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Movement Sequences during Instep Rugby Kick: a 3D Biomechanical Analysis

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Abstract. The purpose of this study was to examine movement sequencing and the contributions of the motions of individual segments to the velocity of the foot during rugby kicking through a novel velocity decomposition method. Seven experienced male players participated in this study and kinematic data from each participant were recorded. The linear velocity of the kicking foot was decomposed to the linear velocities caused by the absolute linear velocity of the pelvis, rotation of the pelvis, rotation of the thigh and flexion/extension of the knee. The results show that a proximal-to-distal sequential pattern of segment motions and knee flexion/extension made the major contribution (75 ± 8%) to the final velocity during rugby kicking, followed in turn by hip flexion, pelvis velocity and pelvis rotation.

Keywords: kinematics; kick; movement sequences

1. Introduction

Many throwing and kicking movements have a kinematic sequence that starts with the most proximal segments and then progress to the distal segments. This principle, known as proximal to distal sequencing, or the summation of speed principle, has been observed for certain activities (baseball pitching, golf swing, shot putt and soccer kicking) with the goal to achieve maximal ball speed, which requires maximization of the velocity of the foot (or hand) before ball contact (Barrentine et al., 1998; Best et al., 1993; Dillman et al., 1993; Feltner and Dapena 1986; Fleisig et al., 2009; Matsuo et al., 2001; Murata 2001; Nunome et al., 2006; Putnam, 1993; Rash and Shapiro 1995; Van Den Tillaar and Ettema 2009).

Rugby union is the most favorite national sport in New Zealand. During a rugby union game, place kicking for maximal resultant ball velocity is often desirable. Like soccer instep kicks, place kicks involve a series of motions that include an initial address to the ball, planting of the support leg beside the ball, and striking of the ball with the instep of the kicking foot (Barfield et. al., 2002; Isokawa and Lees, 1988). While the basic pattern of a place kick is similar to the instep soccer kick, the differences of the ball shapes, tee support, and release angles make the rugby place kicking technique unique.

Biomechanical studies regarding rugby union place-kicking technique are very limited. A two-dimensional analysis by Aitcheson and Lees (1983) found that 'two-stage acceleration' of the lower leg is yielded. The first stage is due to the lower leg falling against gravity and the second stage is due to the interaction between the upper and lower leg segments. Bezodis et. al., (2007) investigated non-kicking-side arm motion during rugby place kicking. They found that the longitudinal angular momentum of the non-kicking-side arm can increase accuracy in maximum distance kicking. It was also reported from soccer kick studies that the speed of the ball is influenced by the trunk segment's rotations about the longitudinal axis (Lees and Nolan, 2002).

In summary, from a kinematic point of view, the velocity of the kicking foot is not only dependent upon the most distal segments, but also on other proximal segments. It has been generally recognized that ball kicking is a combination of segmental and joint rotations in multiple planes following a proximal to distal sequence to achieve maximal foot velocity, which results in the maximal ball release speed. However,

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contributions of different body segments to the foot velocity have not been quantified for rugby kick studies. Insight into the contributions of different body segments to the velocity of the kicking foot aids in understanding the role of each segment during the kick, comparing performance of different groups of players and potentially creating a knowledge base for improving athletes' performance. For example, there is a paradox in training methods in that some coaches suggest the body should adopt a backward lean when kicking, while others emphasize the importance of keeping the head over the ball. A three dimensional kinematic analysis can help quantify the contribution of trunk rotation to the ball release speed. It was noted that the effectiveness of segment rotations depends both on their magnitude and on the end point (foot) positioning with respect to the segment's axis of rotation and this effect can be quantified through a velocity decomposition method (Sprigings et. al., 1994). The velocity decomposition method has been widely used to determine the effectiveness of joint rotations in producing racquet-head speed during tennis serves, and the underlying biomechanical principles have been well outlined (Elliott et al., 1995; Gordon and Dapena, 2006; Sprigings et al., 1994). There is no doubt that this method can be applied for analyzing other movement activities. The objective of this study was to examine the contributions of the motions of segments to the velocity of the foot during rugby kicking through the use of a generalized three dimensional kinematic analysis.

