santos, & Urena, 2004). Finally, for the skill of defense there are two states: free ball and dig, either after serve or after the attack. Following the approach of Florence et al. (2008) dig related skills were merged in a single state in order to avoid having to deal with a sparse matrix of transition frequencies. All the matches were video recorded and the observer was a volleyball coach, expert in evaluation and recording of the volleyball performance data and excellent user of the software. The intra-observer reliability was tested with a test-retest procedure with a two weeks interval, from a random sample of 200 rallies per team. As the acceptable value of Adjusted K Cohen was set .80 (Altman, 1991) and the score of the test-retest procedure for each skill separately was .83 for serve, .88 for attack 1, .89 for attack 2, .84 for block and .81 for pass. Overall, an adjusted K Cohen value of .85, very good, was calculated and the intra-observer reliability was confirmed. All recorded skills and their properties are summarized in Table 1.

Table 1. Performance ratings, levels and categorization for each skill S_i.

Main Skills (# rows in transition matrix)	**Skills (sub)**	**Level code (Level Symbol)**	**Sequences**	**Types**
Serve (Jump & float) (12)	Serve ace. The ball lands in receiving team's court with none or one touch	6(#)		
	The ball drives directly to the serving team's court (overpass)	5(/)		
	The ball is on receiving team's court but with just one option for attack	4(+)		
	The ball is on receiving team's court with two options for attack	3(!)		
	The receiving team has all the options for attack	2(-)		
	Serve error	1(=)		
Pass (vs Jump & vs Float serve) (12)	The receiving team has all the options for attack without adjustments for the setter.	6(#)		

Main Skills (# rows in transition matrix)	Skills (sub)	Level code (Level Symbol)	Sequences	Types
	The receiving team has all the options for attack with adjustments in the approach of the ball for the setter.	5(+)		
	The ball is on receiving team's court with two options for attack	4(!)		
	The ball is on receiving team's court but with just one option for attack	3(-)		
	The ball drives directly to the serving team court	2(/)		
	Pass error.	1(=)		
Block	Block kill	1(#)	2(AS,AA)*	
(6)	Continue Block. The ball stays in the blocking team's court	2	2(AS,AA)	
	Continue Block. The ball stays in the attacking team's court	3	2(AS,AA)	
Setting location	Left Front Side	(LFS)	2	2**
(24)	Right Front side	(RFS)	2	2
	Right Back side	(RBS)	2	2
	Middle Front side	(MFS)	2	1(quick)
	Middle Back side	(MBS)	2	2
	Out of system	(OoS)	2	
	Setter's Tip or attack in 2nd touch	(STR TIP)	2	
	Setting error	(SE)	2	
Direct attack	Attack of an overpass			
(1)				
Defense	Dig		2(AS,AA)*	
(4)	Free ball		2(AS,AA)	

**2 sequences indicate that the skills are recorded for both sequences separately. For block (after serve-AS & after attack-AA), for attack (after pass-Attack1 & after defense-Attack2), for defense (after serve-AS & after attack-AA)*

***2 types indicate that the skills are recorded for quick (fast) and high (slow) type of setting*

Method of Analysis

The paper uses the methodology of Fellingham and Reese (Miskin et al., 2010) to evaluate the importance of each skill. According to their approach, the coefficient of the skill importance for the i-th recorded skill is defined as the ratio of the posterior mean of Pi over its corresponding standard deviation, that is

$$I_i = \frac{E(P_i \mid y)}{\sqrt{V(P_i \mid y)}} \quad (1)$$

where P_i is the probability that this skill will end up in a point in favour of the team under study after two subsequent game moves and is calculated by

$$P_i = P(Y_{t+1} = \text{point}^+ \mid Y_t = S_i) + \sum_{\substack{k=1 \\ k \neq i}}^{n} P(Y_{t+2} = \text{point}^+ \mid Y_{t+1} = S_k) P(Y_{t+1} = S_k \mid Y_t = S_i) \quad (2)$$

with n denoting the number of skills, $P(Y_{t+1} = \text{point}^+ \mid Y_t = S_i)$ denoting the probability of scoring a point in favour of the team under study after a skill S_i and $P(Y_{t+1} = S_k \mid Y_t = S_i)$ denoting the transition probability from skill S_i to skill S_k. It is further assumed that the scoring for each skill is not influenced by the time point hence $P_i = P(Y_{t+1} = \text{point}^+ \mid Y_t = S_i) = P(Y_{t+2} = \text{point}^+ \mid Y_{t+1} = S_i)$.

Ratio (1) provides the opportunity to attach an importance score to every skill and its corresponding levels, capturing the quality and the precision of the corresponding move or skill. Every time the ball is on the side of the team under investigation, the outcome is determined by a sequence of events that follow specific schemes: pass–set–attack 1–outcome, serve–outcome and block–dig–set–attack 2–outcome, with the assumption that these schemes are first-order Markov chains.

These sequences are recorded in a transition matrix of counts (one for each team) where the data of the matrix represent the number of moves from one state to another aggregated over all games under consideration. For each team under study, a transition matrix of observed counts $y=(y_{ij})$ of dimension 59×62 is formed; where $i=1,...59$ and $j=1,...,62$. The three additional states appearing in the columns of the matrix consist of the continuation of the action with the ball in opponent's court and the terminal states of a point scored or lost by the team. This matrix contains the transition frequencies for jump and float serves, passes against jump and float serves, sets after serve's pass by location and type, sets after defense by location and type, block after the serve, blocks after the attack, free balls and digs and possible outcomes. Because of the sequential structure of the game, there are sequences that are not feasible, such as moving from an excellent pass to an ace serve. These cases refer to structural zeros at the observed frequency table of the data and the corresponding probabilities are restricted to zero by the initial model formulation. A simple Bayesian model is used to estimate the transition probabilities $P(Y_{t+1} = S_k \mid Y_t = S_i)$ and the success probabilities P_i as defined by (1). For brevity, let us denote the transition probabilities $P(Y_{t+1} = S_k \mid Y_t = S_i)$ by π_{ik}. For each row (skill-rating combination), a multinomial likelihood is assumed:

$$f(y_{i1},...,y_{i,n},y_{i,n+1},y_{i,n+2} \mid \pi_{i1},...,\pi_{i,n},\pi_{i,n+1},\pi_{i,n+2}) \propto \prod_{k \in M_i} \pi_{ik}^{y_{ik}} \quad (3)$$

with $\sum_{k=1}^{n+3} \pi_{ik} = \sum_{k \in M_i} \pi_{ik} = 1$ for each i; where M_i is the set of indices corresponding to possible following skill S_i.

