POSSIBILITIES TO OBJECTIFY THE TECHNICAL ELEMENTS OF MARTIAL ARTS - KICKBOXING WITH THE HELP OF KINEMATIC ANALYSIS

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Knowing best the Romanian kickboxing trainings level, but also having a good sense of the levels from other martial arts we considered that by using cinematic analyzes through modern technology applicable to motor activities we can objectify the executions of the technical elements from kickboxing in order to have a new approach in terms of evaluating them. For this study, a system of inertial measurement units was used, capturing the movement of the entire human body performing specific kickboxing techniques, each sensor being composed of 3D gyroscopes, accelerometers and 3D magnetometers, small in size along with advanced algorithms and biomechanical models..
The system used in the studio was MVN Awinda, the version based on sensor straps, which transmits data to the PC / laptop wirelessly. There are 17 motion tracking sensors attached to the body in order to reconstruct 3D the human movement. Through this study we wished to link the methodical indications from the specialty literature and concrete technical executions, proving that the biomechanics elements can be objectively measured. Some of the most used striking techniques were chosen, performed by high level Romanian kickboxers and monitored with said equipment in order to objectify them and extract information useful for conducting trainings. We measured key kinematic parameters and extracted precise data about punching velocity, hips and shoulder rotations and angle varations.
Likewise, the research is meant to be a step for future studies, even in other sports disciplines and to encourage the use of technology in sports training.

`***Keywords:*** *martial arts, objectivity, Xsens MVN.*

Introduction

In the past century, technology in all fields has undergone an impressive evolution, making the accomplishment of daily tasks more and more easily, including in sports. Based on such modern technologies, we considered that we can bring an improvement in the martial arts trainings, more specific in kickboxing.

Martial arts, as sports disciplines, aim for victory over the opponent through both direct confrontation, in this case the fights are subdued to the rules of their own branches and styles, and indirect, when the rankings are made by scores obtained separately, without contact with the opponent.

The fighting techniques, both offensive and defensive, are most often executed in fractions of a second, with victory most frequently achieved by the combatant who was first able to throw the opponent, who was the fastest to submit the opponent, or who was the first to reach the target of the strike, with different levels of strength according to the fighting style. Thus, the motor quality probably universally accepted as decisive in achieving success is speed.

As a result, the techniques where performance is aimed, are trained to achieve the highest level of speed and the highest level of force in the shortest possible time.

Currently, these technical executions are most often evaluated solely based on the observations of coaches or other people involved in the training of the athletes. Such observations, regardless of the experience and the level of knowledge of the observer, regardless of the desire to be right and fair in providing methodical indications or comparisons between performers, are influenced by subjectivism.

Besides, capturing all the details of an execution that happens in such a short time, only through human analyzers, is probably impossible.

In high performance trainings, athletes perform techniques tens, hundreds or even thousands of times. Wouldn't it be better if, instead of repeating thousands of times a mistake that might escape the eye, an objective monitoring and analysis would be possible, one that would allow a new perspective on training and reveal new useful information in order to achieving performance?

At such level, any small detail can make the difference between gold or silver medal. We think that's how we can really talk about perfecting techniques.

Romania is well represented in terms of martial arts federations of different styles and also in terms of number of clubs and practitioners by all levels and ages. Through its national teams, Romania obtained remarkable results at International martial arts competitions in modern history, maybe most notable being: medals at Olympics by the women team and numerous top results at the World and European Championships in kickboxing, karate, taekwondo, kempo, judo.

Romanian kickbox is run by the Romanian Contact Martial Arts Federation, the All Styles Department, which is affiliated by the World Association of Kickboxing Organizations (WAKO). Recently, kickboxing has now received full Olympic recognition at the 138th IOC session. Very unlikely in Paris, but Romania might participate the Olympic Games planned to be held in Los Angeles also with the national kickboxing team.

Despite of the existence of various national teams for all ages coordinated by the National Federations and of top private clubs that seeking high performance, most of them are not using advanced technology specific to sports disciplines in their trainings.

The national and international specialized works present different opinions in this direction, both from the perspective of the means used, the results obtained, and the perspective of the approach.

