Application of inertial sensors system for diagnosis of taekwon-do's forms performance – a case study

Jacek Wąsik [ABCDE], **Dariusz Mosler** [BDE], **Tomasz Góra** [BDE], **Dorota Ortenburger** [DE]

Faculty of Health Sciences, Jan Dlugosz University in Czestochowa, Czestochowa, Poland

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C Statistical Analysis
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Abstract

Background and Study Aim: New technology brings new ways to assess performance in the forms in martial arts from biomechanical perspective. The aim of this study is knowledge about the usefulness of kinematic assessment in objective analysis of rhythm (patterned recurrence of movement in time), tempo (speed of motion) and dynamics of taekwondo techniques while performing certain form.

Material and Methods: ITF taekwon-do athlete participated in this study (male; age 30 years; body mass 56 kg; height 160 cm). During an analysis, the participant performed a sequence of techniques called saju-jirugi. For the purpose of this analysis, inertial system were used. Acceleration and angular velocity data from both sensors attached to dorsal area of fist was obtained.

Results: Maximal velocity of striking punch (right), gradually decreases from 11.68 m/s to 8.55 m/s. In the same time, maximal velocities of retracted, opposite hand was higher for every punch (highest value of 12.67 m/s), but without same tendency. There is moderate correlation between maximal velocities of both hands during measured strikes (r = 0.65). Highest correlation is noticed between difference in values of maximal velocities of both hands and value of maximal velocity for retracted (left) hand.

Conclusions: Depending on motion capture devices and techniques, angular and linear velocities could serve equally as determinant of performance quality. Conducted research provides sufficient arguments, that this type of measurement allows to objectively measure performance in a single trial as well as monitoring of its progress.

Keywords: coordination • intentional goal • kicks kinematics • movement analysis • simulation • technique • velocity

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Author's address: Jacek Wąsik, Faculty of Health Sciences, Jan Dlugosz University in Czestochowa, Armii Krajowej St. 13/15, 42-200 Czestochowa, Poland; e-mail: jwasik@konto.pl

Technique– *noun* a way of performing an action [27].

Performance – *noun* the level at which a player or athlete is carrying out their activity, either in relation to others or in relation to personal goals or standards [27].

Coordination – *noun* the ability to use two or more parts of the body at the same time to carry out a movement or task [27].

Rhythm – *noun* a regular movement or beat [27].

Velocity – *noun* the rate of change of position in a given direction, composed of both speed and direction [27].

Simulation – caused in model an event, which under some circumstances is similar to the event occurring in examined real object [28].

INTRODUCTION

Martial art's forms are common part of almost every traditional martial art. They emerged with a purpose of training without partner and equipment. Besides polishing separate techniques, it helps developing proper habits for certain combinations of techniques, which can be used in specific situations. Forms serves as unique catalogue of every technique used in specific martial art. In Japanese martial arts it is called "kata" [1], in China's wu shu and kung-fu it is "taolu" [2], in Korean, depending on federation it is called "poomse" for World Taekwondo Federation [3] and "tule"(meant as "patterns") in International Taekwon-do Federation [4]. Forms have special place, as its mastery is required to attain upper ranks (belts) in each martial art with strict degree system, usually with commonly known black belt for master level. For each rank there are certain requirements for separate technique mastery. There are certain forms, corresponding with its complexity with a level of those techniques.

Practising forms are safest type of practising martial arts. Lack of contact with opponent, alongside with dynamic type of movements makes it pro-health activity. It allows to improve coordination skill and enhance learning abilities, as more complex forms requires to memorize sequence of several moves. This may be important factor while developing and keeping nervous system in good condition through all phases of life – from childhood to elderly [5, 6]. Performing forms requires the same mastery of technique for dominant and non-dominant side of the body, as many moves are performed alternately. Stimulation of both sides of the body have positive effects on nervous system, as good development stimuli for the brain [7-10].

During official competitions, besides sparring competition, there are also competition regarding performing certain forms. In different martial arts, presenting level of mastery with high-complex forms for higher ranks and master ranks are prestigious on a same level as sparring. Mastery of fitness and necessity of certain simulation of real combat makes it interesting performance for competitors and audience [11, 12].

