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Motor Structures in Female Volleyball Players Aged 14–17 According to Technique Quality and Performance

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ABSTRACT

The aim of the study was to identify motor structures in elite female volleyball players aged 14–17, and to assess the effect of these motor structures on their technical and situation efficiency. For this purpose, a battery of 12 motor tests as predictor variables, and a set of six technical elements and evaluation of performance quality as criterion variables were applied in a sample of 147 female volleyballers aged 14–15 and a sample of 50 female volleyballers aged 16–17. Analysis of variance between subgroups within the groups of volleyballers aged 14–15 and those aged 16–17 showed the results on all motor tests to improve with the increase in situation performance, which was especially pronounced in the tests assessing explosive strength and agility. The same held true for the results on all tests assessing volleyball techniques, spike and block in particular. In both samples, factor analysis of motor tests isolated two factors underlain by the generation and regulation of strength, and the mechanism of speed regulation. Canonical correlation analysis between the motor regulatory mechanisms and technical elements revealed determination of the mechanisms of strength and technical efficiency in both samples. Regression correlation analysis showed the mechanisms of strength regulation and speed to be good predictors of game performance in female volleyballers aged 14–15 and 16–17, whereby the mechanism of strength regulation had greater effect on the game performance than the mechanism of speed regulation. Regression correlation analysis also revealed the set of 6 techniques evaluated to be a good predictor of situation efficiency in both groups of female volleyballers aged 14–15 and 16–17. The block and spike techniques were found to be the best predictors of game performance quality in the former, and the techniques of spike and block in the latter. Based on the results obtained, a possible model of selection for supreme score achievement in female volleyball is described.

Key words: *female volleyball players, motor structures, European champions*

Introduction

Modern volleyball is characterized by a very high outreach of male and female volleyball players above the net and high ball velocity on jump service and spiking. A very high speed of reaction and agility are required to be able to control such balls on serve reception, especially in field defense. Many authors consider motor abilities, agility and explosive strength, along with pronounced longitudinal skeleton dimensionality, as the major characteristics for successful volleyball performance[1–9].

In Croatia, volleyball is the most popular sport among women, probably due to the following reasons:

- success of Croatian female teams at major international championships over the last 10 years (seniors as Europe vice-champions in 1995, 1997 and 1999; Croatian female volleyballers aged 16–17 as European champions 2003, and scored fifth at World Championship in 2004);
- the net separating the teams in volleyball prevents physical contact among the players; and
- attractiveness and dynamics of the game.

All this entailed establishment of a large number of volleyball clubs, some of them including hundreds of girls.

On training female volleyballers, it should always be kept in mind that training patterns differ substantially between male and female volleyball players. Weimin (1990)[10] points to the specificities in female training be-

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cause of psychic characteristics (emotionality, lower tendency to companionship as compared with men) and physiologic properties (higher articular mobility, lower muscular strength, higher fat percentage, etc.).

In the area of coordination, good results can be achieved as early as age 7–9 (not later than age 11). In the area of functional abilities, attention should in particular be paid to the development of aerobic capacity at age 14–16. As differentiated from boys, in whom endurance increases without much training, in girls it will decline unless submitted to systematic training.

Balyi (1999)[11] depicts four main periods in the volleyballer career. First is the period when training is done for fun (age 5–10). The main goal is to warm the children up to sports, at the same time creating the widest possible »sports base« which the specific volleyball knowledge will later be built upon. Second period (age 10–14) implies learning the fundamentals of volleyball technique and tactics. The knowledge acquired on training is applied in the game (initially mini-volleyball, then simple game systems with six players). Volleyball is an asymmetrical game predominated by one-hand performance (spike, service). This is especially pronounced in subsequent training periods, when these elements are further improved through numerous repeats. It is therefore of great importance in this stage to stimulate uniform bilateral muscular development (Paolini, 1999)[12]. Third period (age 14–18) is characterized by distribution of particular roles within the team (specialization). Technical and tactical training is adjusted to particular positions in the team. More complex systems including six players, with ever more pronounced game specialization are used at contests. In the fourth period (age 18 to the end of career), the main goal of training is to win at a contest. All effort is invested to upgrade all individual and team capacities to the highest possible level, thereby having to take the basic training principles in consideration so as not to cause any health impairment and to maximally reduce the possibility of chronic injuries in volleyball players.

Puhl et al. (1982)[6] measured some anthropometric characteristics, and motor and functional abilities of the volleyball senior male USA team (n=8) and female college USA team (n=14). The mean values in female volleyballers were: body height 178 cm; body weight 70.5 kg; adipose tissue 17.8%; high jump 46 cm; VO_2max 50.6 ml/kg/min; post-training lactate 8.20 mM.