Among the first research on biomechanics in combat sports is the study by Vos and Binkhorst (1966) on the mechanics of karate kicks. They aimed to understand the process of breaking bricks or concrete slabs by karate practitioners. They compared data obtained from three style experts and from two subjects who had not practiced at all before. All were instructed to break the tiles and bricks using their bare hands. The results showed that those with sports experience are able to develop higher hand speeds than control subjects, with a maximum speed of 14.2 m/s. The researchers used force platforms placed under the breaking materials. They noted the impact forces needed to break, but did not describe what they represented. The final conclusion was that it is important for the hitting segment to develop as high a speed as possible.

In 1975, Walker suggested that an important variable that affects the impact force is the actual mass of the impact, without reporting values of this variable. He performed a kinematic-kinetic analysis at 200 frames / s of the gyaku-zuki karate shot (direct punch) executed in the bag with training gloves. Studies have shown that high fist speeds do not necessarily produce high impact forces.

Wilk, McNair & Feld (1983) were also interested in the breaking objects demonstrations. They presented a kinematic study and a dynamic theory of karate techniques for breaking wooden slabs and concrete blocks. In their study, the researchers reported that karate practitioners can achieve maximum speeds of 5.7-14 m/s for arm kicks and 7.3-14.4 m/s for kicks. They also reported impact forces of 2400-2800 N. Researchers suggest that hand speed just before impact was the main factor that contributed to the greatest impact force in a karate shot compared to that of a non-practitioner. However, they did not verify this hypothesis of the study. They conducted an extensive study of the kinematics and kinetics of hand and foot karate shots using a 1000 Hz and 5000 Hz cine-film camera. The speeds and accelerations of the markers attached to the impact segment on contact with wood and concrete slabs were calculated, highlighting the maximum values of speed and intersegmental coordination. In this study a force platform was used on which they placed wooden and concrete slabs on supports. The force platform measured the force with which the break plates press on the support, due to their reaction force. Values of the maximum forces developed by the subjects as well as of the forces necessary to break the respective plates were highlighted by the researcher. They specified that the subjects of the study generated much greater forces than those necessary to break the plates and that high values of force were obtained even in situations where the target was not destroyed. This showed that the force exerted on them is not the only important parameter of technical performance and that the proper positioning of the fist or foot in the point of contact with the target, as well as the length of the splitting plates, are also critical factors of technical efficiency (Wilk, McNair & Feld 1983).

Atha,Yeadon, Sandover & Parsons (1985) collected data from world-class heavyweight boxers who punched a suspended target like a ballistic pendulum. In 0.1 s from the beginning of the blow, the fist travelled 0.4 m and reached a speed of 8.9 m/s on impact. The impact force was 4096 N and obtained within 14 ms after impact. The transmitted impulse generated an acceleration of the target of 520 m/s^2.

Currently, it is required to engage a muscle chain as big as possible in order to have a strong blow. One such example would be twisting the torso in the direction of the blow, so not only the mass of the hand and arm are involved.

Bolander, Neto & Bir (2009) investigated various applications of kung fu beatings. Fist and palm shots were compared for different heights and distances of a target. The data indicated that the accelerations of both blows were similar, however the impact forces and the accelerations of the target were much higher for the palm blows. In addition, the height at which the shot was fired was also investigated. The overall conclusion of the study was that the slap was much more effective than the punch in terms of force transfer to an object and that the chest attack would be ideal for maximizing the impact force and balancing an opponent. However, this study does not take into account the vital points of the human body and the effectiveness of hitting one of them. In the reality of a fight, the chest area is not a priority target.