This study is focused on taekwon-do ITF (International Taekwon-do Federation) forms. Background of this phenomena will be narrowed to a specificity of this martial art. To reveal a winner from forms competition, judges are making verdict based strictly on official competition's regulations [13]. Each participant is starting with a 10 points, and can potentially loose points by making mistakes. The factors includes improper height of technique, loss of balance, stopping performance for more than 1 second, lack of strength in separate technique, wrong order of steps or improper execution of technique. Therefore, rhythm, tempo and subjective impression of technique's strength is evaluated by judges.

Modern assessment tools used in biomechanics research allows to objective quantitative analysis of measurements such as time, velocity or acceleration. Those components are important while executing basic movement patterns. In more complex diagnosis such analysis could detect and eliminate weak points of every sportsman [14]. It helps optimizing training and improves its safety. Some researcher suggests, that athletes should be assessed by means of biomechanics on a regular basis. Quantitative analysis of progress is more reliable and could prevent possible negative outcomes like injuries [15-18].

As taekwondo forms (patterns) are not common area of interest for researchers. So far biomechanical assessment of movement's kinematics has only been applied to single techniques or series of the same technique.

The aim of this paper was knowledge about the usefulness of kinematic assessment in objective analysis of rhythm (patterned recurrence of movement in time), tempo (speed of motion) and dynamics of taekwondo techniques while performing certain form.

MATERIAL AND METHODS

Subject

ITF taekwon-do athlete (gender: male; age: 30 years; body mass: 56 kg; height: 160 cm) participated in this study. During an analysis, the participant performed a sequence of techniques called *saju-jirugi* [4]. The sequence starts from right punch. As this form could be performed for both sides, depending on starting side of a punch, sole sequence is called "half-form". It is one of basic requirements for novice athletes to obtain white belt (first degree). This form is composed of for straight punches (*gunnun so baro jirugi*) and three blocks for low zone (*gunnun* *so bakat palmok najunde maki*). Those two techniques is performed alternately (Figure 1).

Prior to commencing the study, formal consent was sought from participant. He was informed about test procedures and voluntarily participated in data collection. The study was conducted with ethic rules based on Helsinki Declaration.

Protocol

This case study we examine maximal velocity of both fist of taekwondo athlete while performing