Feris et al. (1995)[1] used a battery of tests for physical and physiologic variables (including hand extension in shoulder joint), also measuring maximal ball throwing velocity by a radar, in 13 female volleyball players. Results showed the strength of shoulder joint extension performed at a high speed to be the predominant physical variable correlating with ball throwing velocity. The throwing strength in female volleyballers can be improved by inclusion of exercises increasing the strength of shoulder joint extension, especially high speed exercises, in the training process. The game performance in volleyball can be upgraded by speed training focused on shoulder joint extensors.

Morales (2002)[4] had for years collected data on the Puerto Rico female volleyball team and USA college female volleyball players, and compared the results obtained on some anthropometric characteristics and motor abilities with game performance. Study results showed body height and agility correlate most closely with game performance, whereas the effect of jumping was less pronounced.

Among other findings, Stamm et al. (2003)[8] found the explosive strength of throwing (as assessed by throwing a medicine ball) to significantly correlate with spiking performance.

The aim of the present study was to identify the mechanisms responsible for the manifestation of motor abilities, i.e. agility, explosive strength and movement frequency, in female volleyball players aged 14–15 and 16–17, and to assess the level and significance of these mechanisms on the performance of specific motor skills, i.e. techniques as well as on the game performance. Thus, the contribution of particular technical-tactical volleyball elements, i.e. techniques to the overall game performance was determined, knowing that game efficiency is defined by the quality of each individual player.

Subjects and Methods

Subject sample

The study included 197 female volleyball players aged 14–17, members of volleyball teams from the Split-Dalmatia, Istria and Zagreb Counties. Study subjects were divided into two age groups aged 14–15 (N=147) and 16–17 (N=50).

Variable sample

Two sets of variables were used in both study groups, whereby motor variables represented the set of predictors, and performance of basic technical volleyball elements and evaluation of situation performance represented criterion variables.

Predictor variables

A set of variables consisting of 12 tests, i.e. 4 tests for evaluation of explosive strength, agility and movement frequency each, were employed for motor ability assessment. Testing was performed from April to June 2004. All teams were tested in the morning, in the same sequence according to circular schedule.

Tests used for explosive strength assessment:

- standing long jump – to jump as far ahead as possible with both legs from the spot;
- standing vertical jump – to take off with maximal strength with both legs and touch the board with closer hand at the highest jump point;
- approach vertical jump – to jump with both legs take-off after volleyball 3-step approach; and

- throwing medicine ball from supine position – to throw 1-kg medicine ball as far ahead as possible without lifting the head from the support and bending the elbows.

Tests for agility assessment were adopted from other studies as follows: 6x6 m run and 9-3-6-3-9 m run from Morales, 2002[4]; T-test from Vanderford et al., 2004[13]; and hexagon test designed by the American Tennis Association from Metikoš et al., 2003[14]. Hexagon test is also used by volleyball coaches, therefore it was important to verify its value in predicting results in female volleyball. The above listed tests can briefly be described as follows:

- 6x6 run – two parallel lines 6 m apart are marked on the support. The subject stands behind one line. On examiner's signal, the subject runs fast to the other line touching it with the ipsilateral palm and foot, and then returns fast to the first line touching it in the same way; it is repeated 6 times. The test is completed when the subject runs across the line from which he/she started;
- 9-3-6-3-9 m run – lines at 6-, 9-, 12- and 18-m distance from the start line are marked on the support. The subject stands behind the start line and runs on the signal to the 9-m line touching it with ipsilateral palm and foot; then returns 3 m back to touch the line in the same way; then runs 6 m ahead, then again 3 m back, and eventually runs fast to the line that is 18 m from the start line. The test is discontinued when the subject runs across the line that is at 18-m distance from the start;
- T-test – four cones are placed on the support as follows: first cone marks the start; second cone is placed 10 m ahead of the first one; third cone is placed 5 m right from the second cone, and fourth cone 5 m left from the second cone. On the examiner's signal, the subject runs forward from the first to the second cone, then side steps right to the third cone, then side steps left to the fourth cone, then side steps right to the second cone and run backwards to the first cone, thereby touching each cone with his/her hand. The test is discontinued when the subject touches the first cone; and
- Hexagon test – a hexagon with 60-cm sides at 120° angle is marked on the support. The subject stands within the hexagon. On the examiner's signal, the subject jumps out of the hexagon with both legs and turns back across the first side of the hexagon, then across the second side, etc., until completing three circles. The test is finished when the subject jumps back into the hexagon after three completed circles.

Tests for assessment of movement frequency:

- hand tapping – to tap with the fingers against tapping boards alternatively for 15 seconds; correct cycles during 15 seconds (1 cycle = 2 taps) are counted;
- double hand tapping – the same as above, only the tapping boards are tapped twice. If the board is tapped once, the cycle is not counted; if tapped more than twice, the cycle is counted;
- foot tapping – to roll one leg as fast as possible over the bar while tapping with the toes or the entire foot alternatively against the left and right side of the tapping boards; the number of regular taps in 15 seconds are counted; and
- foot tapping against the wall – a 20x20 cm square is marked on the wall or any other hard vertical surface, with the lower line of the square placed at 36 cm distance from the support; the square is double-tapped alternatively with the feet; only the taps touching the square twice or more are counted.