Therefore, the corresponding transition probabilities π_{ik} with $k \in M_i$ are quantities under estimation taking values in the (0, 1) interval while all π_{ik} with $k \notin M_i$ are structurally restricted to zero and therefore are not estimated.

For each skill S_i, a conjugate Dirichlet prior distribution is used for the parameters under estimation, $\Pi_i = (\pi_{ik}, k \in M_i)$, of the type

$$f(\Pi_i \mid A_i) \propto \prod_{k \in M_i} \pi_{ik}^{a_{ik}-1}, \tag{4}$$

where $A_i = (a_{ik}, k \in M_i)$ are the prior parameters for parameters Π_i. For each skill (row in the transition matrix) the prior parameters A_i can be elicited by using coaches' expert opinion. In the implementation, two different prior set-ups are used: (1) the minimally informative case and (2) the case with information available from team experts.

Since a conjugate set-up is used, the posterior distribution for the transition probabilities Π_i will be also a Dirichlet distribution with parameters $(y_{ik}+\alpha_{ik})$, for $k \in M_i$, that is

$$f(\Pi_i \mid y_{i+}, A_i) \propto \prod_{k \in M_i} \pi_{ik}^{y_{ik}+a_{ik}-1}, \tag{5}$$

where $y_{i+} = (y_{i1}, \ldots, y_{i,n}, y_{i,n+1}, y_{i,n+2})$. Note that y_{ik} are constrained to zero for all $k \notin M_i$.

Under this setup, the posterior mean and variance are given by:

$$E(\pi_{i,k} \mid y_{i+}) = \frac{y_{ik} + a_{ik}}{\sum_{j=1}^{n+3} y_{ij} + \sum_{j=1}^{n+3} a_{ik}} \quad \text{and} \quad Var(\pi_{i,k} \mid y_{i+}) = \frac{E(\pi_{i,k} \mid y_{i1}, \ldots, y_{i,n+2})\left\{1 - E(\pi_{i,k} \mid y_{i1}, \ldots, y_{i,n+2})\right\}}{\sum_{j=1}^{n+3} y_{ij} + \sum_{j=1}^{n+3} a_{ij} + 1}$$

for all $k \in M_i$, respectively.

For the final evaluation of the skills, the posterior distribution of the success probabilities (2) needs to be calculated and these are not readily available. For this reason, a simple Monte Carlo scheme is applied to obtain a random sample of size T from the posterior distribution. In this way, we obtain estimates of the posterior means of the success probabilities P_i and standard deviations and, finally, the importance scores given by (1).

The sampling scheme can be summarized by the following steps:

- For $t = 1, \ldots T$,
  - For $i = 1, \ldots, n$
    - Find the set M_i of all possible states following S_i
    - Generate Π_i from a Dirichlet distribution with parameters A_i.
    - Calculate the success probability for iteration t using equation (2), that is $P_i = \pi_{i,n+1} + \sum_{k=1, k \neq i}^{n} \pi_{i,k} \pi_{k,n+1}$.

All skills scores were calculated using a simple Monte Carlo scheme of 10,000 iterations. Finally, the similarity between the skills rankings across different ages is assessed by using Spearman correlation since only the ordering of the importance scores should be compared across teams because of the direct connection of importance score index with the sample size.

Model specification with minimal prior information

Usually the minimal prior information is available for the estimation of the transition probabilities $\pi_{ik} = P(Y_{t+1} = S_k \mid Y_t = S_i)$ appearing in (3). Therefore, it is a requisite to specify the prior distribution (4) in such a way that it will have an imperceptible effect on the final results. A minimally informative prior to the Multinomial-Dirichlet model can be specified by considering equal prior parameters and restricting their sum to one. The contribution of the prior information, in this case, is equal to one data point, since their sum is equal to one. Moreover, no preference is expressed for any alternative state (due to the equality of the parameters. Therefore the parameters of the Dirichlet prior for skill S_i are given by

$$a_{ik} = \begin{cases} 1/|M_i| & \text{for } k \in M_i \\ 0 & \text{for } k \notin M_i \end{cases},$$

where $|M_i|$ is the number of possible transitions from a skill-rating combination S_i to a subsequent state.

Elicitation of Prior Information from Experts

The novelty of the present study is based on obtaining posterior results that also combine expert opinions from volleyball coaches of the Greek National teams. Each coach was considered to be an expert for the corresponding age category in the qualification process for the World Championship final phase in the relevant age categories. As a first step, the coaches were familiarized with the notion of the transition matrix, the possible states for each sequence and the grading system of the skills. Subsequently, the coaches were interviewed and provided information about the transition probability matrix.

The collection of such information was a difficult task due to the difficulty of quantifying qualitative knowledge (Albert, Donnet, Guihenneuc - Joyaaux, Low-Choy, Mengersen, & Rousseau, 2012). Due to the uncertainty introduced by this fact, it was decided to attach a low weight to the experts/coaches opinion.

Hence, the prior parameters were set equal to the elicited transition probabilities of experts multiplied by $0.1 \times N_i$ for each skill S_i. Using this method, the information introduced by the experts will account for an additional 10% of the transition probabilities of the observed data points. Using this approach, parameters of the Dirichlet prior (4) for each skill S_i are given by

$$a_{ik} = \begin{cases} \hat{p}_{ik} \times \dfrac{N_i}{10} & \text{for } k \in M_i \\ 0 & \text{for } k \notin M_i \end{cases},$$

with $\hat{p}_{ik}$ denoting the prior estimate of an expert for the probability $\pi_{ik} = P(Y_{t+1} = S_k \mid Y_t = S_i)$.

The Quantile Mid-range Ratio

The importance scores (1) identify skills with high success probabilities but also with high accuracy of estimation (or low uncertainty about the estimated probability). Thus it will focus on frequently played successful skills of the team.

This importance index fails to identify skills which are potentially promising but are not played frequently by the team under study. Such skills have high success probabilities (close to one) but relatively large variance (and therefore high uncertainty) and they are asymmetric since they are defined in the (0,1) interval.

For this reason, it is functional to introduce a different diagnostic measure for tracing important skills by assessing the symmetry of the posterior distributions of success probabilities. This measure is the 90% Quantile Mid-range Ratio (90% QMR) as the ratio of the range between the 50th and the 5th percentile to the range between the 95th and the 50th percentile, that is

$$QMR = \frac{M - Q_{0.05}}{Q_{0.95} - M},$$

where Q_α is an α quantile and M is the median value.

Values close to one indicate equal ranges and possible symmetry, while values away from one identify asymmetric distributions. Values over one indicate negative skewness and values less than one indicating positive skewness. For example, a value equal to 1.3 indicates that the amplitude of 45% of the values below the median is 30% higher than for the corresponding range above the median.