Biomechanical comparisons between beginner and experienced athletes reported for kicks are very rare. Falco et al. (2009) investigated one of the most used foot techniques in taekwondo competitions, namely the circular kick (roundhouse kick or mawashi geri). Because the effectiveness of taekwondo techniques lies in the athlete's ability to make contact with the trunk or face of the opponent with sufficient force and in the shortest possible time, while avoiding injury, the distance between competitors is an important variable to consider. Thus, Falco et al. (2009) examined both the impact force and the execution time in the case of 31 athletes with different levels of competitive performance, measuring these variables with strength platforms. The study showed greater impact forces for experienced athletes. Also, the expert athletes were stronger on a longer distance, compared to the novice athletes on a shorter distance. The results showed that there were no significant differences in terms of impact force relative to distance for experienced athletes, and the differences were significant for competing athletes. The researcher also found significant and positive correlations between body mass and impact strength only for inexperienced athletes. These results corroborated with the results of the actual mass found for arm strokes recall the hypotheses that in contact sports the experience of athletes can alter the actual mass and show that for experienced athletes the technique plays a more important role in their performance than mass (Falco et al., 2009).

Pierce, Reinbold, Lyngard, Goldman & Pastore (2006) obtained the first direct measurements of the punches in professional boxing matches, in which the athletes had force sensors mounted in gloves. The average values of the measured forces ranged from 866.6 N to 1149.2 N. These measurements are considerably lower than those reported in most laboratory research and which, in agreement with the scientific authors, may better reflect the current force developed in the boxing ring (Pierce, Reinbold, Lyngard, Goldman & Pastore, 2006). One conclusion in this regard would be that more studies should be conducted to verify these claims.

Using a single digital video camera, Girodet, Vaslin, Dabonneville, & Lacouture (2005) filmed at 125Hz the gyaku zuki punch to measure the 2D coordinates of the markers attached to the anatomical landmarks of the body as well as to the support of the target, makiwara type (hit pole). The kinetic moment of the center of mass of the body and the momentum of the target were calculated. The large differences between the two kinetic parameters pointed to the limitation of the 2D analysis of the studied motion (Girodet, Vaslin, Dabonneville, & Lacouture , 2005). Unable to take into account the angular moments of the torso and arms around the vertical axis, a 3D analysis proves to be necessary to calculate the total kinetic moment of all body segments involved in the blow.

In biomechanical research in martial arts, the use of inertial systems is new, there are very few references in this regard. Camomilla et al. (2009) performed a kinematic analysis of the joints on elite athletes in the execution of 2 variants of the circular kick (mawashi geri). The researcher used an inertial motion capture system, placing inertial sensors on the targeted segments and measuring the angular orientations and speeds of the pelvis, thigh and leg.

In a comparative study of two variants of the gyaku zuki punch, Gulledge & Dapena (2007) used 2 Kistler force platforms for different purposes. Subjects sat on a horizontal platform (Kistler) fixed to the ground and hit a target attached to a second force platform (AMTI) mounted vertically on a wall. The forces exerted by the foot on the ground and the force exerted by the fist on the target were measured by the force platforms, and the corresponding impulses were calculated for different times of impact. For each situation, the total kinetic moment of the movement and implicitly the final speed of the fist were determined, aiming to find differences in the performance of the two stroke variants (Gulledge & Dapena, 2007).

Wąsik (2011) analyzed kinematic factors of the side kick technique from taekwondo adhering to generally accepted criteria of sports technique biomechanical analysis. Six advanced practitioners executed three times the said technique. Their results showed that greater knee velocity influences the velocity developed by the foot. Also, based on the result that at the 82% of the maximum length of the leg fully extended the average maximum speed was developed, the researcher considers this length to be the optimum value for the maximum dynamics of the striking technique (Wąsik, 2011).

As a way of approaching the issue and conducting the research, the following studies were also of great relevance: Analysis of judo movement using a pulling force device (Hassmann, 2010), biomechanical analysis of combat sport Silat using a motion monitoring system (Kaharuddin et al, 2017), kinematic analysis in combat sports (Zahradníček, Kolářová, Zvonař, & Vít, 2012).

Other authors state that there are few studies published in recent years on the possibility of using motion analysis systems in sports and that not even one in combat sports, so they have taken an approach to determine which devices or methods may be applicable into these fields (Polak, Kulasa, de Brito, Castro & Fernandes, 2016).

An article close to our point of focus is the one by Petru, de Hillerrin & Bidiugan (2014) study on the possibility of highlighting invariants of motion in martial arts kata exercises.