Criterion variables

A set of 6 variables were used for assessment of volleyball technical efficiency. The technique on performing the following six basic technical-tactical elements was evaluated on the 1–5 scale by the analysis of videorecords by six independent assessors (professors of kinesiology, volleyball specialists):

- service – volleyball court (9x9 m) is divided into 4 squares of 4.5x4.5 m; the player shoots the squares with 4 float services (short parallel, long parallel, short diagonal, long diagonal);
- serve reception – the server serves from zone 1 two light serves to zone 5, then two serves to zone 1 (to the 4.5x4.5 squares marked for service); the player stands in the zones, trying to receive serve by forearm pass to the setting zone; the player receives only the serves that have been precisely shot, slightly arched;
- setting – from zone 3, the coach (standing at 1 m from the net, on the line separating the left and the right anterior square) throws four balls to the player for setting; first ball is thrown to zone 2 and set to zone 4; second ball is thrown to zone 1 and set to zone 4; third ball is set from zone 5 to zone 2; and fourth ball is set from zone 4 to zone 2; all settings are performed in front of the head;
- spike – the coach throws four balls with both hands from the setting zone from below to zone 4 (for left-handed players to zone 2); two balls are spiked diagonally and two along the line;
- block – the player simulates block in zone 3, then moves to zone 2 where she blocks the ball thrown by the coach sitting on the bench by handball shot to her hands; this is repeated once again, followed by two blocks from zone 3 to zone 4; and
- field defense – the coach stands at the net in zone 2 (with his back to the net); the player stands in the middle of the square in zone 1; the coach throws two balls sharply to 0.5–1 m in front of the player, who played the ball by sprawl, then throws 2 balls ahead from below to zone 2; the player performs right roll, then left roll.

Situation performance of female volleyball players was assessed by one variable based on team quality and individual player quality within the team:

- team quality – teams were ranked according to quality into 3 groups (Table 1, column 1) as follows: group 1 including elite teams of the respective age group (with contest placing as the criterion); group 2 including medium quality teams; and group 3 including low ranking teams.
- individual player's quality within the team – according to this criterion, the coaches categorize their team players into 3 groups: group 1 including leading team players (1–3); group 2 including the rest of A team players and players entering the game, thus contributing to team result (3–6); and group 3 including players who very rarely or never enter the game.

Using a combination of these assessments, i.e. team quality and individual player's team quality, each player's performance is scored 1–5, as illustrated in Table 1.

TABLE 1
CRITERIA FOR RANKING PLAYERS ACCORDING TO QUALITY

Team quality	Player's quality within the team (evaluated by coaches)		
	Group 1	Group 2	Group 3
Group 1	5	4	3
Group 2	4	3	2
Group 3	3	2	1

The players taking active part in national team of the respective age group are scored 5 and 4, even if ranked as group 3 members. Table 1 shows that there is only one combination for a player to be scored 5 and 1, two combinations to be scored 4 and 2, and three combinations to be scored 3; thus, the variable obtained can be presumed to have normal distribution. This method of performance evaluation is simple, reliable and objective, therefore this original approach to quality assessment has also been proposed for use in other sports.

Data analysis

The basic descriptive parameters of motor variables were calculated first (arithmetic mean and standard deviation) for the study sample as a whole and for each group of study subjects according to their performance quality (score 1–5). In line with the aim of the study, factor analysis of predictor, i.e. motor variables was used first for each group of subjects as varimax rotation of the significant main components of intercorrelation matrix. Correlation between the set of predictor latent motor variables and set of criterion variables (assessment of particular technical elements) was determined by canonical correlation analysis using Hotelling procedure for each group of study subjects. Regression correlation analysis was employed to determine correlation between the set of isolated motor factors and the criterion variable of performance, and between the quality of technique and performance, i.e. playing quality. Partial coefficient of regression (β), coefficient of multiple correlation between the set of predictors and the criterion (ρ), and level of significance of regression coefficients and multiple correlation were calculated.

Results and Discussion

In female volleyball players aged 14–15, results on all tests assessing motor abilities improved with enhanced situation performance, as illustrated in Table 2. These differences were most pronounced on the tests for explosive strength assessment, followed by tests for assessment of agility, and least pronounced on tests assessing movement frequency (except for hand tapping). It should be noted that reverse scale is used in all tests for agility assessment (time variables).

Comparison of the results achieved by female volleyballers of different situation performance revealed great increase in the tests for explosive strength and agility assessment between the groups scored 1 and other groups, even including the group whose situation performance was scored only one point superior.