The QMR values can be used to identify asymmetric posterior distributions of the success probabilities for each skill. Probabilities away from the boundaries of one and zero will be relatively symmetric and therefore their importance score will be evaluated efficiently. Probabilities close to one will be negatively skewed and they will be identified as skills of potentially high importance, even in cases where the variance is large. This is extremely useful when the sample size for a specific skill is small and the posterior variance is high due to lack of data. Speaking strictly from the perspective of the game, such skills may be highly important, leading to crucial points, but they may not occur frequently due to their difficulty or because of the lower skills of the players of the team under study.

Results

The results and the analysis presented here are obtained using the experts' opinion. By incorporating the experts' opinion in our analysis we exploit additional information by the experts which are extremely beneficial for rare events and skills stabilizing the posterior distributions, while for the rest of the skills results minor differences were observed between the minimal informative prior based approach and the prior information from experts. All minimal informative analysis is available by the authors in an electronic supplement.

The success probabilities P_i for each skill or tactical choice are provided in Table 2. Results are summarized according to the evaluation level of each skill from the three age categories. Table 2 shows an unexpected result about serve. When the serve is highly evaluated, the success probabilities are not only increased but they are also decreased in specific cases. For this reason, the total probability of non-failure in the next two touches of the ball after the serve is additionally calculated. Under this approach, the non-failure probabilities are positively associated with the serve quality; see Figure 1 for success and non-failure probabilities for both types of serve.

For serves of the third quality level of the scale, the U19 team has a greater likelihood of achieving a point than U21 & Men team. The same result is reached for the pass in both types of serve of the fourth quality level of the scale. The U19 team is more likely to win the action than the Men's team.

As expected, pass levels 4 - 6 and attack skills have the highest success probabilities. From the posterior analysis of Table 2, it is worth mentioning that the Men's team seems to have systematically higher success probabilities from the middle back zone quick attacks (MB quick) than both U21 & U19 teams for the attack 1 (after the pass) or 2 (after defense). Conversely, attack out of system either after pass or defense has higher probabilities of success for the U19 team than both U21 and Men.

Table 2. Posterior means of success probabilities Pi and summary of posterior differences across age categories for each skill Si

Skills (S_i)	Skills(sub)	Men	U21	U19	Posterior differences*
SrvJump	2(-)	0.326	0.320	0.257	*Men>>U19*
	3(!)	0.315	0.393	0.394	
	4(+)	0.254	0.228	0.287	
	5(/)	0.240	0.402	0.250	
SrvFloat	2(-)	0.336	0.332	0.391	*Men<U19,U21 << U19*
	3(!)	0.286	0.301	0.386	*Men,U21 << U19*
	4(+)	0.280	0.221	0.275	*Men>U21*
	5(/)	0.421	0.553	0.408	*U21>U19*
Continue Block AS	3	0.181	0.283	0.248	*Men<<U21, Men<U19*
	2	0.002	0.003	0.001	
Free ball AS		0.539	0.618	0.595	*Men<U21*
Dig AS		0.345	0.370	0.402	*Men<U19*
Pass in Jump	2(/)	0.269	0.267	0.455	*Men,U21<U19*
	3(-)	0.310	0.335	0.320	
	4(!)	0.524	0.499	0.602	*Men<U19, U21<<U19*
	5(+)	0.579	0.543	0.589	
	6(#)	0.581	0.541	0.557	
Pass in Float	2(/)	0.252	0.192	0.281	
	3(-)	0.331	0.306	0.412	
	4(!)	0.518	0.498	0.573	*Men<U21, Men<<U19*
	5(+)	0.568	0.551	0.591	
	6(#)	0.563	0.541	0.606	*U21<U19*
Attack 1	LS quick	0.556	0.576	0.779	*Men,U21<<<U19*
	LS high	0.473	0.537	0.680	*Men<<U19*
	FRS quick	0.575	0.665	0.765	*Men<U21<U19, Men<<<U19*
	FRS high	0.470	0.464	0.218	*Men, U21>>U19*
	BRS quick	0.616	0.557	0.455	*Men >> U19*
	BRS high	0.448	0.497	0.432	
	MF quick	0.695	0.680	0.635	
	MB quick	0.705	0.563	0.407	*Men>U21, Men>>U19*
	MB high	0.944	0.379	0.427	*Men>>U19*
	STR TIP	0.779	0.546	0.641	
	OoS	0.351	0.336	0.545	*Men, U21<U19*
Attack 2	LS quick	0.530	0.815	0.695	*Men<<<U21, Men<<U19<U21*
	LS high	0.403	0.554	0.376	*Men <U21, U21>U19*
	FRS quick	0.633	0.732	0.830	*Men<<U19*
	FRS high	0.610	0.244	0.664	*Men>>U21, U21<<<U19*
	BRS quick	0.652	0.411	0.846	*U21<< Men<< U19, U21<<<U19*
	BRS high	0.430	0.383	0.140	*Men>>U19, U21>U19*
	MF quick	0.736	0.712	0.697	
	MB quick	0.718	0.675	0.413	*Men>>>U19, U21>>U19*
	MB high	0.448	0.487	0.296	
	STR TIP	0.590	0.466	0.450	
	OoS	0.352	0.451	0.598	*Men<<U21<U19, Men<<<U19*
Direct attack		0.611	0.670	0.573	
Continue Block	3	0.340	0.215	0.340	*Men>>U21, U21< U19*
	2	0.018	0.042	0.004	*U21 > U19*
Free ball AA		0.532	0.518	0.525	
Dig AA		0.362	0.393	0.428	*Men<U19*

* *Inequalities indicate important differences between age categories: Age category A has lower success rates than age category B with posterior probability less than 0.01 ("A<<<B"). between 0.01 and 0.05 ("A<<B"). between 0.05 and 0.10("A<B").*

