MOVEMENT DIRECTION ANALYSIS IN ELITE INDOOR VOLLEYBALL MATCH

Mikuláš Hank[1], Tomáš Malý[1], František Zahálka[1], David Novotný[2], Tomáš Gryc[1] and Pavel Hrásky[1]

[1]Charles University, Faculty of Physical Education and Sport, Prague, Czech Republic,
[2]Visual Geometry Group, University of Oxford, Oxford, United Kingdom

Original scientific paper

Abstract
This study aimed to evaluate directional properties of elite indoor volleyball player's movement. Fourteen elite female players (age = 25 ± 6 years; body height = 182.3 ± 6.2 cm; body mass = 72.1 ± 5.8 kg) were used for 3D kinematic analysis of movement by software TEMA Bio v2.3. (Image Systems Ltd., Sweden). A total number of 4675 distances (4 sets; 41.8 ± 2.2 rallies per set) were analysed for this study. Middle hitters (MH1 and MH2) participated in approximately 60% of all rallies (MH1 in 58.6 % and MH2 in 60.8 %) and the Libero participated in 80.3 % of total of 167 analysed rallies. An average result for forward direction of the movement was 32.2 ± 5.9 %. For backward direction it was 16.4 ± 5.4 %, the right direction reached an average of 28.4 ± 9.8 % and the left direction 22.9 ± 6.1 %. A total of 91.8 ± 1.3 % of movement sections had their length from 0.7 m up to 2 m and 48.1 ± 3.9 % of distances had their length between 1 m to 2 m. Overall, 8 % of the distances were longer than 2 m. For a deep insight of real external workloads during the game conditions, such detail analysis of the movement is crucial.

Key words: *Performance, Distance, 3d Kinematic Analysis, Specificity*

Introduction

Progressive research in volleyball was conducted by Stankiewicz (2013). The study recommended an improvement of volleyball sessions by a deeper scientific implementation or an analysis of biomechanical developmental prerequisites and realization of motor actions. The latest research in top elite volleyball was carried out from point of view following emergency current issues: biomechanical aspects (Coleman, 2017; Chen et al., 2011; Kapidžic et al., 2014; Lobietti, 2009; Seminati et al., 2015; Zahalka et al., 2017), tracking of players and ball (Gomez et al., 2014; Hank et al., 2016; Chen et al., 2012; Li et al., 2017), match analysis (Häyrinen et al., 2011; Silva et al., 2016), technical and tactical game analysis (Häyrinen & Tampouratzis, 2012), effect of strength and conditioning program (Lehnert et al., 2009; Newton et al., 1999; Vavak et al., 2018), morphological aspects (Mala et al., 2010; Mala et al., 2015) and decision making process (Schläppi-Lienhard & Hossnern, 2015). Recent studies (Rabita et al., 2015; Parlebas, 1999; Weynard, 2010) noted that the biological potential of a human locomotion performance is practically exhausted, mostly because of the long-lasting research implementation of research into the training. Volleyball performance is dependent on the complexity between biologic limits, specific technical operations, rules and the speed of the game. In the sense of a specific game or match demands evaluation, we need to detect internal and external loads equally. Then we can enhance the understanding of forces and volumes of the external loads that player surpasses during competitive experience. Intuitively, we can conclude that the movement of a volleyball player requires acceleration, fast direction changes, agility or mental skills like decision making and strategic thinking implemented in the highly technical movement patterns. However, such crude assessment cannot motivate a specific design of an effective volleyball practice. Player positions in elite volleyball differ from each other and consequently, training units got to be customized in particular way (Lehnert et al., 2009). During an elite match, six volleyball players share relatively small court (9 m x 9 m) and the intense movement can easily cause up to 80 % of the maximal hearth rate intensity (Lehnert et al., 2009; Schläppi-Lienhard & Hossner, 2015; Wei-ping, 2009). A guided, long lasting and appropriately designed practice is the critical component for attaining the technical and biological part of all activities including sports games (Ericsson, 1993). Quantification of movement properties was widely used in elite sport via Global Positioning System (GPS) or other automated systems for tracking players (Gomez et al., 2014; Chen et al., 2011, 2012; Kapidzic et al., 2014; LI et al., 2017; Palao, 2014; Seminati et al., 2014; Wagner et al., 2014). When it comes to rapid direction changes, GPS has significantly degraded the accuracy and absolute reliability (Rawstorn et al., 2014). The demands of each player's position must be examined and further differentiated for enabling efficient training and setting an appropriate amount of load (Bompa & Buzzichelli, 2015; Cardinale et al., 2011; Zatsiorski & Kraemer, 2006).