On the other hand, the players scored 5 showed better results in comparison with all other groups on all tests assessing motor abilities, except for foot tapping against the wall. Greatest differences were recorded on the tests assessing jump and throw explosive strength. The results obtained in volleyball players scored 5 can serve as model values for the 14–15 age group.

Table 2 also shows basic parameters of the variables for assessment of volleyball techniques, the quality of which was evaluated by six volleyball coaches. All groups of players achieved lowest scores on the test assessing defense technique. Thus, coaches could be advised to pay more attention to mastering the technique of these elements during the training process (sprawl, forward roll).

The increase in the players' performance quality entailed improvement of results on all tests for assessment of volleyball techniques. The most successful players showed remarkable serve reception, spike and block techniques. The spike and block techniques could be postulated to be mostly integrated motor abilities (explosive strength and agility) in most elite players of this age, allowing them to swiftly change movement direction (blocking), to realize contact with the ball high above the net (spike and block), and strong shooting (spike).

Table 3 presents descriptive parameters of the variables for assessment of motor abilities and assessors' evaluation of the volleyball elements technique performance. The table also shows mean values of the tests for assessment of motor abilities and technique performance of female volleyball players aged 14–17 according to their situation performance.

Analysis of the motor test results revealed the results of tests assessing agility and explosive strength to improve with the increase in situation performance, which did not hold for tests assessing movement frequency. At this age, explosive strength and agility obviously contrib-

TABLE 2
BASIC DESCRIPTIVE PARAMETERS OF VARIABLES (X ± SD) FOR THE SAMPLE OF FEMALE VOLLEYBALL PLAYERS AGED 14–15 AND ANALYSIS OF VARIANCE BETWEEN PLAYER GROUPS OF DIFFERENT SITUATION EFFICIENCY (SCORE 1–5)

Variable	X±SD (N=147)	X				
		1	2	3	4	5
Standing vertical jump	38.07±6.64	32.66	39.47	40.85	44.29	46.09[b]
Aproach vertical jump	40.97±7.38	35.12	42.43	44.02	47.41	50.09[b]
Standing long jump	195.00±20.63	178.83	204.50	202.74	209.41	212.45[b]
Medicine ball throw	785.71±131.3	688.05	798.67	853.33	859.41	975.91[c]
T-test	12.77±0.97	13.44	12.71	12.37	11.96	11.77[b]
6×6 m run	11.68±0.81	12.15	11.46	11.50	11.21	11.02[a]
9-3-6-3-9 m run	9.28±0.67	9.80	9.14	8.95	8.72	8.68[a]
Hexagon	13.12±1.91	13.45	12.83	13.14	12.99	12.30[a]
Hand tapping	33.80±3.99	31.24	34.03	35.37	36.65	38.27[a]
Double hand tapping	17.54±2.00	16.64	17.70	18.20	18.47	18.64
Foot tapping	40.76±2.86	39.71	41.47	41.17	41.65	42.00
Wall foot tapping	22.65±2.60	21.97	23.43	22.83	24.18	23.27
Service	2.94±0.99	2.35	2.52	3.16	3.62	3.76[a]
Serve receiving	3.19±0.90	2.95	2.91	3.22	3.41	4.06[b]
Setting	3.15±0.87	2.55	2.87	3.38	3.61	3.89[b]
Spike	2.90±0.94	2.03	2.67	3.07	3.42	4.24[c]
Block	2.99±0.84	2.25	2.75	3.10	3.54	4.21[c]
Field defense	2.62±1.01	1.95	2.44	2.81	3.01	3.48[a]

[a]p<0.05, [b]p<0.01, [c]p<0.001

TABLE 3
BASIC DESCRIPTIVE PARAMETERS OF VARIABLES (X ± SD) FOR THE SAMPLE OF FEMALE VOLLEYBALL PLAYERS AGED 16–17 AND ANALYSIS OF VARIANCE BETWEEN PLAYER GROUPS OF DIFFERENT SITUATION EFFICIENCY (SCORE 1–5)