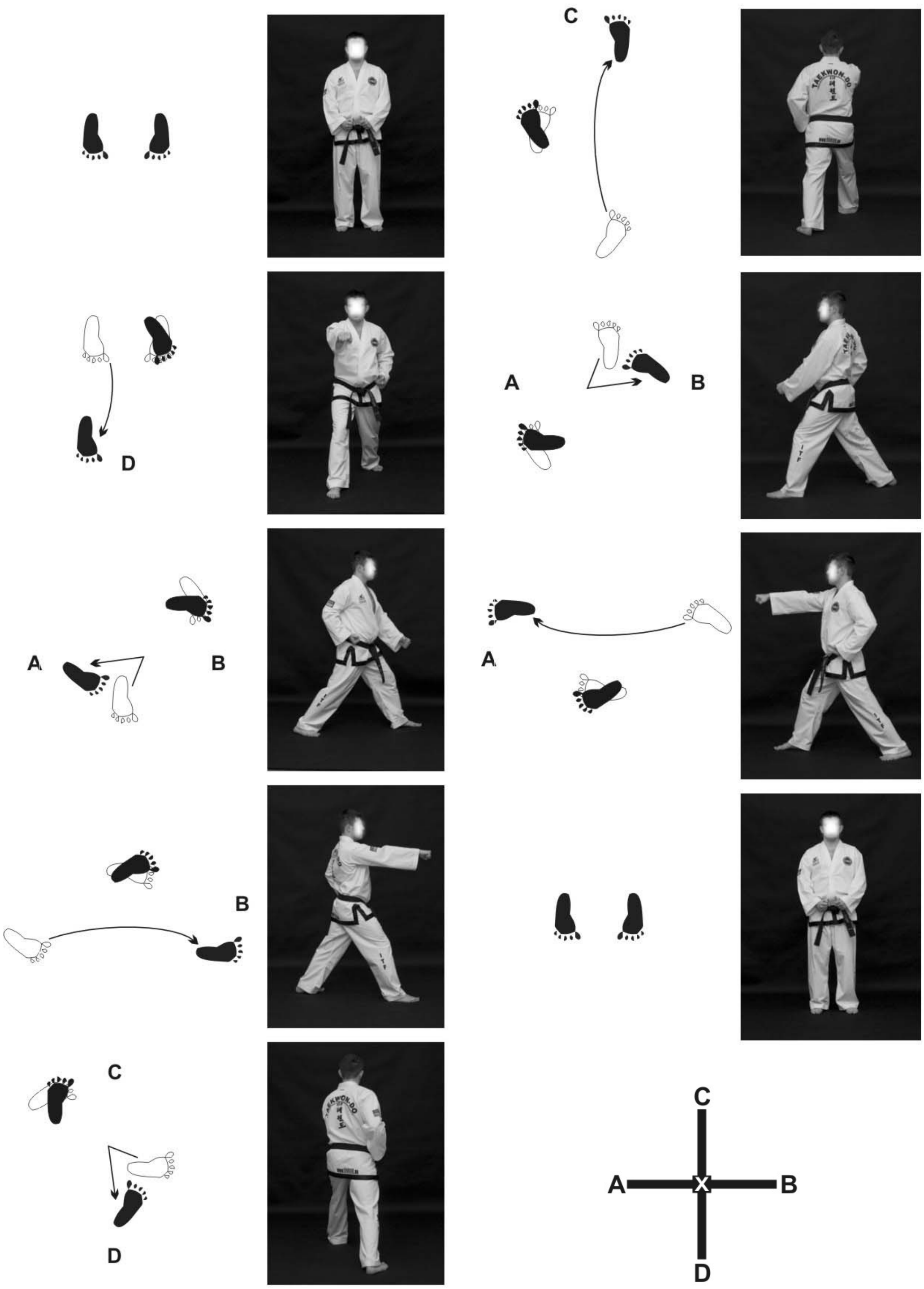

Figure 1. Presentation of *saju jirugi* form with a movement direction diagram.

certain form and which components affects its value during specific phases of movement.

Hardware specifications: for the purpose of this analysis, inertial system created by Noraxon Ultimum® EMG were used (Figure 2). EMG sensors were used as Ultium Internal Inertial Measurement Unit (IMU) for measuring acceleration in three dimensions. The Ultium™ sensor contains an IMU which allows for the measurement and transmission of angular velocity, acceleration, and magnetic field amplitude. Sampling rate were set to 2000 Hz, which gives data acquisition every 0.005 s. Specification of sensors parameters: Gyroscope ±2000 degrees/second; Accelerometer ±16 g; Magnetometer ±4800 μT.

Acceleration and angular velocity data from both sensors attached to dorsal area of fist was obtained. Data was obtained for three axis (X, Y, Z) separately. From resultant acceleration, velocity values was calculated for every measured frame accordingly to Euclidean norm of vectors. Resultant angular velocity was from three axis (X, Y, Z).

Maximal velocities (both linear and angular) and time of its occurrence was determined using algorithm written in python programming language with use of SciPy library. Those calculations were conducted in Jupyter Lab environment. Computation method was valid and previously used as vector method [19].

Statistical analysis

Mean and standard deviation was calculated for all registered maximal velocities. Correlation between chosen kinematic variables was determined by using Pearson's correlation coefficient. All calculation was conducted using MS Excel 2000.

RESULTS

On the graph, "theoretical perfection line (red)" was set. Its shows expected values for every single strike (Figure 2). Maximal velocity of striking punch (right), gradually decreases from 11.68 m/s to 8.55 m/s. In the same time, maximal velocities of retracted, opposite hand was higher for every punch (highest value of 12.67 m/s), but without same tendency (Table 1). There is moderate correlation between maximal velocities of both hands during measured strikes (r = 0.65). There is also moderate negative correlation between difference in time when maximal velocity occurs and maximal velocities for both hands during strike (r = −0.59 for right hand and r = −0.52). Highest correlation was between difference in values of maximal velocities of both hands and value of maximal velocity for retracted (left) hand (r = 0.95) (details in Table 2).