The data for a whole analysis of movement during the elite volleyball match is still unavailable to find, probably because the official rules does not allow using any wearable devices during the official game. Therefore, the aim of this study was to choose appropriate method that allows to analyse a live

official elite match and evaluate the movement as accurately as possible.

Methods

Participants

An official CEV Champions League play-off match and 14 elite female indoor volleyball players (n=14; age = 25 ± 6 years; height = 182.3 ± 6.2 cm; weight = 72.1 ± 5.8 kg) were chosen for evaluation. Professional players at this level complete 6-7 practice sessions per week.

Data collection

The match has been recorded by two stably positioned HD digital camcorders (SONY HDC90E Sony Ltd., frame rate 50 half-frames/s, 1920 x 1080 pixels). 3D Kinematic Analysis was selected for semi-automated tracking of a player position on the court via the TEMA Bio v2.3 software. (Image Systems Ltd., Sweden). The average error of the three-dimensional reconstruction was calculated by DLT (Direct Linear Transformation) and was 0.033 m for Cam1 and 0.026 m for Cam2. In pursuance of official game rules (it is not permitted to mark players or interfere with a live match) and other practical reasons (movement of clothing, rapid rotation of the body etc.), the center of the head was preferred over the hip (iliac spine) as a representative landmark for the body movement. The duration of the individual rallies was standardized by recording the time interval between two events. The first event was the beginning of rally, which was the service throw and the ball was released from players' hand. The second was the end of the rally which was the immediate moment of ball hitting the surface or any other erroneous situation that caused the end of rally. The shortest section of a movement distance that was analyzsed as a single linear move was adjusted to 70 cm (in consideration of sorting short movements, respectively).

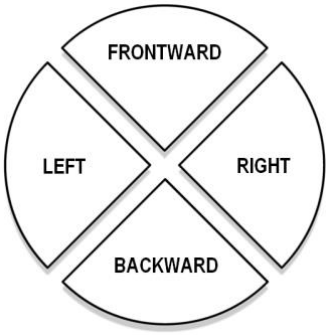

Figure 1. The distribution of four movement direction by 90° according to the volleyball net

Data processing

Matlab (c 2015 The MathWorks, Inc.) was utilized for approximation of rally movement sequences. Based on the relative position of the volleyball net, the player movements were classified into four directions (shown in Figure 1.) as follows: Forward (FD); Backward (BD); Right (RD); Left (LD).

IBM® SPSS® v2.1 (Statistical Package for Social Science, Inc., Chicago, IL, 2012) was chosen for conducting a statistical analysis.

Results

A total amount of 4675 distances (4 sets; 41.8 ± 2.2 rallies per set) were analysed for this study. The maximal distance of movement was reached by the Middle Hitter 1 (MH1) with 41.1 % into RD. The minimal distance was travelled by MH2 with 7.3 % into BD shown in Table 1. The Outside Hitter 1 (OH1) reached a maximal total length of 1015.4 m between players that participated in all rallies. The highest percentage quantification of FM was 38.8 % for positions Opposite (OP) and also 37.7 % for OH1 and OH2. The Setter (SE) was mostly active in directions RD (38.3 %) or FD (25.6 %) and the least active in BD (15.7 %). Libero transitioned mostly in LD (31.2%). Mean distance for FD was 32.2 ± 5.9 %, BD 16.4 ± 5.4 %, RD 28.4 ± 9.8 % and for LD it was 22.9 ± 6.1 %. Middle hitters participated in approximately 60% of all rallies (MH1 in 58.6 % and MH2 in 60.8 %) and Libero in 80.3 % of total of 167 analysed rallies. OH1 reached 91.6 % of total movement sections between 0.7 m to 2 m and 52.1 % between 1 m to 2 m. The distribution of various sections of distances is shown in Table 1 and Table 2 or Figure 3. Average percentage of sections with length 0.7 m to 1 m was 43.6 ± 3.3 %. For the section between 1 m to 2 m it was 48.1 ± 3.9 %. Sections in one linear direction longer than 3 m were present in 0.86 ± 0.5 % cases.