Variable	X±SD (N=50)	X				
		1	2	3	4	5
Standing vertical jump	40.84±5.91	35.43	41.80	42.27	45.80	47.00[b]
Aproach vertical jump	43.47±6.51	37.07	45.10	44.73	48.80	51.75[b]
Standing long jump	206.3±16.8	187.93	209.50	214.07	218.60	222.50[b]
Medicine ball throw	854.7±118.8	780.00	825.00	868.67	898.00	1080.0[c]
T-test	12.40±0.97	13.51	12.20	12.01	11.71	11.41[a]
6×6 m run	11.32±0.66	11.82	11.39	11.13	10.69	10.74[a]
9-3-6-3-9 m run	9.04±0.71	9.85	8.88	8.81	8.33	8.29[a]
Hexagon	12.49±1.87	12.94	12.56	12.88	12.12	9.98[a]
Hand tapping	35.37±2.97	33.43	35.80	36.53	36.00	36.00
Double hand tapping	18.33±1.76	18.07	18.10	18.40	18.20	19.75
Foot tapping	42.57±3.35	40.57	42.10	44.13	43.40	43.50[a]
Wall foot tapping	24.47±2.53	23.43	24.70	25.00	25.40	24.50
Service	3.45±0.96	2.85	2.97	3.71	4.50	4.25[a]
Serve receiving	3.25±0.83	3.00	2.93	3.40	3.75	3.92[a]
Setting	3.53±0.78	2.90	3.38	3.79	4.00	4.38[b]
Spike	3.38±0.84	2.42	3.18	3.77	4.06	4.42[c]
Block	3.27±0.76	2.48	3.28	3.37	3.58	4.46[c]
Field defense	2.94±0.77	2.72	2.59	3.03	3.29	3.75[a]

[a]p<0.05, [b]p<0.01, [c]p<0.001

uted significantly to group differentiation according to situation performance. Analysis of the rise in the results between adjacent groups yielded highest differences between the groups scored 1 and 2.

Improvement in the technique of all volleyball elements with the increase in situation performance was also recorded in case of variables assessing the quality of technique of volleyball elements. All groups except the one scored 1 had lowest mean values on the test assessing the techniques of field defense. The players scored 1 had lowest mean values on the tests assessing the spike and block techniques. On the other hand, the most successful group showed very high mean values of the quality of technique of all volleyball elements, with highest scores for spike and block. This is highly important, as spike and block are the elements bringing highest scores at contests. It could be postulated that the high quality technique of these elements contributed to the efficient game performance, i.e. highest scores at contests, in the most successful group of players. It also seems likely that, the least successful players make numerous errors, thus losing score at contests, due to the poor technique of these very elements.

It is concluded that elite female volleyball players aged 16–17 are characterized by prominent explosive strength and agility, along with good technique of all volleyball elements. The results of the volleyball players scored 5 (situation performance) could be used as model values for female volleyballers the respective age group, as these players have achieved top results, i.e. European Championship 2003 and fifth place at World Championship 2004.

Analysis of differences between age groups revealed the female volleyballers aged 16–17 to be significantly superior to those aged 14–15 on all motor tests. Differences between these two age groups on all tests assessing movement frequency (due to the great genetic determination of psychomotor speed) could not be explained by the impact of training process, but must have been due to the process of selection. In contrast, significant differences between the 14–15 and 16–17 age groups in all variables for assessment of explosive strength and agility could be explained by the process of selection as well as by the influence of training process.

The pronounced explosive strength and agility should be seriously considered in the process of selection, because these are mostly genetically determined and show positive correlation with contest performance. Yet, in contrast to movement frequency, these abilities can also be influenced upon after puberty, generally through the component of force.

The female volleyball players of various age groups differed significantly in all variables for assessment of the quality of technique of volleyball elements. It was expected because a high quality technique is a precondition for top contest results. Also, a quality technique allows the players to maximally use their motor abilities.

Volleyball elements are technically very demanding, especially those performed on jump (spike, block, service and jump set). A great number of repeats over years of training are required for the technique of volleyball elements to maximally improve and become automatic. Therefore, it is no surprise that significant changes in the quality of the serve, setting and spike techniques occurred at the turn between the two age groups (14–15 and 16–17 years).

In the group of female volleyballers aged 14–15, factor analysis of motor variables isolated two factors that accounted for some 69% of the overall system variance (Table 4). The variables assessing explosive strength and those assessing agility exerted pronounced projections upon the first factor isolated by factor analysis. The speed of upper extremity movements in terms of swing on take-off and stretch of the upper legs and trunk had a favorable impact especially on jump performance. Accordingly, the first factor integrated explosive strength and agility into a unique factor responsible for generating maximal force on solving specific motor tasks in volleyball (for example, spike and block). The mechanism of force regulation is the basis of motor functioning in young female volleyball players and is closely related to the game requirements (explaining as much as 46% of total system variance).