2. Method

2.1. Data Collection

Seven skilled male university rugby kickers participated in this study. Kinematic data from each participant was recorded in the Biomechanics Laboratory at The University of Auckland, using an eight camera Vicon ™ motion analysis system sampling at 250 Hz and calibrated according to the manufacturer's instructions. The experiment protocol was approved by The University of Auckland's Human Research Ethics committee. Before data collection, each participant performed three to five practice trials to acquaint themselves with the testing equipment. Spherical markers were attached to specific anatomical landmarks on the lower extremities of participants (Fig. 1) for use with the plug-in-gait model (ViconTM, Oxford Metrics Ltd., Oxford, UK). Two markers were also attached to either side of the ball in order to track its movement.

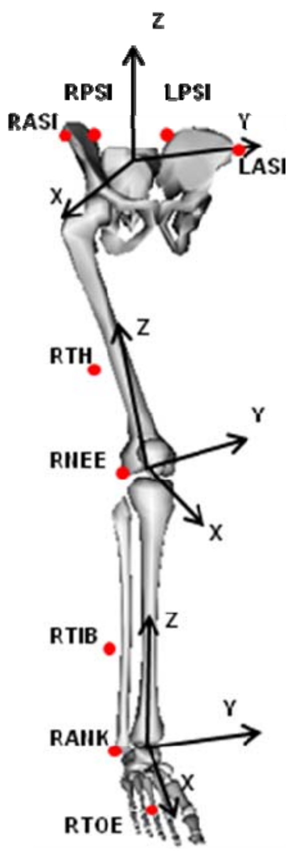

Figure 1. Illustration of the marker set and coordinate systems

After calibrating the Vicon system and the eight cameras, a global coordinate system (ground) was defined. The ball was placed in the middle of the capture area with tee support. Before any kicking trials were recorded, a static trial of each participant and the ball was recorded. Each participant then completed twelve trials of maximum effort right foot kicking.

2.2. Data Reduction

For each trial, 3D coordinates for each of the reflective markers were reconstructed using the Workstation software. The centre of the ball (CB) was found by finding the mean value of the coordinates of the two attached markers. Ball contact was determined from initial displacements of the CB. A complete kick was defined as the time interval between the initial back-swing of the kicking-leg and the final ball-foot interaction.

The recorded markers' positions were smoothed using a Butterworth low-pass filter (cut-off frequency 12 Hz) and then input into a biomechanical model to determine joint centre positions and joint coordinate systems (CS). The axes in these CS were defined based on bony landmarks (Fig. 1). The pelvis system was defined using the LPSI, RPSI, LASI and RASI markers. The origin of the pelvis system (OPELVIS) was defined at the midpoint between the LASI and RASI. The Y-axis was along the line of RASI to LASI. Z-axis was defined orthogonal to the plane formed by LASIS, RASIS and the midpoint between LPSI and RPSI. The X-axis is orthogonal to the y and z planes (Fig. 1). The right hip joint centre (HJC) was defined relative to the pelvis CS and estimated using a regression equation (Shea et al., 1997). The right knee joint centre (KJC) was determined by the HJC, RTH and KNEE positions. Then, the femoral CS was defined with the origin at the KJC and the Z-axis as the line passing through the KJC to the HJC. The X-axis of the femoral CS was defined as the line passing through the KJC and orthogonal to a plane defined by RNEE and Z-axis, and the Y-axis orthogonal to the X and Z-axes (Fig. 1). The right ankle joint centre (AJC) was determined by the KJC, RTIB and RANK positions. Then, the femoral CS was defined with the origin at the AJC and the Z-axis as the line passing through the AJC to the KJC. The X-axis was defined as the line passing through the AJC and orthogonal to a plane defined by RANK and Z-axis, and a Y-axis orthogonal to the X and Z-axes (Fig. 1).

Once coordinate systems are defined, the rotations of the referred segment in each time frame with respect to the reference segment can be represented by Euler angles. Following the general Euler joint angle sequence proposed by Grood and Suntay (1983), three Euler angles were determined following the flexion/extension (F/E), adduction/abduction (ADD), and internal/external (I/E) order (Y-X-Z order). By taking the time-derivatives and matrix transformations, angular velocities and angular accelerations were obtained based on Euler angles (Winter 2005). Meanwhile, the linear velocities of the foot, ball and pelvis were determined by differentiating the time series coordinates of RTOE, CB, and OPELVIS, respectively.