Most studies consulted are limited to strikes performed with the upper limbs, especially executed with a frontal (direct) trajectory, and the few studies on kicks also analyze the direct trajectory. Thus, for this case study, we chose circular punches, but being able to analyze any other striking technique, without limitations set by the trajectory.

Research design

The planned scientific research targets the disciplines with hitting techniques and aims to help them to apply new means of monitoring that would reveal key aspects of the technical executions.

In the present research we carry out a case study through which we follow the objective analysis of the technical executions specific to kickbox, taking into account the technical-methodical indications from the specialized books and from practice, with the help of the inertial measurement units (IMUs)

The main purpose of this research is to apply a kinematic analysis designed to provide information focused on technique in kickboxing so that the coaches and other specialists can have another perspective on evaluating practitioners and improve their training.

Fighting with imaginary partner/targets, widely called “shadow fighting” is a very popular part of a martial artist’s whole training. In this type of training, the athletes try to perform their techniques as fast and as correct regarding form as they can.

Plenty of martial arts have also a very important part given by Kata. Kata is a Japanese word describing detailed choreographed patterns of movements practiced either solo or in pairs. When participating in Kata competitions, the martial artists try to perform the “perfect” techniques, set by strict rules.

Being able to perform very well also on the non-dominant side is a highly important asset for an athlete that may bring him victory, forming a training goal for many.

It was hypothesized that by using IMUs technology, key kinematic parameters can be measured during technical executions, in dominant and non-dominant stance.

Such data is meant to facilitate the evaluations of the executions done by the coaches and other specialists involved in the practitioners’ trainings.

For this research, there have been used two top senior kickboxers with multiple national and international results also competing for the national Romanian team.

Figure 1. Subject number 1

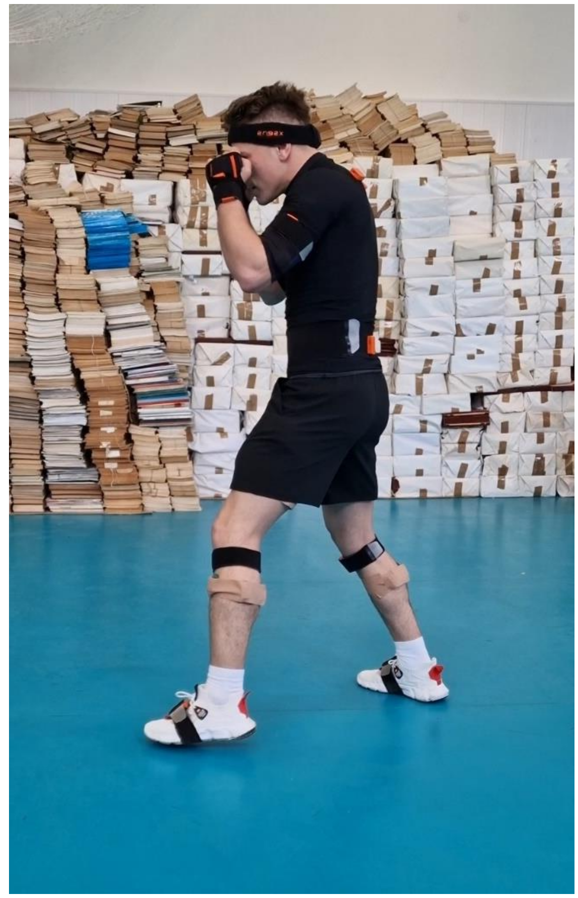

Figure 2. Subject number 2

The research took place at the National Research Institute for Sports: measurements in the technology laboratory of sports performance (biometrics), data processing within the technical department.

A system of inertial measurement units was used, capturing the movement of the entire human body performing specific kickboxing techniques, each sensor being composed of 3D gyroscopes, accelerometers and 3D magnetometers, small in size along with advanced algorithms and biomechanical models.