The second factor isolated by factor analysis was defined by high and intermediate projections of the variables assessing movement frequency. This factor is underlain by the mechanism of speed regulation and accounts for 23% of overall system variance. This factor is better defined by the frequency of lower extremity movements, which is to a certain extent related to agility tests. It should be noted herewith that the test intended

TABLE 4
FACTORIAL STRUCTURE OF MOTOR VARIABLES

Variable	Players aged 14–15 (N=147)		Players aged 16–17 (N=50)	
	F1	F2	F1	F2
Standing vertical jump	0.90	0.22	0.93	–0.03
Aproach vertical jump	0.90	0.21	0.94	0.05
Standing long jump	0.83	0.25	0.81	0.20
Medicine ball throw	0.79	0.19	0.65	0.24
T-test	–0.85	–0.26	–0.76	–0.45
6×6 m run	–0.77	–0.34	–0.58	–0.58
9-3-6-3-9 m run	–0.84	–0.31	–0.77	–0.48
Hexagon	–0.12	–0.60	–0.05	–0.62
Hand tapping	0.56	0.48	0.48	0.40
Double hand tapping	0.34	0.63	0.20	0.32
Foot tapping	0.25	0.77	0.15	0.63
Wall foot tapping	0.19	0.84	0.08	0.80
Lambda	5.48	2.76	4.64	2.56
Variance %	45.70	23.00	38.33	21.33

for agility evaluation (hexagon) is a quite reliable test for movement frequency, as demonstrated on factor analysis carried out in the sample of female volleyball players aged 16–17.

The results obtained are consistent with those reported by Katić et al. in 2004[15], showing the developmental processes in elementary school female fourth-graders to lead to the formation of two general mechanisms responsible for motor efficiency in the form of force regulation and speed regulation. The authors conclude that the 11-year-old girls have obviously entered the stage of development in which the morphological-motor system elements have reached an optimal inter-relationship and a higher, relatively stable level.

Thus, two basic mechanisms of motor functioning were established in the group of female volleyball players aged 14–15. The first mechanism, defined by the first factor isolated, is responsible for force regulation, as especially notable on forceful movements whereby a large amount of muscle units are being activated *per* time unit, and requires functioning of the centrally, i.e. cortically located mechanisms. In volleyball, this is best exemplified by spike which, like any acquired specific motor knowledge, integrates a number of different movements and/or routines into a unique entity, which requires fine regulation of the muscle unit excitation/inhibition and sequence of their induction. The second mechanism, defined by the second factor isolated, is responsible for speed regulation, which manifests in the frequency of movements or speed of performing a single movement, upon abolishing (partializing) the impact of energy component upon these movements. The mechanisms of information flow rate, i.e. serial information processing, are primarily responsible for the psychomotor speed.

As motor activities are complex ones, both mechanisms are always present, however, at a varying ratio, implying the existence of a superior mechanism controlling and regulating the activity of subordinate mechanisms, in this case force and speed. So, in the study by Katić (2003)[16], a unique motor taxon responsible for overall motor effiiciency was determined in girls as young as 8 years of age.

In the female volleyball players aged 16–17, the factorial structure of motor variables was found to be comparable to that determined in the players aged 14–15, however, with some substantial differences that could to a considerable extent be ascribed to volleyball training. During the process of learning specific motor skills, the contribution of individual basic motor abilities in performing these motor skills varies, among others because particular motor abilities bear greater burden in the overall motor functioning during a particular stage of development.

The first motor factor isolated was predominantly defined by the variables assessing explosive strength at jump, followed by the variables of agility, and to a minor extent the variables of upper extremitiy movement frequency. Such a motor structure accounted for more than 38% of the sample variability, and could be related to particular specific motor skills and abilities in volleyball (on spike, block and serve performance), thus yielding the following order of relevance: explosive strength at vertical jump, agility in terms of fast multidirectional movement, explosive strength in terms of ball throwing, and speed of upper extremity movements in terms of hand tapping. It should be noted that run or movement to the position of take-off is part of performing the mentioned technical-tactical elements, which strongly points to the importance of agility in the performance of forceful movement structures.

The second factor isolated was defined by the variables for assessment of lower extremity movement frequency, the variables for assessment of agility, and to a minor extent by the variables of upper extremity movement frequency. Such a motor structure integrating the speed of lower extremity movements and agility accounted for more than 21% of the sample variability, and could be related to particular technical-tactical elements associated with defense.

Upon identification of the mechanisms of motor functioning according to age in volleyball players aged 16–17, the relations of these mechanisms with technical and situation efficiency of the players were studied. The association of the mechanisms of force and speed regulation with the volleyball technique performance was determined by use of canonical correlation analysis, which yielded one significant canonical correlation in each of the two subject samples (Table 5). Canonical correlation of these two sets of variables was quite high (0.80) in the sample of volleyball players aged 14–15 and somewhat lower (0.64) in the sample of volleyball players aged 16–17.