Table 1. Results of four movement directions according to each player position; represented by distance in meters (sections from 0,7 - inf) and percentage of distance (%)

	Distance (m)	Forward (%)	Backward (%)	Right (%)	Left (%)
Outside 1	1015.4	37.7	21.9	19.4	21.0
Outside 2	940.1	37.6	18.4	21.4	22.6
Setter	815.2	25.6	15.7	38.3	20.4
Opposite	977.3	38.8	21.1	26.9	13.1
Middle 1	561.8	25.6	10.9	41.1	22.4
Middle 2	571.5	27.2	7.3	35.3	30.2
Libero	798.1	32.6	19.7	16.5	31.2
Mean (std.)		32.2 (±5.9)	16.4 (±5.4)	28.4 (±9.8)	22.9 (±6.1)

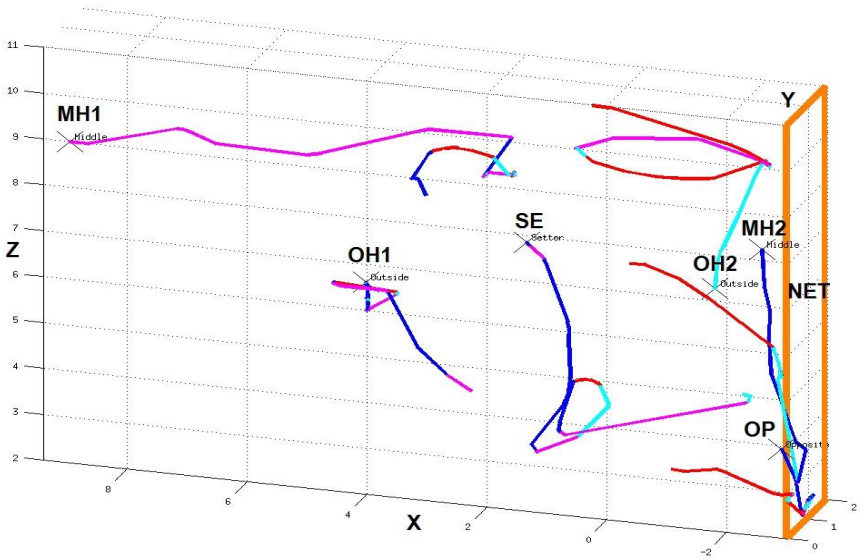

Figure 2. Three-dimensional visualization example of individual movement sequences for each player position according to the volleyball net; Matlab (c 1994-2015 The MathWorks, Inc.); Positions of players at the beginning of various rally; OH1 – Outside Hitter 1, OH 2 – Outside Hitter 2, SE – Setter, OP – Opposite, MH1 – Middle Hitter 1 and MH2 – Middle Hitter 2