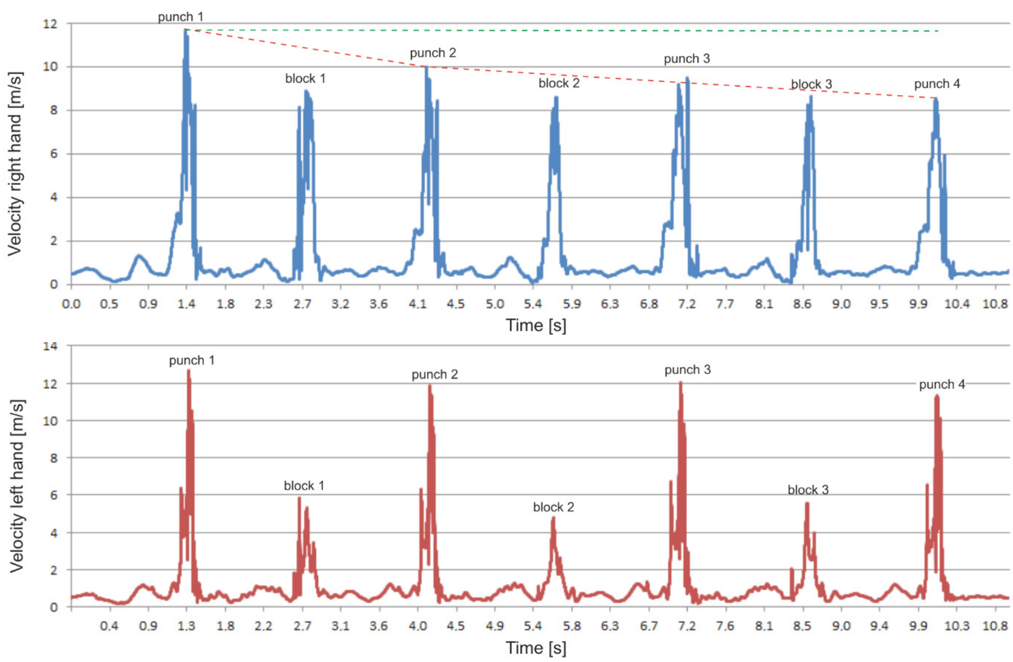

Figure 2. Velocity changes for a right (striking) hand and a retracted (left) hand during *Saju-Jirugu*, started from right punch.

Table 1. Chosen linear indicator's values during Saju-jirugi performance.

Technique	Right hand		Left hand		Right hand	Left hand	Δv	ΔT
	T_R [s]	V_R [m/s]	T_L [s]	V_L [m/s]	δT_R	δT_L		
Punch 1	3.33	11.68	3.37	12.67	-	-	0.99	−0.04
Block 1	4.75	8.90	4.67	5.83	1.42	1.30	−3.07	0.08
Punch 2	6.16	10.00	6.20	11.88	1.41	1.53	1.88	−0.04
Block 2	7.67	8.62	7.64	4.80	1.51	1.44	−3.81	0.03
Punch 3	9.20	9.50	9.12	12.04	1.54	1.48	2.54	0.08
Block 3	10.64	8.68	10.60	5.55	1.44	1.48	−3.13	0.04
Punch 4	12.11	8.55	12.11	11.31	1.47	1.51	2.76	0.00

$\mathbf{T_R}$, $\mathbf{T_L}$ time (T) of maximal velocity occurrence for right (R) and left (L) hand; $\mathbf{V_R}$, $\mathbf{V_L}$ maximal velocity value for right (R) and left (L) hand; $\delta\mathbf{T_R}$, $\delta\mathbf{T_L}$ time between occurrence of maximal velocity of each move for right (R) and left (L) hand; $\Delta\mathbf{v}$ difference between $\mathbf{V_L}$ and $\mathbf{V_R}$, $\Delta\mathbf{T}$ – difference between $T_R - T_L$

Table 2. Pearon's correlation matrix between chosen linear indices.

Indicator	V_R	V_L	δT_R	δT_L	Δv	ΔT
V_R	-	**0.65**	−0.19	0.29	0.41	**−0.59**
V_L	**0.65**	-	0.11	**0.61**	**0.95**	**−0.52**

$\mathbf{T_R}$, $\mathbf{T_L}$ time (T) of maximal velocity occurrence for right (R) and left (L) hand; $\mathbf{V_R}$, $\mathbf{V_L}$ maximal velocity value for right (R) and left (L) hand; $\delta\mathbf{T_R}$, $\delta\mathbf{T_L}$ time between occurrence of maximal velocity of each move for right (R) and left (L) hand; Δv difference between V_L and V_R; $\Delta\mathbf{T}$ – difference between $T_R - T_L$; bolded values states for statistical significance at $p<0.05$

For obtained maximal values of an angular velocity, there is the same phenomena, where retracted fist values are higher than striking one (minimal value for left hand is 2980.67 deg/s while maximal for striking hand is 2414.40 deg/s). Also, while performing blocks, where an angular velocity values are higher (Table 3). In case of an angular velocity values, correlation between right and left hand maximal velocities was higher in comparison to linear ones, but negative (r = −0.87). All correlation of a maximal angular velocities for both hands, between difference in velocities values and time was high or very high. For right hand, correlations were positive (r = 0.92 for difference between maximal angular velocities and r = 0.80 for difference between time of its occurrence). For left hand correlation values was higher, but it was negative (r = −0.99 for difference between maximal angular velocities and r = −0.97 for difference between time of its occurrence). Details are presented in table 4.