The canonical factor isolated from the set of latent motor variables in the samples of female volleyballers aged 14–15 and 16–17 was defined by maximal saturation with the mechanism responsible for force regulation. The canonical factor isolated from the set of vari-

TABLE 5
CANONICAL CORRELATION ANALYSIS BETWEEN LATENT MOTOR VARIABLES AND TECHNIQUE VARIABLES

Players aged 14–15 (N=147)		Players aged 16–17 (N=50)	
Variable	CAN1	Variable	CAN1
Force	–0.94	Force	–0.98
Speed	–0.12	Speed	–0.18
Service	–0.56	Service	–0.46
Serve receiving	–0.61	Serve receiving	–0.41
Setting	–0.82	Setting	–0.91
Spike	–0.88	Spike	–0.75
Block	–0.86	Block	–0.58
Field defense	–0.64	Field defense	–0.30
CANR	0.80[c]	CANR	0.64[a]

CAN – canonical variable, CANR – canonical correlation
[a]p<0.05, [b]p<0.01, [c]p<0.001

ables of volleyball technique followed a pattern of a general factor of technical efficiency, i.e. adoption of specific motor skills in volleyball, in both study samples. In both study samples, the association between the two canonical factors obtained was underlain by general determination of the motor mechanism of force regulation and technical efficiency in volleyball. The techniques of spike, block and setting contributed most to canonical correlation in the area of technique variables in the players aged 14–15, and those of setting, spike and block in the players aged 16–17. Accordingly, the latter predominantly used the ability of force generation and regulation on setting, whereas the former used the same ability predominantly and uniformly on spiking, blocking and setting. The techniques of spike and block could be presumed to be mastered at a faster rate than the technique of setting, and setting to be most energy demanding in terms of integration of the motor abilities of explosive strength and agility, also saturated by psychomotor speed in the players aged 16–17.

The association of the mechanisms of force and speed regulation with situation efficiency, i.e. their performance, was determined by use of regression correlation analysis (Table 6). The mechanisms of force and speed regulation were found to be a good predictor of performance quality in both samples of volleyball players. However, the contribution of predictor variables with the criterion was more pronounced in the 14–15 age group (ρ=0.74) than in the 16–17 age group (ρ=0.60), suggesting that some anthropologic features not considered in this study (morphological, functional, cognitive and conative) gained importance in the game performance of the latter.

TABLE 6
REGRESSION ANALYSIS OF SITUATION PERFORMANCE IN LATENT MOTOR AREA

	Players aged 14–15 (N=147)	Players aged 16–17 (N=50)
Factor	β	β
Force	0.72^c	0.52^c
Speed	0.17^b	0.29^b
ρ	0.74^c	0.60^c

β – regression coefficient, ρ – multiple correlation
$^a p<0.05$, $^b p<0.01$, $^c p<0.001$

In both samples of volleyball players, the mechanism of force regulation had a considerably greater impact on their game performance than the mechanism of speed regulation, as also demonstrated in previous analyses. Comparison of regression coefficients between the players aged 14–15 and 16–17 showed the relationship between the force and speed mechanisms in the prediction of performance to be also modified with the development of game performance. Thus, the force to speed ratio could be postulated to be 4:1 and 2:1 in the players aged 14–15 and 16–17, respectively. With the development of game performance, an optimal relationship of all relevant anthropologic complex subsegments influencing the score in volleyball is being established, whereby two motor structures play a major role in situation efficiency, i.e. in game performance. The first structure is predominated by explosive strength, followed to a certain extent by agility and psychomotor speed, whereas the second structure is predominated by psychomotor speed (in the form of lower extremity movement frequency), followed by agility. Study results revealed that solving of game situations predominated by the first motor structure based on the mechanism of force regulation had a greater contribution to game performance (e.g., spike, block and setting) than the situations predominated by the second motor structure based on the mechanism of speed regulation (e.g., serve receiving and field defense). Obviously, volleyball is a complex activity determined by manifold functioning of a number of cortically located mechanisms, whereas technique adoption and its integration in the anthropologic complex is a longterm process proceeding concurrently with the process of selection for this particular sport.

Having introduced technique structure in the motor area, it was of utmost importance to determine the impact of particular volleyball techniques on the situation efficiency of female volleyball players, in order to get a comprehensive insight into the parallel development of the basic motor abilities and specific motor skills relative to the development of game performance. The set of 6 evaluated techniques was found to be a very good predictor of situation efficiency in both 14–15 and 16–17 age groups of female volleyball players (Table 7). Game performance improved with the technique quality upgrading. So, multiple correlation of the set of predictors with the criterion increased from 0.79 in the players aged 14–15 to 0.84 in those aged 16–17.