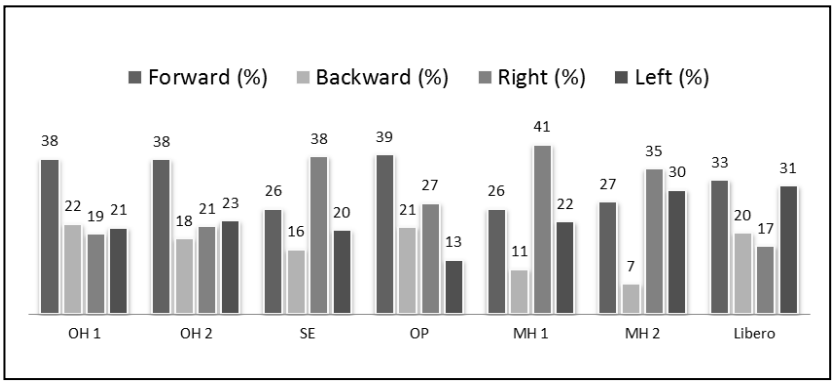

Figure 3. Results of four movement directions according to each player`s position; represented by percentage of distance (%); OH1 – Outside Hitter 1, OH 2 – Outside Hitter 2, SE – Setter, OP – Opposite, MH1 – Middle Hitter 1 and MH2 – Middle Hitter 2

Table 2. Results of four movement directions according to each player position and various distances; represented by occurrence (n) and percentage (%); OH1 – Outside Hitter 1, OH 2 – Outside Hitter 2, SE – Setter, OP – Opposite, MH1 – Middle Hitter 1 and MH2 – Middle Hitter 2

Player Position (occurrence)	Direction	0.7 m - inf m	0.7 m – 1 m	0.7 m – 2 m	0.7 m – 3 m	1 m – 2 m	2 m – 3 m	3 m – inf
OH1 (n = 810)	FD (%)	35.4	11.1	32.0	34.3	20.9	2.3	1.1
	BD (%)	22.5	10.0	20.9	22.1	10.9	1.2	0.4
	RD (%)	18.6	6.3	16.5	18.6	10.2	2.1	0.0
	LD (%)	23.5	12.1	22.2	23.5	10.1	1.2	0.0
	TOTAL %	100.0	39.5	91.6	98.5	52.1	6.9	1.5
OH2 (n = 771)	FD (%)	36.1	13.9	32.3	35.1	18.4	2.9	0.9
	BD (%)	18.0	8.0	16.1	17.9	8.0	1.8	0.1
	RD (%)	21.0	8.2	18.8	20.8	10.6	1.9	0.3
	LD (%)	24.9	13.1	23.6	24.8	10.5	1.2	0.1
	TOTAL %	100.0	43.2	90.8	98.6	47.6	7.8	1.4
SE (n = 688)	FD (%)	23.7	7.4	21.7	23.5	14.2	1.9	0.1
	BD (%)	17.6	9.7	17.3	17.4	7.6	0.1	0.1
	RD (%)	37.8	14.2	35.5	37.8	21.2	2.3	0.0
	LD (%)	20.9	8.7	19.8	20.9	11.0	1.2	0.0
	TOTAL %	100.0	40.1	94.2	99.7	54.1	5.5	0.3
OP (n = 803)	FD (%)	36.1	13.4	31.8	35.9	18.3	4.1	0.2
	BD (%)	21.7	10.3	20.2	21.7	9.8	1.5	0.0
	RD (%)	28.6	14.6	27.3	28.6	12.7	1.4	0.0
	LD (%)	13.6	6.2	12.8	13.4	6.6	0.6	0.1
	TOTAL %	100.0	44.6	92.0	99.6	47.4	7.6	0.4
MH1 (n = 483)	FD (%)	25.1	13.3	22.6	24.6	9.3	2.1	0.4
	BD (%)	11.4	5.8	10.8	11.4	5.0	0.6	0.0
	RD (%)	40.0	18.6	36.9	39.8	18.2	2.9	0.2
	LD (%)	23.6	11.4	22.2	23.6	10.8	1.4	0.0
	TOTAL %	100.0	49.1	92.3	99.4	43.3	7.0	0.6
MH2 (n = 469)	FD (%)	26.4	11.9	22.8	26.2	10.9	3.4	0.2
	BD (%)	8.7	5.3	8.5	8.7	3.2	0.2	0.0
	RD (%)	35.4	16.2	32.0	35.0	15.8	3.0	0.4
	LD (%)	29.4	12.6	26.9	29.2	14.3	2.3	0.2
	TOTAL %	100.0	46.1	90.2	99.1	44.1	9.0	0.9
Libero (n = 651)	FD (%)	29.8	9.8	26.3	29.3	16.4	3.1	0.5
	BD (%)	20.4	10.1	18.9	20.3	8.8	1.4	0.2
	RD (%)	18.0	9.7	16.6	17.8	6.9	1.2	0.2
	LD (%)	31.8	13.4	29.5	31.6	16.1	2.2	0.2
	TOTAL %	100.0	43.0	91.2	99.1	48.2	7.8	0.9
AVG	TOTAL %	100	43.6 (±3.3)	91.8 (±1.3)	99.1 (±0.5)	48.1 (±3.9)	7.37 (±1.1)	0.86 (±0.5)

