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Comparative Study of Kinematic Parameters of Circular Punch Applied in Semi-Contact and Full-Contact System

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Abstract

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Using inertial navigation technology built into MOVEN motion capture equipment, we calculated, based on the position of a kickboxer's body segments, several kinematic parameters of circular punch features. These are the length of fist trajectory from the beginning of the movement to its contact with the target, the length of fist path measured from the beginning of the elbow extension to the contact with the target, the variation in time of the elbow extension angle, the variation in time of shoulder and hip lines and the difference between them during impact with the target, the average speed on certain segment motions, maximum speed of the fist before impact with the target, acceleration of the fist at the impact with the target. Measurements were made at "Ciprian Sora" Sports Club in Bucharest, on 28 August 2014, and the subject was the national champion of the year in full-contact kickboxing and kickboxing world vice-champion in 2014, in 63kg weight class. After fitting the MOVEN equipment and its calibration was performed, the subject applied ten circular punch strokes in semi-contact system and then ten circular punch strokes in full-contact system. Data acquisition was performed with a frequency of 100 Hz (the acquisition rate of 10 ms). Data were converted using the equipment-related software in .mvnx format, and then were imported into Excel 2010 and processed. The mentioned kinematic parameters were calculated to analyse the strike features and the comparison of each fight system.

Keywords: Kickboxing; circular punch; kinematic parameters; MOVEN.

1. Introduction

A statistic presented in the *Handbook of Biomechanics and Human Movement Science* (2008) shows that, out of 8000 articles on martial arts in SportDiscus, only 2 percent are biomechanics-related, so we can tell the biomechanics of the martial arts is just at the beginning. There are very few quantitative descriptions explaining how techniques should be conducted and, as it is expected, most part of the researchers' studies try to find out how experts' movements are (Vieten, 2008).

This study is part of the range referring to the biometric analysis of the fist strikes used in combat sports. In this study, we analyse the circular fist kick applied with the back arm, large hook, swing, or gyaku mawashi tsuki – all of them being synonyms in naming the same technique. We will make reference to the strikes applied in semi-contact system (with controlled contact) and in full contact.

The purpose of this study is to obtain objective and accurate information regarding this technique and to point out some aspects regarding the distance, trajectory, fist's velocity and execution velocity. The circular punch is aimed to touch the target (a part of the body that points in competitions or in a box bag, in our experiment) on a curved trajectory. The fist has a longer trajectory, but its speed at the moment of reaching the target is bigger compared with the direct punch. The impact power is higher, surprising the opponent and reducing his/her abilities to organize one's defence (blocking, parade or shirk). As we mentioned in previous studies (Băiţel & Deliu, 2013a; Băiţel & Deliu, 2013b; Băiţel, Deliu, & Cordun, 2015), even if the majority of fist strike techniques are apparently simple, in every of these techniques, there can be precisely defined moving sequences with their space and time limits.

For a better understanding of the facts, we have to make some references to the concepts used: trajectory, distance, shoulder line, hip line. Every acquisition in segment coordinates represents the distances, on the three axes, towards the orthogonal system, defined by the system in the moment of calibration of the equipment. Totalizing the recorded values (calculated in space) between two temporal landmarks provides the length of the trajectory that segment goes through the space. The difference of the two values (initial and final ones) provides the distance between initial and final position of the segment, which, in the circular punch situation, is shorter than the fist's trajectory between the two limits.

The shoulder line represents the angle between the shoulder line and the Ox axis, and the hip line represents the angle between the hip line and the same Ox axis. These two angles are calculated in a horizontal plane, using the Ox and Oy coordinates of the segments. Through these cinematic parameters, we get information about the succession of upper and lower body involvement in a certain movement and about those segments stiffening at the impact moment with the target. This is a very important aspect in full-contact strikes; the impact power depends of the involved muscular mass. The way the body segments are kinetically coupled influences the increasing or decreasing of the involved muscular mass.

2. Materials and methods

Taking into account the action velocity required by real-fighting conditions (competition), with an unpredictable opponent, this time the delimitation of movement sequences is possible only if we have very precise measuring instruments. That is the reason why we used the MOVEN from Xsense acquisition system. The sensors of this equipment cover the inertial navigation technology.