At any instant, the linear velocity of the foot (V_f) was considered to be the sum of the linear velocities contributed by: the absolute linear velocity of the pelvis (V_g), the 3D rotation of the pelvis relative to the ground (V_p), the 3D rotation of the thigh segment relative to the pelvis (V_t), and the flexion/extension of the shank segment relative to the thigh (V_l). By using the velocity decomposition method (Sprigings et. al., 1994), the foot velocity can be represented as:

$$V_f = V_g + \underbrace{\omega_{px} \times L_p + \omega_{py} \times L_p + \omega_{pz} \times L_p}_{V_p} + \underbrace{\omega_{tx} \times L_t + \omega_{ty} \times L_t + \omega_{tz} \times L_t}_{V_t} + \underbrace{\omega_y \times L_l}_{V_l}$$

where L_p, L_t, and L_l are vectors pointing from the centres of pelvis, hip, and knee, respectively, to the foot, which was directly obtained from the 3D coordinate data. ω_{px}, ω_{py}, ω_{pz} are the angular velocities of pelvis adduction/abduction, flexion/extension and internal/external rotation relative to the ground respectively. ω_{tx}, ω_{ty}, ω_{tz} are the angular velocities of thigh adduction/abduction, flexion/extension and internal/external rotation relative to the pelvis respectively. ω_{ly} is the angular velocity of knee flexion/extension relative to the thigh.

To quantify the contributions of each segment to foot speed at ball contact, each component in equation 1 was projected to the direction of foot velocity vector and the magnitude of the total projection was divided by foot velocity to obtain a percentage value. A positive value means positive contribution and vice versa.

3. Results

As shown in Table 1, the mean ball velocity at release was 17.8±2.5 m/s and the mean foot velocity at release was 16.8±1.6 m/s. The duration of the throw was 0.27±0.04 s and was similar between the players.

Table 1. Duration of kick trials and velocities of foot and ball at release moment

Subject No.	Duration (s)	Ball Velocity (m/s)	Foot Velocity (m/s)
1	0.30±0.03	18.3±1.6	17.4±0.6
2	0.27±0.05	16.2±1.4	18.0±1.6
3	0.25±0.02	18.1±2.0	15.1±1.1
4	0.27±0.03	18.4±1.6	17.5±0.9
5	0.24±0.04	17.7±1.9	16.2±1.2
6	0.25±0.05	18.0±1.8	16.3±1.3
7	0.29±0.03	17.6±1.5	17.4±1.5
Average	0.27±0.04	17.8±2.5	16.8±1.6

A proximal-to-distal sequential pattern of segment motion was consistently observed for all subjects. As shown from Figure 2, before the initial forward swing, the backward swing of the thigh was observed. After backward swing, the thigh started to swing forward and the angular velocity of the thigh increased continuously until it reached its peak during the latter part of the kick. After reaching the peak magnitude, the forward angular velocity of the thigh rapidly decreased before ball contact. The lower leg motion was started by its backward rotation and reached its peak minimum angular velocity during the latter part of the kick. Then the forward angular velocity increased continuously and attained the maximal value at ball impact. The proximal-to-distal sequential pattern was also observed for all trials, with peak forward angular velocity of the lower leg occurring at ball contact in most cases, or else immediately before ball impact. In contrast, peak forward angular velocity of the thigh occurred during forward swing.