The block and spike techniques were the best predictors of game performance in the group of female volleyballers aged 14–15, and the techniques of spike and block in those aged 16–17. These results indicate the se-

TABLE 7
REGRESSION ANALYSIS OF SITUATION PERFORMANCE IN VOLLEYBALL TECHNIQUE AREA

Technique	Players aged 14–15 (N=147)	Players aged 16–17 (N=50)
	β	β
Service	0.16^a	0.15
Serve receiving	–0.11	0.06
Setting	0.04	0.03
Spike	0.35^c	0.45^c
Block	0.43^c	0.35^b
Field defense	0.03	–0.02
ρ	0.79^c	0.84^c

β – regression coefficient, ρ – multiple correlation
$^a p<0.05$, $^b p<0.01$, $^c p<0.001$

quence and rate of learning particular volleyball techniques, which is closely related to the respective technique complexity. After having learned the techniques of serve receiving and service to a certain extent, the players aged 14–15 mastered the block technique, followed by adoption of the spike technique in elite players aged 16–17. The selection of players from the 16–17 age group to junior team is based on the spike and block technical efficiency. Upon selection according to the spike and block technical efficiency to junior team (or national team), the players will show less variation in these technical elements, which will not have a predominant effect on their game performance anymore but will probably be replaced by the techniques that are most demanding in motor terms, i.e. the techniques of field defense and jump service.

Conclusion

The results obtained in the present study illustrated the formation of ideal motor complexes in female volleyball across the 14–15 and 16–17 age groups. Motor complexes were related to technical and situation efficiency, describing two types of female volleyballers, i.e. those more efficient at the net (explosive strength + agility) and those more efficient in the field (psychomotor speed + agility). Also, model values of motor tests and scores on technique elements were obtained in (elite) female volleyball players aged 14–15 and 16–17.

Based on the results collected in the present study and those reported by Katić et al. 2001[17], Katić 2003[16] and Katić et al. 2005[18] on the motor development in general, a model of selection in female volleyball could be established, which should be performed stepwise, as follows:

- at age 9, selection should be based on psychomotor speed and coordination on solving complex motor problems. These motor abilities will ultimately limit elite game performance: psychomotor speed by facilitating technique performance, and coordination and/or motor intelligence through faster motor learning and efficient solution of game situations;
- at age 11, selection should be based on coordination in terms of agility and explosive strength facilitating performance of basic technique elements, e.g., service and serve receipt;
- at age 13, selection should be based on explosive strength and agility that facilitate performance of techniques, e.g., block and spike;
- at age 15, selection should be based on specific motor abilities that are primarily related to body height, strength and spike precision, i.e. specific explosive strength and specific agility-mobility; and
- at age 17, selection should be done by evaluation of all specific motor abilities, especially specific speed and specific agility-mobility, enabling elite female volleyballers to efficiently manage all possible game situations and facilitate their technique performance, especially those in field defense.

The timing of particular selection steps should be considered approximative, due to specificities and variation in the quality of various national teams as well as individual differences among players from these teams in both their quality and rate of quality development.

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MOTORIČKE STRUKTURE MLADIH ODBOJKAŠICA U ODNOSU NA KVALITETU TEHNIKE I USPJEH U IGRI

S A Ž E T A K

Cilj istraživanja je identificirati motoričke strukture vrhunskih odbojkašica-kadetkinja i utvrditi utjecaj tih motoričkih struktura na tehničku i situacijsku efikasnost. U tu svrhu na uzorku od 147 odbojkašica starosne dobi 14–15 godina i uzorku od 50 odbojkašica starosne dobi 16–17 godina primijenjen je skup od 12 motoričkih testova kao varijabli prediktora i skup od 6 elemenata tehnike i procjena igračke kvalitete kao varijabli kriterija. Analizom varijance između grupa odbojkašica različite situacijske uspješnosti, a unutar pojedinih dobnih skupina utvrđeno je da s porastom situacijske uspješnosti se poboljšavaju rezultati u svim motoričkim testovima, a posebno u testovima za procjenu eksplozivne snage i agilnosti, kao i rezultati u svim testovima za procjenu odbojkaških tehnika, posebno smeča i bloka. Faktorska analiza motoričkih testova kod oba uzorka odbojkašica je izolirala dva faktora u osnovi kojih su mehanizam za generiranje i regulaciju sile i mehanizam za regulaciju brzine. Kanonička korelacijska analiza između motoričkih regulacijskih mehanizama i elemenata tehnike je kod oba uzorka utvrdila determiniranost mehanizma za regulaciju sile i tehničke efikasnosti. Regresijska korelacijska analiza je utvrdila da su mehanizmi za regulaciju sile i brzine dobri prediktori igračke kvalitete kod odbojkašica starosne dobi 14–15 godina i kod odbojkašica starosne dobi 16–17 godina, s tim da mehanizam za regulaciju sile u odnosu na mehanizam za regulaciju brzine, ima znatno veći utjecaj na igračku kvalitetu. Regresijska korelacijska analiza je također utvrdila da je skup varijabli od 6 procijenjenih tehnika dosta dobar prediktor situacijske efikasnosti kako kod mlađe tako i kod starije skupine odbojkašica, pa su najbolji prediktori igračke kvalitete kod mlađe skupine tehnike bloka i smeča, a kod starije skupine smeč i blok. Temeljem rezultata opisan je mogući model selekcije za postizanje vrhunskih rezultata u ženskoj odbojci.