Table 3. Chosen angular indices registered by gyroscope during *saju-jirugi* performance.

Technique	Right hand		Left hand		Right hand	Left hand	Δv	ΔT_ω
	$T_{R\omega}$ [s]	ωR [deg/s]	$T_{L\omega}$ [s]	ωL [deg/s]	$\delta T_{R\omega}$	$\delta T_{L\omega}$		
Punch 1	3.35	2414.40	3.36	3004.42	-	-	**−590.01**	−0.01
Block 1	4.76	2486.75	4.73	2089.39	1.41	1.37	397.35	0.03
Punch 2	6.18	2284.35	6.19	3041.50	1.41	1.45	**−757.14**	−0.01
Block 2	7.64	2629.69	7.61	1977.66	1.46	1.43	652.02	0.02
Punch 3	9.10	2190.88	9.11	3026.14	1.47	1.49	**−835.26**	−0.01
Block 3	10.60	2481.43	10.58	2159.02	1.50	1.47	322.42	0.02
Punch 4	12.09	2202.38	12.11	2980.67	1.49	1.52	−778.29	−0.01

$\mathbf{T_{R\omega}}$, $\mathbf{T_{L\omega}}$ time (T) of maximal angular velocity(w) occurrence for right (R) and left (L) hand; **ωR, ωL** maximal angular velocity(ω) value for right (R) and left (L) hand; $\delta\mathbf{T_{R\omega}}$, $\delta\mathbf{T_{L\omega}}$ time between occurrence of maximal angular velocity (ω) of each move for right (R) and left (L) hand; $\Delta\omega$ difference between ωR and Lω; $\Delta\mathbf{T}$ difference between $T_{R\omega} - T_{L\omega}$

Table 4. Pearon's correlation matrix between chosen angular indicies.

Indicator	ωR	ωL	$\delta T_{R\omega}$	$\delta T_{L\omega}$	Δw	ΔT_{ω}
ωR	-	**−0.87**	−0.11	**−0.65**	**0.92**	**0.80**
ωL	**−0.87**	-	0.00	**0.66**	**−0.99**	**−0.97**

$T_{R\omega}$, $T_{L\omega}$ time (T) of maximal angular velocity(ω) occurrence for right (R) and left (L) hand; **ωR, ωL** maximal angular velocity(ω) value for right (R) and left (L) hand; $\delta T_{R\omega}$, $\delta T_{L\omega}$ time between occurrence of maximal angular velocity (ω) of each move for right (R) and left (L) hand; Δω difference between ωR and Lω; **ΔT** difference between $T_{R\omega} - T_{L\omega}$; Bolded values states for statistical significance at p<0.05

Comparison of linear and angular indices for strikes values only shows that there are high and very high correlation values between maximal angular velocity values of right hand and maximal linear velocity values of both hand (r = 0.94 for right and r = 0.80 for left hand). Results of angular velocity values of left hand did not correlate with those indices. Moreover, there is high, negative correlation between differences in maximal linear velocity values for both hands and corresponding values of angular velocity (r = −0.91) (detailed in Table 5).

DISCUSSION

Participant strikes with mean linear velocity of 9.93 ±1.13 m/s. However, mean value does not provide any substantial information in that case. Crucial element of proper performance of taekwon-do forms is constant dynamics of movements on a high level as presented in Figure 2 in a manner of theoretical perfection line. In this case, participant obtained high value of first strike (11.68 m/s), which is higher values that reported in previous studies. All available reports of kinematic analysis of this technique was previously examined by authors of this study. Mean values for straight punch without specific target (aimless punch) was 7.19 m/s [20] in study from 2016, 8.05 m/s from study in 2017 [21], 6.20-8.01 m/s from study in 2018, but those punches was aimed for no-impact target [22]. Most up-to-date studies revealed velocities of 9.17 m/s for traditional technique of straight punch, similar as in this study [23]. Rest of values of participant of this study was decreasing with following strikes up to 8.55 m/s. This may indicate, that laboratory environment may affect athlete performance, while measuring performance during forms presentation could be closer to their reality, which evoke their true potential in terms of maximal kinematic values.