Discussion

In spite of the fact that a volleyball player is naturally forced to move in a certain direction due to its strategic position during the match, relevant data capturing the exact distances or directions of player movement were not disclosed to this time. Our 3D kinematic analysis brings such insight that quantifies specific ratios of the movement. Using data from elite level players in a real match environment was the most important aspect for this study. Shnodell and Reynaud (2002) noted that competitive demands through the season should significantly influence design of the practice drills. An increased specificity of the training is a must for a modern training session, not only for the a particular sport but also for a specific position. The more the exercise imitates the game movements, the greater the effect of training (Black, 1995; Hedrick, 2007; Newton et al., 1999; Travlos, 2010; Zatsiorsky & Kraemer, 2006). Within the range of 0.7 m to 2 m were executed 91.8 ± 1.3 % of the distance sections. Concluding from the results of this study, we state that half of all one directional movements had their length larger than 0.7 m but lower than 1 m (48.1 ± 3.9 %). Almost 50 % of the other distances consisted of movements larger than 1 m but lower than 2 m (43.6 ± 1.3 %). The 92 % probability that a player's linear movement in indoor volleyball will be executed within 2 m distance is crucial for designing a practice. Next to the distance evaluation stands the direction of the movement. The recorded distribution of directions has shown that each player position mostly prefers two main directions. Outside Hitters were more likely to use FD (37.7 %). This is contrasted to Setter (25.6 %), for whom RD was crucial (38.3 %). Outside hitters together with Opposite moved mostly backwards (22 % and 21 % respectively) probably due to the repeated dynamic retreating from the net (the purpose is to get ready for the next attacking approach or to get into a defensive position). It seems that different player positions moved backwards in various ways. Middle Hitters focused more on the side movements to the right (40%) and left (30%) and retreated only in 7 to 11 % where more defensive OH, OP and Libero represented BD in range 20 - 22 %. This result is very important in terms of getting closer look to the specificity of the distance and direction, which is crucial for an indoor volleyball practice or an evaluation of player external load and performance. It is important (not only) for MH to be able to repetitively maintain core strength (Hagerman, 2005; Prieske et al., 2016) for the lateral acceleration followed by rapid deceleration on the borders of the net.

A similar approach of a software-based analysis of a volleyball game was used in many recent studies (Coleman, 1997; Hank et al., 2016; Häyrinen et al., 2004, 2011, 2012; Chen at al., 2011; 2012; LI et al., 2017; Lobietti, 2009; Seminati et al., 2015, Silva et al., 2016). Silva et al. (2016) analysed rotations in relation to the result of a match. Despite a balanced result, different rotations have their positive and also negative aspects of strategy and external loads to players. Setter in back row rotations has to travel longer distance from a defensive to a setting position, so FD and mostly RD linear acceleration and deceleration is highly required. The wide variety of each player's responsibilities and differences between positions during the game are yielding the deteriorations within inter-player comparisons. The strategy of a game is also an inconsiderable factor that determines the possible loads for players. As game rules allow, Libero and Middle Hitters are constantly alternating on a court among rally breaks and so, according to participation differences, percentage quantification of movement frequency is required. The strategy of a game should be beneficial not only against an opponent but also for a home team, which means to prepare the players to their individual needs. Limitations of this study were a limnited sample size and a large time-consuming measurent process that was used to collect the data. For further analysis of a significance and generalization, evaluation of a higher number of elite matches and players is recommended together with a focus to male indoor volleyball.