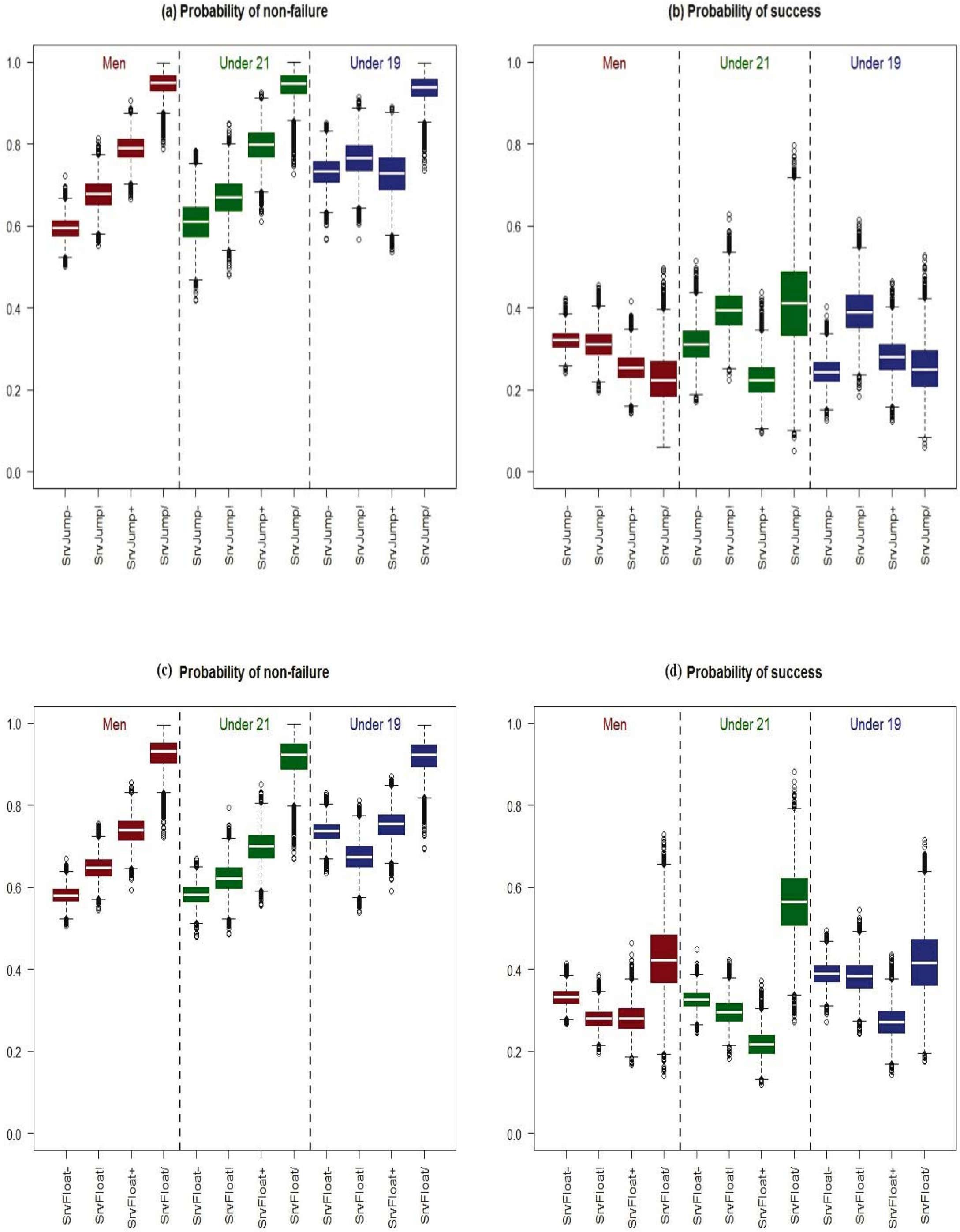

Figure 1. Box plots of the non-failure (a,c) and success (b,d) probabilities Pi according to the quality of Serve Jump & Serve Float for Men, U21 & U19.

Table 3. Posterior probabilities for differences of Pi between quick and high type of setting for attack of type 1 or 2.

Skills *(S_i)*	Sub-Skill	Men	U21	U19
Attack 1	LS	0.093*	0.324	0.121
	FRS	0.162	0.040**	0.000***
	BRS	0.073*	0.341	0.399
	MB	0.488	0.246	0.443
Attack 2	LS	0.051*	0.006***	0.002***
	FRS	0.411	0.002***	0.033**
	BRS	0.049**	0.416	0.000***
	MB	0.091*	0.206	0.243

The posterior probability Pi of quick tempo attacks to be higher than the P_i of high tempo attacks is lower than 0.01 (***), between 0.01 and 0.05 (**) and between 0.05 and 0.10 (*).

Table 3 presents the posterior probabilities for a difference of P_i between the quick and high type of setting for attack 1 or 2. In particular, attack 2 is affected more by the type of setting than attack 1, since in 8 out of 12 comparisons; important differences were traced (since the corresponding posterior distributions were away from zero). For the U19 team, the posterior differences were more striking than for the other age categories. For the Men's team, large differences were observed between quick and high type of setting for attack from Left Side (LS) and Back Right Side (BRS) for both attacks 1& 2 and Middle Back (MB).

Subsequently, the importance scores are used to estimate the impact of performance in a specific skill by also considering their uncertainty. Uncertainty is directly connected to the number of executions of each skill. The more often performed skills receive higher importance scores. As for the comparison of importance scores across teams or age categories, only ranking of importance scores should be compared. Passing skills have higher importance scores of all ages. For attacking and serving skills, there is not a stable scenario of ranking for each age. Results are summarized by focusing on importance scores and their relevance ranking for each level of every skill for the three age categories (see Table 4). The Spearman correlation indices of the importance scores for different age categories are Spearman's rho Men - U21= .907 (p=.000), Men – U19= .865 (p=.000) and U21-U19= .857 (p=.000) suggesting very strong relationships among skill rankings across different ages.

The posterior uncertainty of the success probabilities P_i for each skill S_i can be visualized in the boxplots of Figure 2. Outliers have been removed for clearer visualization. The corresponding box plots of skills of U21 & U19 age categories are provided in Figure 3 & Figure 4.

Table 5 presents the number of skills for each age category with negative skewness higher than 10%, 20% and 30% in terms of QMR. Since the number of skills with negative QMR skewness over 10% is high (22%, 10% and 15% of the total skills for U19, U21 and Men teams respectively), the value of 1.2 is selected as a threshold for reporting skills of potential interest due to unusually high negative skewness. Thus, 5% - 7% of the skill-rating combinations were identified as skills of potential interest due to QMR greater than1.2; see Table 6 for the full list of QMR.

Table 4. Importance scores Ii for each skill Si (skill rankings in brackets).