Obtained values of blocks kinematic indices were more stable (from 8.90 m/s to 8.62 m/s) with a difference not exceeding 0.28 m/s. For retracting hand during a strike and blocks, values were also decreasing. We can suppose, that this phenomena is connected with possible lack of sufficient endurance or motivation. Another factor may be lack of self-assessment competence, where participant could not determine himself, whereas his strike was slower in following sequence.

Interesting phenomena was revealed by comparing difference between maximal velocities for every movement (Δv). Blocks could be detected solely by negative values of this indicator. Based on Table 2, we can conclude, that (Δv) have high influence on strike's velocity. It was also confirmed by correlation between V_R and V_L (r = 0.65). Therefore, velocity of retracting hand affects, velocity of striking hand, which corresponds with Newton Laws of Dynamic. As the direction of vectors are opposite, it produces

Table 5. Correlation matrix only for strikes indicator values.

Indicator	ωR	ωL	Δω
V_R	**0.94**	0.25	**0.85**
V_L	**0.80**	0.31	**0.71**
Δv	**−0.98**	−0.19	**−0.91**

ωR, ωL maximal angular velocity(ω) value for right (R) and left (L) hand; $\mathbf{V_R}$, $\mathbf{V_L}$ maximal velocity value for right (R) and left (L) hand; Δω difference between ωR and Lω; **Δv** difference between V_L and V_R; bolded values states for statistical significance an p<0.05

additional torso torque, which enhances strike velocity. Not only velocity, but also time between occurrence of a maximal velocity for both is significant (ΔT) (r = −0.52; r = −0.59). The lesser is that difference, the higher is the maximal velocity of performed move. Therefore important application information from this study is, that trainers should put special attention to retracting hand during learning and mastering process.

With use of δT_L, δT_R we can describe a tempo and rhythm of following sequence of moves. In the registered form of *saju-jirugi*, those values are not constant. In an ideal performance, those indicators should have the same values throughout all sequence. In this assessment, differences ranged from 0.01 s to 0.1 s for right hand and from 0.001 s to 0.23 s for left hand. Moreover, the velocity of a strike is correlated with a rhythm (r = 0.61).

Obtained data reveals that striking and blocking hand (right one) have lower values of an angular velocities (2190.88-2414.40 deg/s) than left hand (2980.67-3026.14 deg/s). Therefore supination of forearm movement of is faster that pronation of forearm of striking hand. Moreover, proper synergy of scapula's muscles is necessary for efficient force production. Therefore, proper scapula retraction and energy transfer contributes to throwing-like motion of straight punch strike.

Difference in an angular velocity of the fist (Δv) indicates reversed correlation with Δv (Table 4). In this case, blocks could be detected by positive values of this indicator. Another interesting correlation is shown between pronation of one hand and supination of another (r = −0.87). This phenomena is confirmed in correlation between Δv and ωR and also between Δv and ωL.

Despite described crucial contribution in producing maximal velocity of striking punch, there were no significant correlation between linear and angular velocity of retracted hand. However, for striking hand, those values were highly correlated. In the applicational assumption from this study, it could indicate, that depending of motion capture devices and techniques, angular and linear velocities could serve equally as determinant of performance quality. This is important, because of cost of equipment and availability of such measurement as common technique in broad group of athletes. Sometimes it is easier to obtain gyroscope data than full accelerometer, not to mention stereogrammetry data with support of additional sensors.

Empirical verification of martial art forms performance contributes to development of innovative agonology, as a concept of evidence-based science about struggle [25]. As martial arts forms imitates fight with multiple opponents, objective feedback about what is right (repetitive values of maximal velocity of each strike perceived as full effort of practitioner) may be as beneficial as punishment of unproper behaviour during therapy with use of fun forms of martial arts [26].

CONCLUSIONS

Conducted research provides sufficient arguments, that this type of measurement allows to objectively measure performance in a single trial as well as monitoring of its progress. It allows detailed and complex diagnosis of a level of preparedness of an athlete for competition. Results of such measurement allows to control a training process and detect a weak parts of athlete performance. It allows to adjust training in following months to correct errors and improve performance for aimed competition.

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