Practical application

Transitioning within a fast game like volleyball involves superior acceleration and deceleration skills (acceleration for getting to the position and controlled deceleration brings the opportunity to perform a technical and stable play). A position placement or game rules are a determining factor for the location where a player should or shouldn't perform. The variability of a movement direction and it's specific demands are often overlooked and the need of its implementation can prepare players more intentionally. What ratios between various lengths and directions should the agility exercises have? For an objectification of a volleyball player movement, a more diverse elite match analysis is recommended. Studies like this can bring more insights into a load specification for a practice. In this study, attackers (OH; OP) were more active in the linear forward or backward transitions. Results suggest to combine front movement with a run-up jump by 40% and back, right and left sections to equally divide the remaining 60 % of the acceleration and deceleration agility transition for practice (the length sections from 1 m to 2 m). Libero should be focused on front and left movement by 65 % and dedicate the back and right sections to the remaining 35 %. Because of the rapid acceleration followed by deceleration on the borders of the net or in deep court - it is very important for all players to be able to repetitively maintain core strength as mentioned earlier. Middle Hitters are very active in side movements (40 %) but also in the forward movement which was represented by almost 30 % in this study.

Conclusion

The aim of this study was to evaluate the occurrence and distance of the movement directions in elite female indoor volleyball during an official match. Real conditions often collide with a lack of knowledge of exercise loads. By competition of this analysis, they should be equally categorized. In this study the total number of 4 balanced sets (41.8 ± 2.2 rallies/set, 167 rallies and 4675 distances) were analysed. A 3D kinematic analysis was chosen to evaluate the movement of individual players, later differentiated by their positions. Semi-automated tracking by calibrated space was chosen due to the inability to interfere with an official match by body markers etc. Recorded directions were classified according to the volleyball net and divided by 90° as Forward, Backward, Right and Left (Figure 1). 91.8 % of movement sections measured between 0.7 m and 2 m. Almost 50 % of distances had their length between 1 m to 2 m. 8 % of distances were longer than 2 m. The proposed performance analysis indicates substantial movement evaluation which should be further used as grounds for preparation of a more specific conditioning.

ACKNOWLEDGEMENTS
This study was supported by GACR 16-21791 S; UNCE/HUM/032 and SVV 2017 - 2019 – 260466