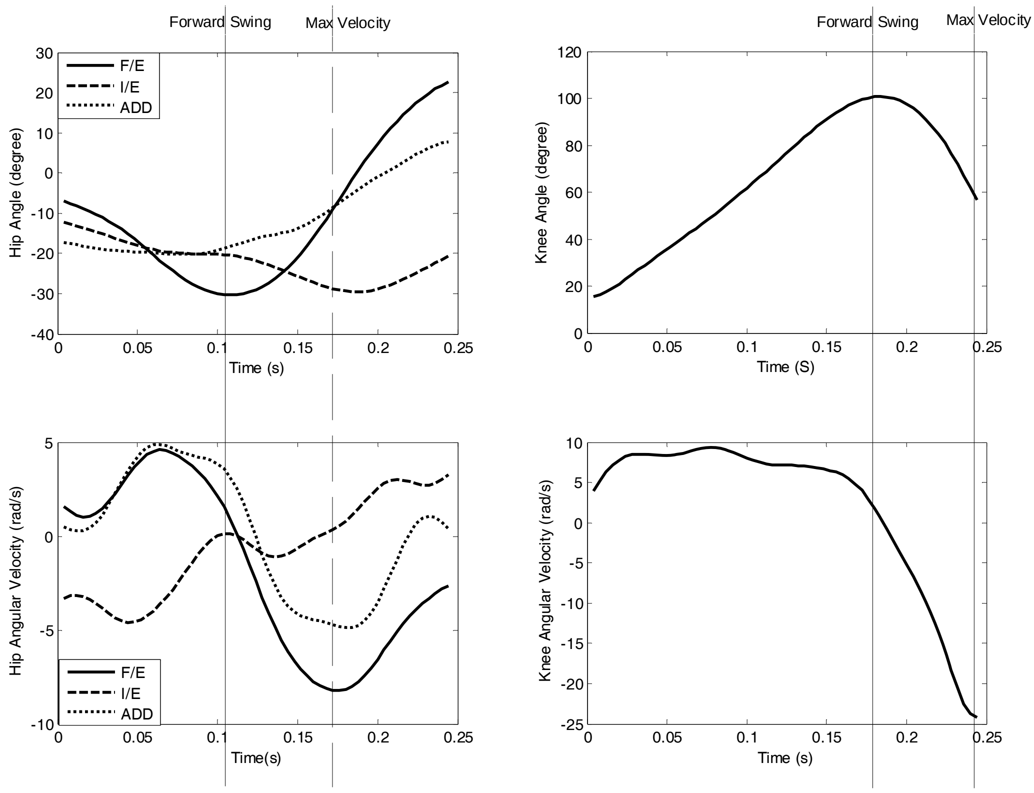

Figure 2. Graphical representations of angular trajectories during rugby kick from a representative trial

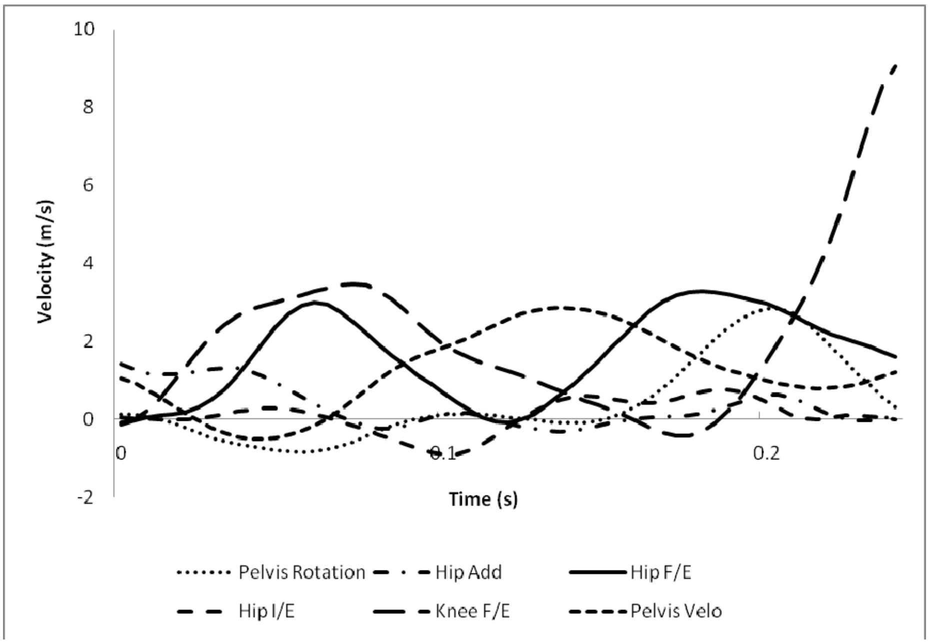

Figure 3. Graphical representations of the contributions of all segments to the speed of the foot during a rugby kick from a representative trial

Figure 3 shows the contributions of all segments to the speed of the foot during a rugby kick. For this trial, the greatest contributor to the foot speed at ball contact was knee F/E (9.1 m/s), followed in turn by hip F/E (1.6 m/s), pelvis velocity (1.2 m/s), pelvis rotation (0.3 m/s). The contributions of hip adduction/abduction and hip internal/external rotation are quite low. More insightful information was provided by the velocity profiles from back swing to ball contact. It was revealed that the contribution of each segment rotation was not constant during the kick phase. During the back swing phase, flexion at the hip and knee are the most important contributors while the linear velocities of the pelvis and pelvis rotation cause a negative contribution to the total speed. During the first half forward swing phase, the linear velocities of the pelvis are the most important contributors. During the second half forward swing phase, flexion at the knee is the dominant contributor.