Skills (S_i)	Skills(sub)	Men		U21		U19	
SrvJump	2(-)	14.1	(14)	7.2	(23)	7.6	(21)
	3(!)	9.3	(24)	7.7	(22)	7.0	(23)
	4(+)	7.5	(32)	5.3	(34)	6.4	(28)
	5(/)	3.8	(44)	3.7	(42)	4.1	(39)
SrvFloat	2(-)	17.8	(8)	15.2	(8)	14.0	(8)
	3(!)	11.9	(17)	9.7	(17)	10.1	(18)
	4(+)	8.4	(27)	7.1	(24)	7.4	(22)
	5(/)	5.1	(39)	6.8	(28)	5.3	(33)
Continue BlockAS	3	6.3	(36)	6.1	(29)	6.4	(27)
	2	0.6	(49)	0.4	(49)	---	(49)
Free ball AS		15.4	(12)	12.3	(13)	11.9	(13)
Dig AS		15.8	(11)	11.7	(14)	10.7	(15)
Pass in Jump	2(/)	5.0	(40)	5.2	(35)	3.7	(40)
	3(-)	8.5	(25)	6.1	(30)	3.5	(42)
	4(!)	24.9	(5)	16.0	(7)	13.8	(9)
	5(+)	27.0	(4)	20.0	(4)	14.2	(7)
	6(#)	27.4	(2)	17.6	(5)	12.5	(11)
Pass in Float	2(/)	5.7	(37)	2.9	(44)	5.8	(29)
	3(-)	8.4	(28)	6.0	(31)	5.4	(32)
	4(!)	22.8	(6)	16.4	(6)	17.1	(4)
	5(+)	27.6	(1)	21.4	(2)	20.1	(3)
	6(#)	27.2	(3)	21.7	(1)	21.3	(2)
Attack 1	LS quick	17.2	(9)	14.2	(10)	22.6	(1)
	LS high	8.5	(26)	6.9	(27)	7.0	(24)
	FRS quick	13.9	(15)	14.4	(9)	16.6	(5)
	FRS high	4.4	(42)	4.1	(38)	2.8	(45)
	BRS quick	11.7	(18)	7.0	(25)	5.7	(30)
	BRS high	4.0	(43)	3.8	(41)	3.3	(43)
	MF quick	21.9	(7)	20.3	(3)	13.7	(10)
	MB quick	12.3	(16)	5.8	(32)	2.9	(44)
	MB high	6.4	(34)	1.0	(48)	4.9	(35)
	STR TIP	4.8	(41)	4.0	(39)	5.0	(34)
	OoS	6.7	(33)	4.8	(36)	4.9	(37)
Attack 2	LS quick	11.0	(19)	12.9	(11)	10.5	(17)
	LS high	6.3	(35)	7.0	(26)	4.5	(38)
	FRS quick	10.5	(21)	10.1	(16)	15.2	(6)
	FRS high	5.5	(38)	1.9	(45)	7.0	(25)
	BRS quick	9.9	(23)	3.9	(40)	12.4	(12)
	BRS high	3.4	(45)	3.3	(43)	1.3	(47)
	MF quick	10.2	(22)	9.6	(18)	10.0	(19)
	MB quick	7.5	(31)	7.9	(21)	5.5	(31)
	MB high	2.2	(47)	1.8	(47)	2.0	(46)
	STR TIP	3.1	(46)	4.4	(37)	3.6	(41)
	OoS	10.9	(20)	9.4	(19)	6.8	(26)
Direct attack		8.0	(29)	9.2	(20)	7.9	(20)
Continue Block AA	3	7.7	(30)	5.3	(33)	4.9	(36)
	2	1.2	(48)	1.8	(46)	0.4	(48)
Free ball AA		15.2	(13)	11.2	(15)	10.6	(16)
Dig AA		16.6	(10)	12.8	(12)	10.7	(14)