References

Black, B. (1995). Conditioning for volleyball. *Strength & Conditioning Journal*, *17*(5), 53-55.
Bompa, T., & Buzzichelli, C. (2015). *Periodization training for sports, 3E*. Human Kinetics.
Cardinale, M., Newton, R., & Nosaka, K. (Eds.). (2011). *Strength and conditioning: biological principles and practical applications*. John Wiley & Sons.
Coleman, S. (1997). A 3D kinematic analysis of the volleyball jump serve. In *Proceedings of the XV international symposium on biomechanics in sports*.
Ericsson, K. A., Krampe, R. T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological review*, 100(3), 363.
Gomez, G., López, P. H., Link, D., & Eskofier, B. (2014). Tracking of ball and players in beach volleyball videos. *PloS One*, 9(11), e111730.
Hagerman, P. (2005). Putting on the brakes: Deceleration training. *Strength and Conditioning Journal*, *27*(1), 57.
Hank, M., Malý, T., Zahálka, F., Dragijský, M., & Bujnovský, D. (2016). Evaluation of the horizontal movement distance of elite female beach volleyball players during an official match. *International Journal of Performance Analysis in Sport*, *16*(3), 1087-1101.
Häyrinen, M., Hoivala, T., & Blomqvist, M. (2004). Differences between winning and losing teams in men's European top-level volleyball. In *Proceedings of VI Conference Performance Analysis* (Vol. 168177).
Häyrinen, M., Lehto, H., Mikkola, T., Honkanen, P., Lahtinen, P., Paananen, A., & Blomqvist, M. (2011). Time analysis of men's and youth boy's top-level volleyball. *British Journal of Sports Medicine*, *45*(6), 542-542.
Häyrinen, M., & Tampouratzis, K. (2012). Technical and tactical game analysis of elite female beach volleyball. *Jyväskylä, KIHU: Research Institute for Olympic Sports*.
Hedrick, A. (2007). Training for High Level Performance in Women's Collegiate Volleyball: Part I Training Requirements. *Strength & Conditioning Journal*, *29*(6), 50-53.
Chen, P., Huang, C., & Shih, S. (2011). Differences in 3D kinematics between genders during volleyball spike. In *Proceedings of the Congress of the International Society of Biomechanics. Brussels: Belgium*.
Chen, H. T., Tsai, W. J., Lee, S. Y., & Yu, J. Y. (2012). Ball tracking and 3D trajectory approximation with applications to tactics analysis from single-camera volleyball sequences. *Multimedia Tools and Applications*, *60*(3), 641-667.
Kapidžic, A., Huremović, T., Biberović, A., Mehinović, J., Selimović, A., & Smajić, M. (2014). Kinematic Analysis Forearm Passing in Volleyball at Different Distances. *Journal of Education and Practice*, 5(10), 75-84.
Lehnert, M., Lamrová, I., & Elfmark, M. (2009). Changes in speed and strength in female volleyball players during and after a plyometric training program. *Acta Gymnica*, 39(1), 59-66.
Li, C., Yee, L. Y., Maruyama, H., & Yamaguchi, Y. (2017). FPGA-based Volleyball Player Tracker. *ACM SIGARCH Computer Architecture News*, *44*(4), 80-86.
Lobietti, R. (2009). A review of blocking in volleyball: from the notational analysis to biomechanics.
Mala, L., Maly, T., Zahalka, F., & Bunc, V. (2010). The profile and comparison of body composition of elite female volleyball players. *Kinesiology*, *42*(1), 90-97.
Mala, L., Maly, T., Zahalka, F., Bunc, V., Kaplan, A., Jebavy, R., & Tuma, M. (2015). Body composition of elite female players in five different sports games. *Journal of Human Kinetics*, *45*(1), 207-215.
Newton, R. U., Kraemer, W. J., & Häkkinen, K. (1999). Effects of ballistic training on preseason preparation of elite volleyball players. *Medicine and Science in Sports and Exercise*, *31*, 323-330.
Palao, J. M. (2014). Normative profiles for serve speed for the training of the serve and reception in volleyball. *Sport Journal*.
Parlebas, P. (1999). *Jeux, sports et sociétés: lexique de praxéologie motrice*. Paris: Insep.
Polakovicova, M., Vavak, M., Olle, R., Lehnert, M., & Sigmund, M. (2018). Vertical jump development in elite adolescent volleyball players: Effects of sex and age. *Acta Gymnica*, 48(3), 115-120.
Prieske, O., Muehlbauer, T., Borde, R., Gube, M., Bruhn, S., Behm, D. G., & Granacher, U. (2016). Neuromuscular and athletic performance following core strength training in elite youth soccer: Role of instability. *Scandinavian Journal of Medicine & Science in Sports*, *26*(1), 48-56.
Rabita, G., Dorel, S., Slawinski, J., Sàez-De-Villarreal, E., Couturier, A., Samozino, P., & Morin, J. B. (2015). Sprint mechanics in world-class athletes: a new insight into the limits of human locomotion. *Scandinavian Journal of Medicine & Science in Sports*, *25*(5), 583-594.
Rawstorn, J. C., Maddison, R., Ali, A., Foskett, A., & Gant, N. (2014). Rapid directional change degrades GPS distance measurement validity during intermittent intensity running. *PloS One*, 9(4), e93693.