The equipment was attached, using a strip system, to the research subject, a kickboxer of international level – second in World Championship full-contact boxing, 63 kg, in 2014. The subject applied 10 swing semi-contact strikes and 10 full-contact ones in a suspended 30-kg boxing bag. The test was done in August 2014, in the training hall of "Ciprian Sora" Sports Club.

The 17 kinetic sensors of the equipment were attached to the whole body of the athlete: feet, lower legs, upper legs, hands, forearms, arms, shoulders, sternum, pelvis and head. The Xbus masters synchronize the 17 sensors' acquisitions and send wireless information on the position, in relationship with the orthogonal axes, to the MVN Studio software on a laptop. The .mvn files are transferred to .mvnx format and then to Excel 2010. From the multitude of information concerning the 23 body segments, we chose those related to fist, elbow and right shoulder (the side that makes the kick) and those concerning the hips and shoulders (both, left and right). The MVN system is a full-body inertial system for measuring the cinematic, having video data in phase. Using the pre-recorded anthropometric parameters, the MVN software creates a subject's avatar that can be 3D visualized any time after recording, with different speeds – even frame by frame. The acquisition rate is 100Hz.

In this research, we used: observation method, bibliographical study method, experimental method, mathematical method, graphical method and case study method.

3. Results

The methodology in the biomechanical analysis of the circular strike, with the inertial navigation technology, is almost similar with what we have presented in previous works concerning the straight fist strikes:

- The import of the position acquisitions concerning the interested segments: fist, elbow and right shoulder, and hips and shoulders, all of them with reference to the orthogonal coordinate axes;

- The calculation, based on purchased data, of the hip space position and, following its position, the time variation on the whole movement length. It uses the Pythagorean space theorem – formula (1):

$$p = \sqrt{x^2 + y^2 + z^2} \qquad (1)$$

Where:

$x = x_n - x_{n-1}$

$y = y_n - y_{n-1}$

$z = z_n - z_{n-1}$

- Intersegmental angle calculation – elbow extension (2), the angle between humerus and the vertical (6) and their time variation:

$$\alpha = \text{acos} \frac{a^2 + b^2 - i^2}{2ab} \times \frac{180}{\pi} \; [°] \qquad (2)$$

Where:

a = forearm length

b = arm length

i = distance between shoulder and fist

$$a = \sqrt{(p_x - c_x)^2 + (p_y - c_y)^2 + (p_z - c_z)^2} \qquad (3)$$

$$b = \sqrt{(c_x - u_x)^2 + (c_y - u_y)^2 + (c_z - u_z)^2} \qquad (4)$$

$$i = \sqrt{(p_x - u_x)^2 + \left(p_y - u_y\right)^2 + (p_z - u_z)^2} \qquad (5)$$

Where:

p_x, p_y, p_z = fist coordinates on ox, oy, oz axes

c_x, c_y, c_z = elbow coordinates on ox, oy, oz axes

u_x, u_y, u_z = shoulder-fist distance

$$\beta = acos \frac{u_z - c_z}{\sqrt{(c_x - u_x)^2 + (c_y - u_y)^2 + (c_z - u_z)^2}} * \frac{180}{\pi} \quad [°] \qquad (6)$$

Where:

β = angle between humerus and horizontal

u_x, u_y, u_z = shoulder coordinates on x, y, z axes

c_x, c_y, c_z = elbow coordinates on x, y, z axes

▪ Calculation of the shoulder line, hip line and their time variation:

$$S_l = atan2(s_{drx} - s_{stx} , s_{dry} - s_{sty}) \qquad [°] \qquad (7)$$

Where:

S_l = shoulder line

s_{drx}, s_{dry} = right shoulder position coordinates on Ox, respectively Oy axes

s_{stx}, s_{sty} = left shoulder position coordinates on Ox, respectively Oy axes

And:

$$H_l = atan2(h_{drx} - h_{stx}, h_{dry} - h_{sty}) \qquad [°] \qquad (8)$$

Where:

H_l = hip line

h_{drx}, h_{dry} = right hip coordinates on Ox, respectively Oy axes

h_{stx}, h_{sty} = left hip coordinates on Ox, respectively Oy axes

▪ Fist acceleration during time:

$$a_{cc} = (v_2 - v_1) / 0{,}010 \ [m/s^2] \qquad (9)$$

▪ Distance between the beginning of the attack and the point where the fist reaches the target:

$$d = \sqrt{\left(x_f - x_i\right)^2 + \left(y_f - y_i\right)^2 + \left(z_f - z_i\right)^2} \ [m] \qquad (10)$$

▪ Putting the results into Rota

▪ Identification of the move sequences for each strike:

    o The reinforcement (the slow part of the move) – z decreases

    o The attack (the speed part of the strike)

    o The impact (the sudden decrease in speed)

    o The fist's withdrawal

▪ Setting the temporal sequences

▪ Estimation of the fist trajectory length during the established movements

- Estimation of the average speed of the fist during the move sequence delimited by the beginning of elbow extension and the impact with the target (the moment is recording a minimum fist's acceleration);
- Estimation of the average speed of the fist at the contact with the target;
- Estimation of the maximum speed of the fist before the contact with the target;
- Comparing the cinematic parameters for semi-contact and full-contact strikes.

In Table 1, we present the main cinematic parameters calculated for semi-contact strikes, where:

T_1 – space for preparing the strike (armouring) [ms];

T_2 – space of fist attack (the beginning of high speed drive of the fist through the impact with the target) [ms];

T_3 – space from the impact through the beginning of the fist's withdrawal [ms];

L_1, L_2, L_3 – fist's trajectory length during T_1, T_2, T_3;

L – fist's trajectory length during $T_1 + T_2$;

v_{1-2} – fist's velocity during T_1 [m/s];

v_2 – fist's velocity during T_2 (the attack) [m/s];

a_{cc} – fist's acceleration on impact [m/s²];

v_{max} – fist's maximum velocity (before the impact) [m/s];

α – elbow extension angle at the impact and at the beginning of the fist's withdrawal [°];

β – angle between arm and the vertical axis on the impact moment and at the beginning of the fist withdrawal [°];

Hl – Sl – difference between the hip and shoulder lines at the impact and at the beginning of the fist withdrawal [°];

d – distance between the point considered the beginning of the attack phase and the point where the impact occurs [m];

d'_{xoy} – length of the projection into xOy plane for the d segment [m].

**Table 1.** Cinematic parameters for semi-contact punch strikes

T1 [s]	T2 [s]	T3 [s]	L1 [m]	L2 [m]	L3 [m]	L [m]	v1-2 [m/s]	v2-3 [m/s]	vmax [m/s]	v strike [m/s]	α [°]	β [°]	Hl - Sl [°]	d [m]	d'xoy [m]	z2 [m]
0.09	0.110	0.030	0.142	0.57	0.11	0.72	1.57	6.38	6.68	5.49	55.68	59.1	7.3	0.6	0.56	1.30
0.14	0.080	0.010	0.302	0.60	0.05	0.90	2.16	7.47	8.84	7.07	135.2	66.8	8.9	0.57	0.55	1.33
0.06	0.080	0.010	0.189	0.61	0.08	0.80	3.15	7.67	8.09	7.21	129.7	84.7	1.36	0.6	0.53	1.36
0.07	0.080	0.020	0.210	0.62	0.06	0.83	3.00	7.78	8.53	7.28	142.5	86.7	1.33	0.6	0.57	1.33
0.07	0.08	0.02	0.212	0.64	0.06	0.86	3.03	8.05	9.47	7.50	139.6	95.5	-4.3	0.6	0.56	1.43
0.06	0.090	0.010	0.194	0.61	0.08	0.81	3.23	6.82	7.62	5.86	126.5	85.8	-9.5	0.53	0.50	1.37
0.08	0.080	0.020	0.224	0.63	0.08	0.85	2.80	7.83	9.06	6.83	132.1	91.2	-3.0	0.55	0.52	1.39
0.08	0.070	0.020	0.136	0.53	0.08	0.77	1.70	7.59	8.40	7.23	136.0	84.4	-8.2	0.51	0.45	1.31
0.07	0.070	0.020	0.221	0.59	0.06	0.81	3.16	8.39	9.61	7.34	127.8	80.4	-5.4	0.51	0.49	1.32
0.09	0.080	0.020	0.240	0.57	0.06	0.81	2.67	7.08	7.28	6.11	127.6	82.1	-10.2	0.49	0.44	1.35

In Table 2, we present the same cinematic parameters calculated for full-contact strikes.