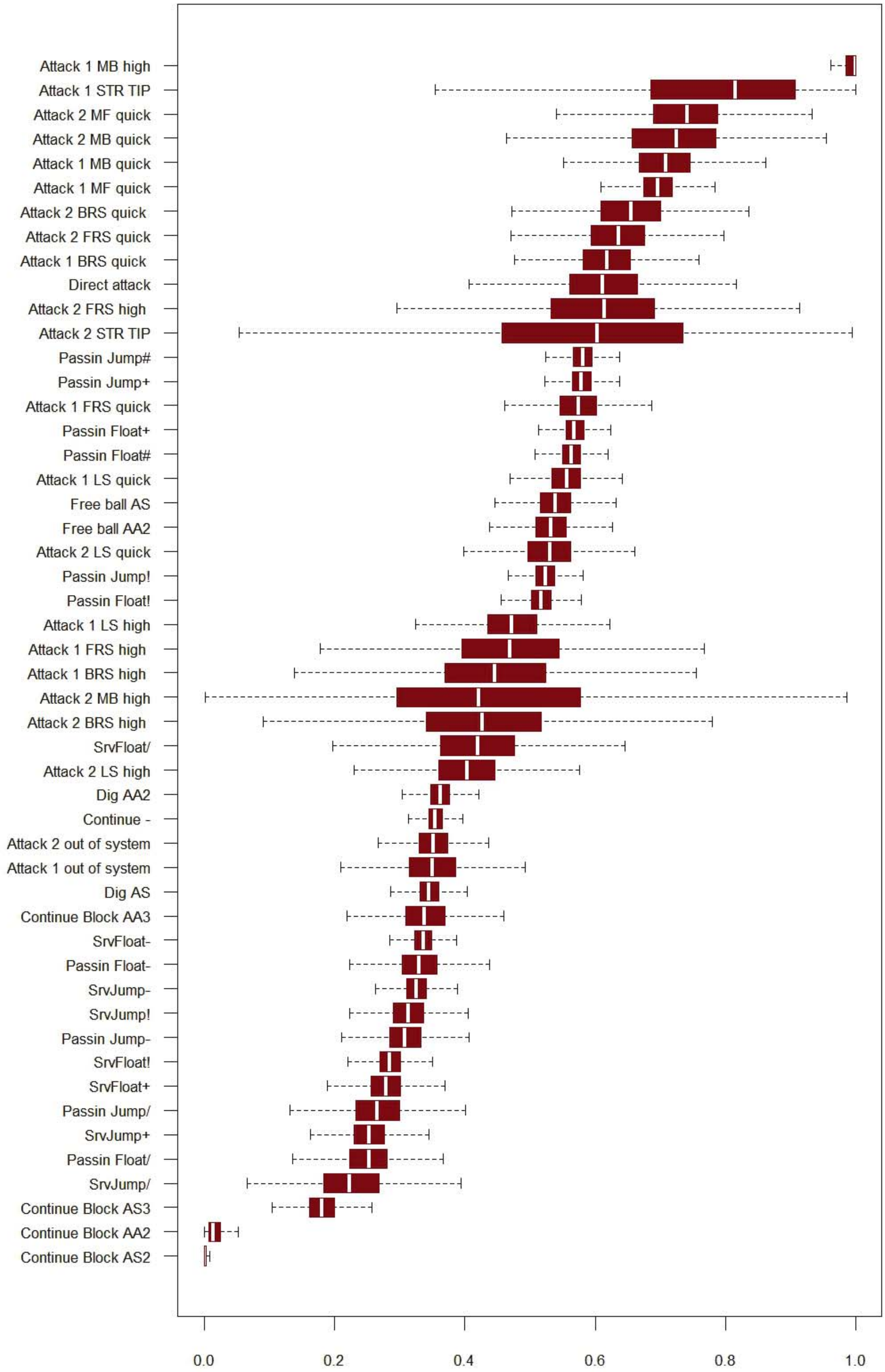

Figure 2. Box plots of the success probabilities Pi of each skill Si for men

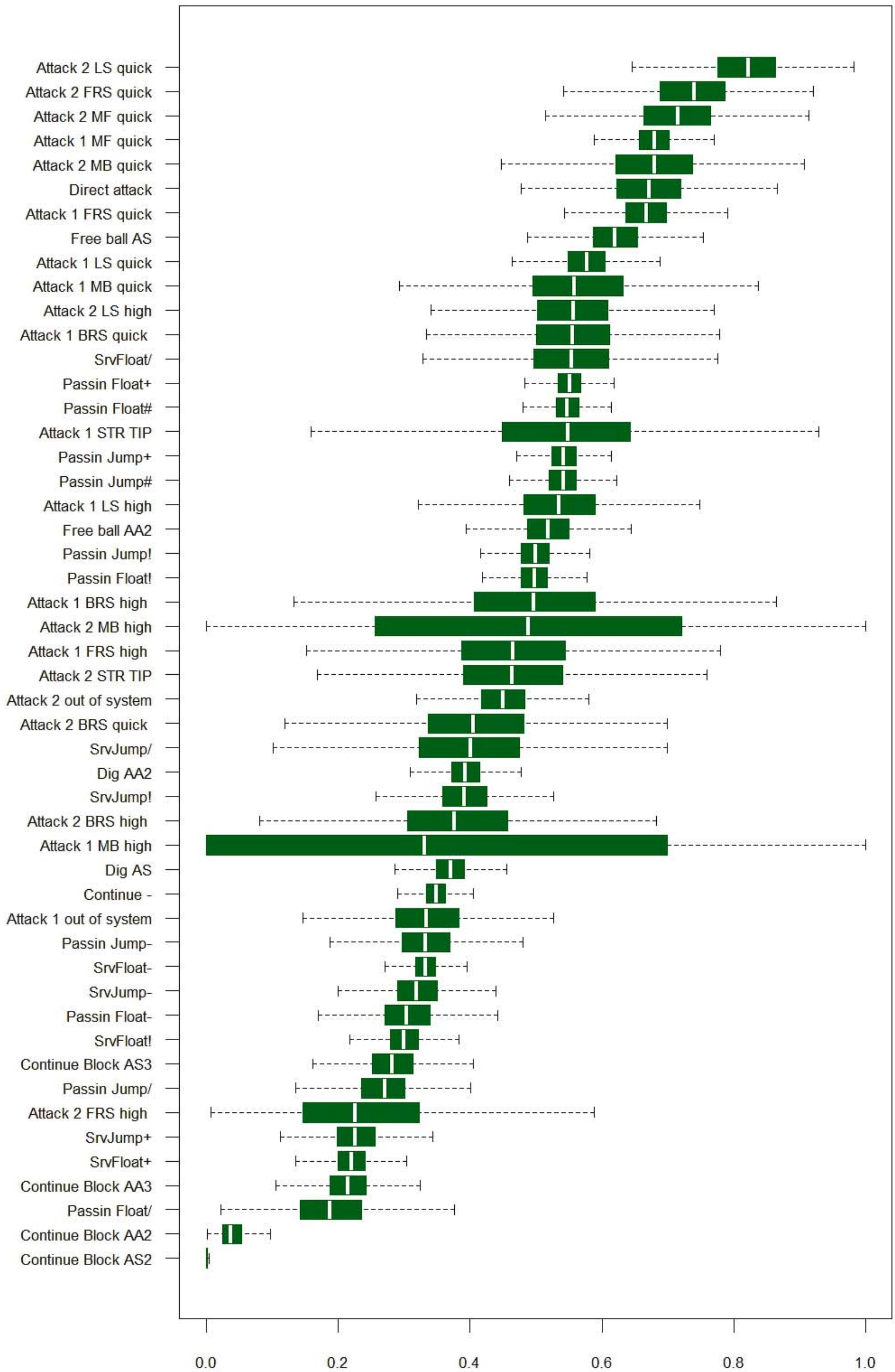

Figure 3. Box plots of the success probabilities Pi of each skill Si for U21

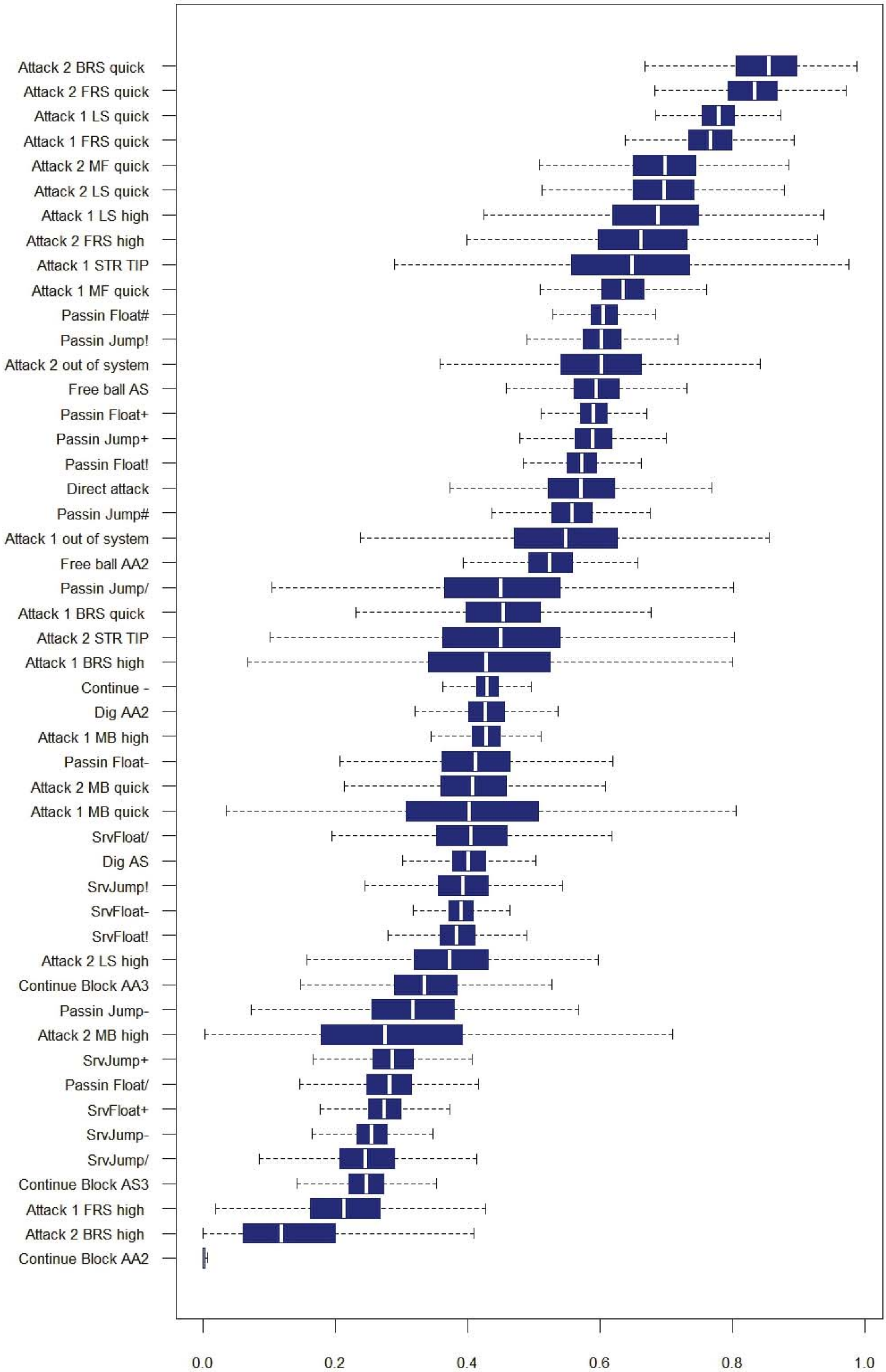

Figure 4. Box plots of the success probabilities Pi of each skill Si for U19

The U19 team demonstrated negative skewness in attack 1 high type of setting from the left side of the court and in attack 2 quick type of setting from both front and back right side. For the U21 team, negative skewness for attack 2 from the quick attacks of the wings of defensive zone was observed. In the Men's team, negative skewness was found for the attack performed from the middle (offensive & defensive) zone of court either with the high or quick type of setting and setter's attack. Finally, from all the levels of serve and pass, only a pass with two options for attack from a jump serve in the U21 team had negative skewness.

Table 5.Number of skills for each age category with 90% QMRvalues greater than 1.1, 1.2 and 1.3

QMR	MEN	U21	U19
>1.1	9	6	13
>1.2	3	3	3
>1.3	2	2	2

Discussion

The purpose of the current study was to determine the importance of detailed skills and skill sequences within each rally and to compare results across the World champions' teams of the three male age categories (youth-U19, juniors–U21 and men). Thus, the discussion is arranged with the aim to highlight the importance of each skill separately.

Starting with the ***serve***, all levels of float serves are more important than the corresponding levels of jump serves in all age categories. Also, serves (either float or jump) at level 2 have higher importance score than serves at levels 3 & 4. This is not only due to the nature of importance scores as was explained above. An easy serve of level 2 is executed more times than serves of level 3 & 4 during a match but the serving team maintains the right to fight for the point even if circumstances are against it since the ball was in its opponent with all attacking abilities. The examination of success and non-failure probabilities for serves reveals a characteristic finding: the difficulty of serve does not correspond with the outcome, i.e. the probability of winning the rally does not increase proportionally with the quality of the serve. Teams do not serve to increase their probability of winning the action, but they try to serve more effectively so as not to lose the action directly. This is sensible since the serve is reported as a disadvantage for the team that executes it for top-level men's volleyball (Kountouris et al., 2015; Pena, Rodriguez - Guerra, Busca, & Serra, 2012). In the present work, the findings suggest that this principle is also valid for the world champions in the other two age categories (U21 and U19 teams).