Seminati, E., Marzari, A., Vacondio, O., & Minetti, A. E. (2015). Shoulder 3D range of motion and humerus rotation in two volleyball spike techniques: injury prevention and performance. *Sports Biomechanics*, *14*(2), 216-231.
Schläppi-Lienhard, O., & Hossner, E. J. (2015). Decision making in beach volleyball defence: Crucial factors derived from interviews with top-level experts. *Psychology of Sport and Exercise*, *16*, 60-73.
Shondell, S., & Reynaud, C., (2002). *The Volleyball Coaching Bible*. Human Kinetics
Silva, M., Sattler, T., Lacerda, D., & João, P. V. (2016). Match analysis according to the performance of team rotations in Volleyball. *International Journal of Performance Analysis in Sport*, *16*(3), 1076-1086.
Stankiewicz, B. (2013). Status, problems and future directions of research in volleyball. *Pedagogics, Psychology, Medical-biological Problems of Physical Training and Sports*, *12*.
Travlos, A. K. (2010). Specificity and variability of practice, and contextual interference in acquisition and transfer of an underhand volleyball serve. *Perceptual and Motor Skills*, *110*(1), 298-312.
Wagner, H., Pfusterschmied, J., Tilp, M., Landlinger, J., Von Duvillard, S. P., & Müller, E. (2014). Upper-body kinematics in team-handball throw, tennis serve, and volleyball spike. *Scandinavian Journal of Medicine & Science in Sports*, 24(2), 345-354.
Wei-Ping, M. A. (2009). Volleyball Competition's Time Characteristics and Analysis of Its Energy Metabolism. *Journal of Gansu Lianhe University (Natural Science Edition)*, *1*, 028.
Weyand, P. G., Sandell, R. F., Prime, D. N., & Bundle, M. W. (2010). The biological limits to running speed are imposed from the ground up. *Journal of Applied Physiology*, *108*(4), 950-961.
Zahalka, F., Maly, T., Mala, L., Ejem, M., & Zawartka, M. (2017). Kinematic analysis of volleyball attack in the net center with various types of take-off. *Journal of Human Kinetics, 58*(1), 261-271.
Zatsiorsky, V. M., & Kraemer, W. J. (2006). *Science and Practice of Strength Training*. Human Kinetics.

ANALIZA POKRETA U VRHUNSKOJ ODBOJCI

Sažetak

Cilj ovog istraživanja bio je procijeniti smjerna svojstva pokreta elitnih igračica odbojke. Za 3D kinematičku analizu kretanja pomoću softvera TEMA Bio v2.3 korišteno je četrnaest elitnih ženskih igrača (dob = 25 ± 6 godina; visina tijela = 182,3 ± 6,2 cm; tjelesna masa = 72,1 ± 5,8 kg). (Image Systems Ltd., Švedska). Za ovu studiju analiziran je ukupan broj od 4675 udaljenosti (4 seta; 41.8 ± 2.2 rallya po setu). Srednji hitteri (MH1 i MH2) sudjelovali su u oko 60% svih skupova (MH1 u 58,6% i MH2 u 60,8%), a Libero je sudjelovao u 80,3% od ukupno 167 analiziranih skupova. Prosječni rezultat za pravac kretanja prema naprijed bio je 32,2 ± 5,9%. Za pravac unatrag bio je 16,4 ± 5,4%, pravi smjer dosegao je srednju vrijednost 28,4 ± 9,8%, a lijevi smjer 22,9 ± 6,1%. Ukupno 91,8 ± 1,3% dionica kretanja imalo je dužinu od 0,7 m do 2 m, a 48,1 ± 3,9% udaljenosti imalo je duljinu između 1 m i 2 m. Ukupno 8% udaljenosti bilo je dulje od 2 m. Za dublji uvid u stvarna vanjska opterećenja tijekom uvjeta igre potrebna je detaljna analiza kretanja.

Ključne riječi: *Izvedba, udaljenost, 3d kinematička analiza, specifičnost*

Corresponding information:

Received: 09.12. 2018.
Accepted: 06. 03. 2019.
Correspondence to: Mikuláš Hank
University: Charles University, José Martího 31, 162 52, Prague 6
Faculty: Faculty of Physical Education and Sport, Sport Research Centre
Phone: +420 730 816 723
E-mail: miki.hank@gmail.com