Figure 4 illustrates the percentage contributions of each segment rotation for all data. It shows that the knee made the largest contribution (75 ± 8%) during the rugby kicks, followed in turn by hip flexion (13 ± 2%), pelvis velocity (9 ± 1%) and pelvis rotation (2 ± 1%). The contributions of hip adduction/abduction and hip internal/external rotation are negligible.

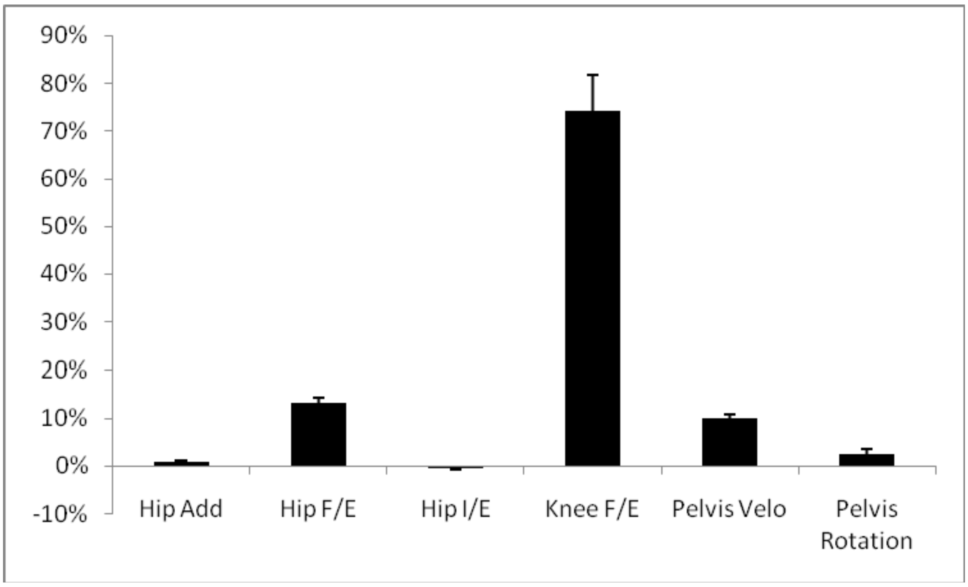

Figure 4. Percentage of the contributions of all segments to the speed of the foot

4. Discussion and Conclusion

The purpose of this study was to quantify the contributions of the motions of individual segments to the velocity of the foot during rugby kicking. The results show that the knee extension made the largest contribution (75 ± 8%) to the final velocity during the rugby kick, followed in turn by hip flexion, pelvis velocity and pelvis rotation. The angular velocity profiles show proximal to distal sequences during rugby kicking which indicate that the interaction between adjacent segments plays an important role during this movement (Putnam, 1993).

The main advantage of the kinematic method used in this study is that joint angular velocities can be directly obtained from motion capture systems or video images and be functionally linked to foot velocity, which cannot be revealed by kinetic analysis (Sprigings et. al., 1994). Our future work will use this method to compare different kicking techniques or different athletes groups to evaluate the effectiveness of the production of kicking speed. For this study, a clear picture of the kinematic chain of the rugby kick can be represented by following steps. In the final step into the plant spot, the kicking leg generates back swing: the farther back the leg is, the more force and leg speed can be potentially generated; then, the thigh moves forward followed by the passive movement of the shank through the knee; finally, the shank extends to yield the maximum speed right as the instep contacts the ball while the thigh decelerates. As the major contributor to knee extension, the quadriceps would generate high intensity forces. Therefore, from a biomechanical point of view, the strength training for knee muscle groups may be of particular importance for rugby players, not only for performance enhancement, but also for injury prevention during kicking.

5. References

[1] Aitcheson, I., and Lees, A.. A biomechanical analysis of place kicking in rugby union football. *Journal of Sports Sciences*. 1983, **1**: 136–137.

[2] Barfield, W.R., Kirkendall, D.T. and Yu, B. Kinematic instep kicking differences between elite female and male soccer players. *Journal of Sports Science and Medicine*. 2002, **11**: 72-79.