The importance of ***pass*** and complex 1 in men's volleyball is extremely high (Barzouka, Nikolaidou, Malousaris, & Bergeles, Perfomance Excellence of male Setters and attackers in Complex 1 and 2 on Volleyball teams in the 2004 Olympic games, 2006; Zetou, Moustakidis, Tsigilis, & Komninakidou, 2007). High-quality passes (evaluated as 4^{th}, 5^{th} and 6^{th} level of the scale) lie within the top-ten most important scores. For the U19 team, the *passing skill against jump serve* is not as highly ranked as in Men and U21 teams. Also for the U19 team, passing against float or jump serve with two options for attack (4^{th} level) has higher success probability than for U21 and Men. Additionally for the U19 team, the success probability of the *pass against jump serve* (0.60, 0.59, and 0.56 for 4^{th}, 5^{th}, 6^{th} level respectively) seems to be negatively associated with the accuracy of the pass. This may indicate a need for adjusting the passing rating system at least for the teams under consideration. This finding is in agreement with the ones suggested by Miskin et al. (2010) for a collegiate women's team.

Table 6. 90% QMR symmetry indexes (0.8>value>1.2 **in bold**)

Skills *(S_i)*	Skills(sub)	MEN	U21	U19
SrvJump	2(-)	0.924	0.858	0.893
	3(!)	0.884	0.934	0.937
	4(+)	0.893	0.814	0.975
	5(/)	**0.796**	1.029	0.824
SrvFloat	2(-)	0.967	0.953	0.961
	3(!)	0.878	0.903	0.933
	4(+)	0.919	0.853	0.904
	5(/)	0.948	1.064	0.930
Continue Block AS	3	0.865	0.835	0.971
	2	**0.083**	**0.005**	NaN
Free ball AS		0.976	1.028	1.073
Dig AS		0.938	0.937	0.970
Pass in Jump	2(/)	0.824	**1.347**	0.897
	3(-)	0.927	0.922	0.862
	4(!)	1.027	1.016	1.200
	5(+)	0.997	1.015	1.128
	6(#)	0.992	1.076	1.123
Pass in Float	2(/)	1.146	0.866	1.046
	3(-)	0.933	0.881	0.949
	4(!)	1.016	1.062	1.059
	5(+)	0.982	1.004	1.050
	6(#)	1.043	0.997	1.027
Attack 1	LS quick	1.049	1.044	1.148
	LS high	0.998	0.994	**1.228**
	FRS quick	1.000	1.098	1.139
	FRS high	0.915	0.922	0.847
	BRS quick	1.098	1.043	0.936
	BRS high	0.901	1.023	0.885
	MF quick	1.028	1.062	1.078
	MB quick	1.122	**0.778**	0.876
	MB high	**NA***	0.500	**NA***
	STR TIP	**2.093**	1.086	1.183
	OoS	0.878	0.861	1.041
Attack 2	LS quick	1.019	**1.359**	1.180
	LS high	0.942	1.035	0.888
	FRS quick	1.045	1.198	**1.322**
	FRS high	1.128	**0.625**	1.022
	BRS quick	1.132	0.896	**1.491**
	BRS high	0.879	**0.773**	**0.482**
	MF quick	**1.258**	**1.204**	1.156
	MB quick	**1.320**	1.153	0.896
	MB high	**0.797**	0.952	**0.677**
	STR TIP	1.128	0.929	0.899
	OoS	0.933	0.988	1.101
Direct attack		1.089	1.114	1.081
Continue Block AA	3	0.875	0.988	0.866
	2	**0.338**	**0.540**	**0.012**
Free ball AA		1.006	0.991	1.052
Dig AA		0.971	0.990	0.970