Table 2. Cinematic parameters for full-contact punch strikes

T1 [s]	T2 [s]	T3 [s]	L1 [m]	L2 [m]	L3 [m]	L [m]	v1-2 [m/s]	v2-3 [m/s]	vmax [m/s]	v strike [m/s]	α [°]	β [°]	Hl-Sl [°]	d [m]	d'xoy [m]	z2 [m]
0.1	0.090	0.010	0.259	1.00	0.05	1.26	2.59	11.13	12.99	9.64	130.2	87.5	-0.4	0.87	0.83	1.31
0.08	0.090	0.020	0.228	1.07	0.09	1.30	2.85	11.93	13.13	10.17	121.2	96.2	0.7	0.9	0.85	1.34
0.1	0.090	0.020	0.257	1.06	0.07	1.31	2.57	11.75	13.60	10.12	124.6	100.3	6.2	0.9	0.82	1.40
0.13	0.080	0.020	0.290	0.86	0.08	1.15	2.23	10.70	11.27	9.26	128.0	89.9	4.3	0.74	0.73	1.29
0.10	0.090	0.020	0.221	0.92	0.07	1.14	2.21	10.18	12.68	8.91	137.3	91.1	10.1	0.80	0.75	1.31
0.09	0.090	0.020	0.222	1.02	0.06	1.24	2.47	11.31	12.87	9.76	130.1	101.6	7.3	0.88	0.80	1.42
0.09	0.080	0.020	0.210	0.87	0.10	1.08	2.34	10.89	11.77	9.48	99.3	72.1	-8.0	0.76	0.74	1.23
0.11	0.090	0.020	0.248	1.02	0.06	1.27	2.25	11.34	13.11	9.83	135.9	89.5	11.8	0.88	0.83	1.30