The system used in the studio was MVN Awinda, the version based on sensor straps, which transmits data to the PC / laptop wirelessly. There are 17 motion tracking sensors attached to the body in order to reconstruct 3D the human movement

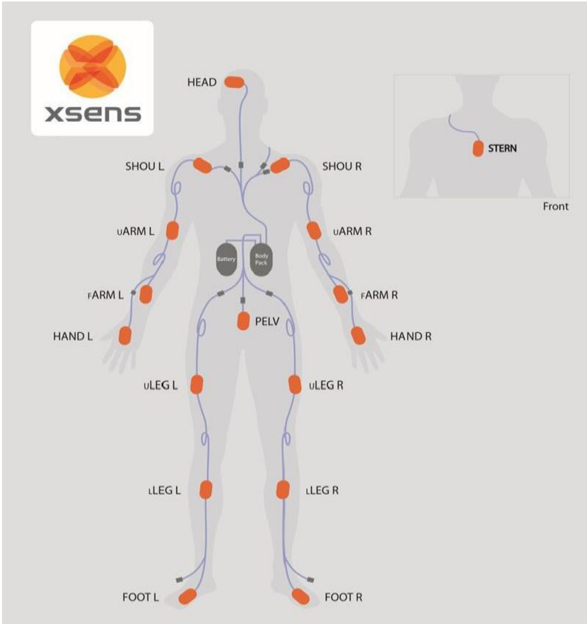

Figure 3. The 17 sensors

Before use, the system requires calibration adapted to the subject. Information on the subject is introduced in advance, the minimum being the height and size of the foot, but others can be added, for example the width of the arms, the height of the hips or shoulders.

Data acquisition is performed at a frequency of 60 Hz.

The working protocol consisted of:

a. Establishing the techniques set to be measured;

b. Equipping the MVN-Awinda device;

c. Add subject data and calibrate the device;

d. Start of data acquisition.

Considering the frequency of their use in kickboxing, the high-level circular punches were chosen, executed in combination. More precisely, the combination consisted of two circular punches, first striking with the front arm, then with the back arm.

The subjects performed this technical chaining with imaginary target 5 times from the dominant guard stance (left hand and leg in front, right hand and leg behind) and another 5 times from the non-dominant stance (right hand and leg in front, left hand and leg behind)

In order to obtain objectively the values of angles at the level of the tracked joints, a series of mathematical calculations was needed using the Excel program, as the raw data consisted of values on each of the 3 XYZ coordinates.

Therefore, for the calculation of the distance between two points in space, the generalized Pythagorean formula was used, and for the calculation of each angle, the cosine theorem. Also, another commonly used calculation was the transformation from radians to degrees, for a better highlighting and understanding of the data.

To calculate the rotations of the hips and shoulders, an uncontested methodical indication, the tangent theorem was used. Also at this topic, for an easy understanding and comparisons with other executions, a series of subtractions have been made.

In the data analysis and in their graphical representation, key moments were chosen based on the relevance criterion in martial arts, these representing the initial position, the end of the first punch, the end of the second punch. However, any moment of the technical chain can be analyzed, possibly in future studies.

Taking into account the theoretical-methodical indications, the following angles were considered important and were calculated and highlighted graphically:

- the angle regarding the rotation of the pelvis in relation to the transversal plane;
- the angle regarding the rotation of the shoulders in relation to the transversal plane;
- shoulder joint abduction/adduction (for both the right arm and the left arm);
- the angle between the forearm and the arm (both for the right arm and for the left arm).

The moment of impact was chosen when the hitting hand had the largest value on the Z axis (the highest height).

Results

One way in which data can be presented is through tables of absolute values in key moments.

Table 1. *Kinematic values registered by the first subject performing the technical combination*