** NA: QMR is not reliably estimated due to a small sample (N≤1). Most of the variability of the distribution is due to the prior distribution.*

Moreover, the 2nd (overpass) and 3rd (pass off the net) levels of the passing scale have the same characteristics in all ages. The penalty for the overpass is higher than the penalty for pass off the net. On the other hand, if the ball is exactly on the net (pass level 6) the team advantage is minor compared to passes of level 5. An interesting research question that requires further attention is whether the ball from the passers should be directed a little bit further from the net (instead of the usual practice), especially when the team's setter is in the defensive zone (rotations 1, 6, 5) (Silva, Lacerda and Joao 2014).

Regarding *the* ***attack 1***, *quick tempo attack after serve's pass* is more important than *attack with high tempo*. This result consistently appears in all age categories. Furthermore, *front row attacks* are more important than *back row attacks*. However, there is a difference in men: The importance scores of *back-row attack from the right* side (i.e. the opposite player executes a shot) is closer, in terms of importance, to *the front row attack* (11.7 and 4.0 instead of 13.9 and 4.4 for quick and high tempo, back row/front row respectively), with a higher success probability for the first in quick tempo (0.62 instead of 0.58). This finding highlights the importance of an attack from the opposite for men's teams (Milian-Sanchez, Rabago, Hernadez, Femia Marzo, & Urena, 2015). The quick attack from the Middle Front zone (MF quick) is an effective attack for all the age categories with high success probabilities. But only the Men's team keeps this asset for Middle Back quick attack (MB quick), probably because of the complexity of the skill and the necessary synchronization between setter and attacker. *Attack 1 out of system* refers to attacks of any location and tempo when the setting does not come from the setter. For this type of attack, the U19 team has a higher probability of scoring a point (0.54) than Men and U21 teams (0.35 and 0.34 respectively). This finding, in conjunction with the limited importance of passing accuracy against the jump serve and the higher success probability in the pass with just two options for attack, implies that the difference between the U19 team and the men or U21 teams is due to the rhythm of the offensive game during complex 1. The U19 team must prepare better for a slower offensive tempo than more experienced teams. This is most likely because the game in this age is not yet well integrated, suggesting that the subsequent actions (e.g. attack) do not have high functional dependence relative to the previous ones (e.g. pass) (Costa et al., 2011; Garcia-de-Alcaraz, Valades, & Palao, 2017), which may be associated with the maturity process and the development of anthropometric and physical characteristics (Nikolaidis, Alfonso, Busko, Ingebrigtsen, Chtourou, & Martin, 2015). Notably, the attack of a setter has the highest success probability of all the rest of attacks 1, even though its importance score is smaller due to the increased variability of this skill. All levels of well-organized attacks 1 have higher importance scores than attacks 2. Clearly, this suggests that complex 1 skills and moves are of high importance for male volleyball games (Drikos & Tsoukos, 2018).

Attack 2 (or counterattack) is one of the main determinants of the final outcome in a Volleyball game (Zetou et al., 2006). *Attack out of the system* has the highest importance score (10.9, 9.4 and 6.8 for Men, U21 and U19 team respectively) compared to all the other high tempo attacks for all ages. It is one of the most important attack skills in complex 2. This result suggests volleyball coaches should spend more time working on plays when the setting is out of tempo (Stutzig, Zimmermann, Busch, & Siebert, 2015). Similarly to attacks 1 moves, setting quick tempo moves is more efficient than high tempo attacks for all ages. Concerning ***direct attacks***, the main finding is that their importance reduces with age. As direct attack and free ball are two skills that sometimes exclude one another, it is an interesting finding that direct attack in the age category of Men & U21 has higher success probabilities than free ball after serve or attack. Thus, if more experienced players have the opportunity to spike the ball directly from an overpass; they must prefer it to organize a counter-attack after the free ball.

Dig or free ball moves can take place in two situations: either when responding to the opponents' action or from a technical spike to opponent's block, when circumstances are not ideal for a powerful attack. In both complexes, such skills are ranked in positions between 10 and 20 concerning their importance scores.

The **QMR index** can help to identify skills with negative skewness but a lower importance index that still might have high success probabilities. *Quick tempo attack 2 from the middle* side of the court (with QMR 1.26 and 1.32 and importance ranks 22 and 31 for front and back positions respectively, but with success probabilities over 0.7) and *setter's attack 1* (with QMR 2.1 and 41 importance rank but success probability 0.78) for men are two examples. Similarly, for the U19 team, the *high tempo attack 1 from the left* side also has a high QMR value (1.28) with a relatively low importance score (24) but a high success probability (0.68). Concerning the quick *attack 2 from the middle,* it is a desirable but not common offensive strategy chosen by the setter because of a poor dig, as a first touch of the ball or poor coordination between setter and attackers. The setter's attack in the second touch of the ball is a skill executed rarely and only when the setter is in the front row (rotations 4, 3, 2) due to the rotation rule. All these skills have a high probability of scoring a point, even though their importance scores are not high, due to the large uncertainty of the skills. These skills have considerably smaller sample sizes than the rest of the skills but their contribution to the team's performance and efficiency is extremely important.

Conclusion

According to the present findings, the importance of volleyball skills for world champions' male teams across ages was found to be similar. Minor differences appear for the *pass against jump serve* skill for the U19 team, for *attack 1 from the opposite* player for men, for *attack* 2 *from back zone middle and right for men,* for *attack out of the system* for U19 and for *direct attack* for both the U21 and the Men teams. Concerning the pass rating system, further investigation is needed in order to reach firm conclusions and suggestions.

This type of analysis of such data provides a valuable insight into the importance of each skill for volleyball coaches, especially in national teams, in order to maximize the efficacy of practice time, in top-level volleyball, where it is limited. Other directions that require further attention are the study of the evolution of the game across genders and different levels of tournaments (local, national, international) and also the incorporation of past performance analysis data from a team as prior information.

To conclude, this study proposes an extended and thorough performance analysis system for ranking the importance not only of each volleyball skill but also of each quality level of the skills. These results should assist volleyball coaches in identifying important skills by age category to allocate training time and available resources more efficiently.

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