Figures 1, 2 and 3 show the variations in time for the fist's velocity, fist's acceleration and intersegmental angles (elbow extension, angle between arm and the frontal plane, difference between hip line and shoulder line). Graphs are presented comparatively for semi- and full contact for a better observance and differentiation.
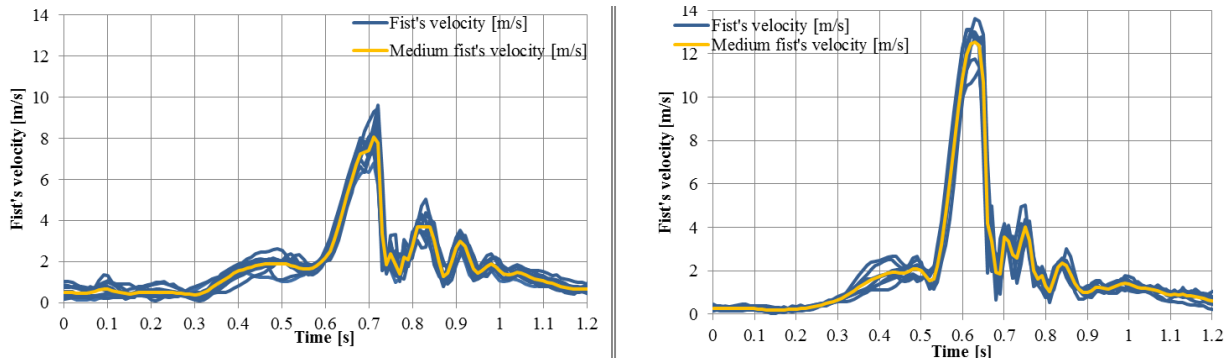
Fig. 1. Fist's velocity variation in time for semi-contact (left) and full contact (right)
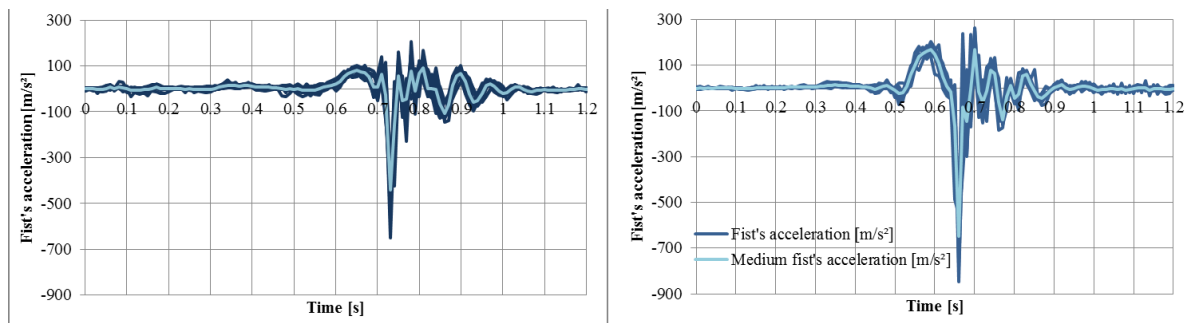
Fig. 2. Fist's acceleration variation in time for semi-contact (left) and full contact (right)
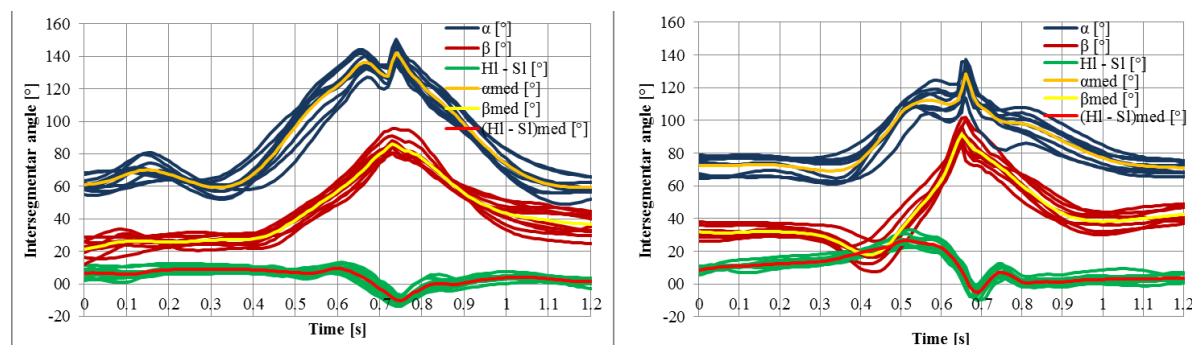
Fig. 3. Fist's intersegmental angle variation in time for semi-contact (left) and full contact (right)

4. Discussions and conclusions

We can see a lot of similitudes between the semi-contact and full-contact kicks:

- The reinforcement is a slow moment for both moves;
- The length of the attack phase is similar for both styles;
- The preferred striking level was the same;
- The difference between hip and shoulder lines was smaller than 15° for all strikes, no matter the style.

However, we can underline a lot of important differences, too:

- The speed of the attack is higher in full-contact;
- The fist's acceleration is bigger on the attack phase and smaller to the impact for the full-contact kicks;
- The elbow extension is shorter for the full-contact kicks;
- The difference to the impact between hip and shoulder lines is a negative one for all semi-contact kicks. The shoulder's twisting is more accentuated than the hip's for a better control at the impact moment;
- The positive values show a good kinetic connection between the upper and lower body for touching the purpose: a maximum impact.

Regarding the results, some specifications should be made concerning the fist's velocity in the strike. As we have shown, the movement sequences composing the specific technique are developed over a time and with different speeds. This allows different interpretations when we speak about the strike's velocity, or the execution velocity, mainly a circular one. On the other hand, we consider the fist's speed as being the ratio between the length of the trajectory and the time that the fist needs to do this. Secondly, and more pragmatically, we make reference to the necessary time to get from point A to point B (Deliu, 2008a), no matter the trajectory. In this manner, we refer to the execution velocity. Not least, referring to the fighting distance (Deliu, 2008b), we must take account the projection into the horizontal of the distance $-d'_{xOy}$ parameter.

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