[3] Barrentine, S.W., Matsuo, T., Escamilla, R.F., Fleisig, G.S., Andrews, J.R. Kinematic analysis of the wrist and forearm during baseball pitching. *Journal of Applied Biomechanics*. 1998, **14**: 24-39.

[4] Best, R.J., Bartlett, R.M., Morriss, C.J. A three-dimensional analysis of javelin throwing technique. *Journal of Sports Sciences*. 1993, **11**: 315-328.

[5] Bezodis, N., Trewartha, G., Wilson, C. and Irwin, G. Contributions of the non-kicking-side arm to rugby place-kicking technique. *Sports Biomechanics.* 2007, **6**(2): 171-186.

[6] Dillman, C.J., Fleisig, G.S., Andrews, J.R. Biomechanics of pitching with emphasis upon shoulder kinematics. *Journal of Orthopaedic & Sports Physical Therapy*. 1993, **18**: 402-408.

[7] Elliott, B. Marshall, R.N. and Noffal, G.J. Contributions of upper limb segment rotations during the power serve in tennis. *Journal of Applied Biomechanics.* 1995, **11**: 433-42.

[8] Feltner, M., Dapena, J. Dynamics of the Shoulder and Elbow Joints of the Throwing Arm during a Baseball Pitch. *International Journal of Sport Biomechanics*. 1986, **2**: 235-259.

[9] Fleisig, G., Chu, Y., Weber, A., Andrews, J. Variability in baseball pitching biomechanics among various levels of competition. *Sports Biomechanics*. 2009, **8**: 10-21.

[10] Gordon, B.J. and Dapena, J. Contributions of joint rotations to racquet speed in the tennis serve. *Journal of Sports Sciences*. 2006, **24**: 31-49.

[11] Grood, E.S. and Suntay, W.J. A joint coordinate system for the clinical description of three-dimensional motions: Application to the knee. *Journal of Biomechanical Engineering*. 1983, **5**: 136- 144.

[12] Isokawa, M. and Lees, A. A biomechanical analysis of the instep kick motion in soccer. In: *Science and Football.* Ed: Reilly, T., Lees, A., Davids, K. and Murphy, W.J. London, E and FN Spon. 1988, pp. 449-455.

[13] Lees, A., and Nolan, L. Three-dimensional kinematic analysis of the instep kick under speed and accuracy conditions. In T. Reilly,W. Spinks, and A. Murphy (Eds.), *Science and football IV*. London: E & FN Spon. 2002, pp. 16-21.

[14] Matsuo, T., Escamilla, R.F., Fleisig, G.S., Barrentine, S.W., Andrews, J.R. Comparison of kinematic and temporal parameters between different pitch velocity groups. *Journal of Applied Biomechanics.* 2001, **17**: 1-13.

[15] Murata, A. Shoulder joint movement of the non-throwing arm during baseball pitch--comparison between skilled and unskilled pitchers. *Journal of Biomechanics*. 2001, **34**: 1643-1647.

[16] Nunome, H., Ikegami, Y., Kozakai, R., Apriantono, T., Sano, S. Segmental dynamics of soccer instep kicking with the preferred and non-preferred leg. *Journal of Sports Sciences.* 2006, **24**: 529-541.

[17] Putnam, C. A. Sequential Motions of Body Segments in Striking and Throwing Skills - Descriptions and Explanations. *Journal of Biomechanics*. 1993, **26**: 125-135.

[18] Rash, G.S., Shapiro, R. A 3-Dimensional Dynamic Analysis of the Quarterbacks Throwing Motion in American Football. *Journal of Applied Biomechanics*. 1995, **11**: 443-459.

[19] Shea, K.M., Lenhoff, M.W., Otis, J.C., and Backus S.I. Validation of a method for location of the hip joint center. *Gait & Posture*. 1997, **5**: 157–158.

[20] Sprigings, E., Marshall, R., Elliott, B. and Jennings, L. A three-dimensional kinematic method for determining the effectiveness of arm segment rotations in producing racquet-head speed. *J Biomech*. 1994, **27**(3): 245-54.

[21] Winter, D.A. *Biomechanics and Motor Control of Human Movement* (3rd edition). New York: John Wiley & Sons, 2005.

[22] Van den Tillaar, R., Ettema, G. Is there a proximal-to-distal sequence in overarm throwing in team handball? *Journal of Sports Sciences*. 2009, **27**: 949-955.