dominant stance (left hand in front)			**non-dominant stance (right hand in front)**		
	@ impact	highest value		@ impact	highest value
Average absolute hand velocity (m/s)			Average absolute hand velocity (m/s)		
left hand velocity	5.02 ± 0.20	5.27 ± 0.17	left hand velocity	5.53 ± 0.55	7.12 ± 0.65
right hand velocity	6.42 ± 0.68	9.77 ± 0.36	right hand velocity	3.09 ± 1.08	6.54 ± 0.40
Average shoulder line rotation in transversal plane (degree)			Average shoulder line rotation in transversal plane (degree)		
right rotation	27.48 ± 6.86	34.74 ± 6.54	right rotation	62.22 ± 9.17	91.88 ± 3.51
left rotation	86.39 ± 5.99	119.07 ± 9.43	left rotation	48.07 ± 4.30	48.92 ± 5.87
Average pelvis line rotation in transversal plane (degree)			Average pelvis line rotation in transversal plane (degree)		
right rotation	25.59 ± 5.51	27.70 ± 4.63	right rotation	59.74 ± 6.82	65.62 ± 6.59
left rotation	87.18 ± 4.93	93.96 ± 6.98	left rotation	38.16 ± 9.91	45.93 ± 3.70
Average shoulder joint (abduction/adduction) variation (degree)			Average shoulder joint (abduction/adduction) variation (degree)		
right shoulder	75.67 ± 4.28	75.67 ± 4.28	right shoulder	72.07 ± 5.25	72.07 ± 5.25
left shoulder	66.00 ± 2.38	78.25 ± 2.14	left shoulder	54.32 ± 9.91	74.26 ± 2.61
Average elbow joint angular variation (degree)			Average elbow joint angular variation (degree)		
right elbow	75.01 ± 3.81	75.40 ± 2.66	right elbow	75.88 ± 2.50	83.32 ± 3.69
left elbow	67.95 ± 7.65	83.89 ± 7.43	left elbow	70.62 ± 1.24	79.00 ± 4.26

Table 2. *Kinematic values registered by the second subject performing the technical combination*

dominant stance (left hand in front)			**non-dominant stance (right hand in front)**		
	@ impact	highest value		@ impact	highest value
Average absolute hand velocity (m/s)			Average absolute hand velocity (m/s)		
left hand velocity	6.40 ± 0.34	8.03 ± 0.59	left hand velocity	7.70 ± 1.12	9.55 ± 0.77
right hand velocity	3.98 ± 1.06	9.69 ± 0.52	right hand velocity	6.27 ± 0.6	7.49 ± 0.42
Average shoulder line rotation in transversal plane (degree)			Average shoulder line rotation in transversal plane (degree)		
right rotation	21.33 ± 16.19	45.65 ± 8.13	right rotation	63.11 ± 4.82	87.88 ± 6.31
left rotation	84.93 ± 13.42	86.86 ± 8.43	left rotation	35.84 ± 8.92	51.44 ± 7.51
Average pelvis line rotation in transversal plane (degree)			Average pelvis line rotation in transversal plane (degree)		
right rotation	27.52 ± 4.89	27.98 ± 4.48	right rotation	55.06 ± 5.10	66.59 ± 4.74
left rotation	76.91 ± 3.87	78.89 ± 4.72	left rotation	38.16 ± 5.68	38.16 ± 5.68
Average shoulder joint (abduction/adduction) variation (degree)			Average shoulder joint (abduction/adduction) variation (degree)		
right shoulder	42.78 ± 5.87	58.70 ± 3.92	right shoulder	61.63 ± 4.23	61.63 ± 4.23
left shoulder	48.07 ± 6.59	60.84 ± 1.24	left shoulder	53.02 ± 2.00	53.02 ± 2.00
Average elbow joint angular variation (degree)			Average elbow joint angular variation (degree)		
right elbow	92.64 ± 8.1	101.80 ± 4.7	right elbow	90.68 ± 3.95	90.79 ± 3.15
left elbow	80.56 ± 3.06	117.75 ± 5.43	left elbow	94.77 ± 4.66	119 ± 13.50

As we mentioned before, the subjects performed 10 technical combinations consisting in 2 circular punches, front arm striking first, back arm striking second. When they changed the guard stances, the new front arm punched first, followed by the new rear arm.

Taking this into consideration, the values registered on the left side (hand velocity, rotations, joint variation) having the dominant stance should be compared with the values registered on the right side having the non-dominant stance and vice-versa.

We opted to present the average of kinematic values registered at the moment of the considered impact with their variations (±) and also the highest values registered on the trajectory of the strikes and their variations.

Contrary of some would think, the highest speed of the punch is not in the moment of the impact (although desirable in order for highest efficiency), but along the way.

Another way to present the data is through graphs that cover the full technical executions of the subjects, highlighting the key moments.

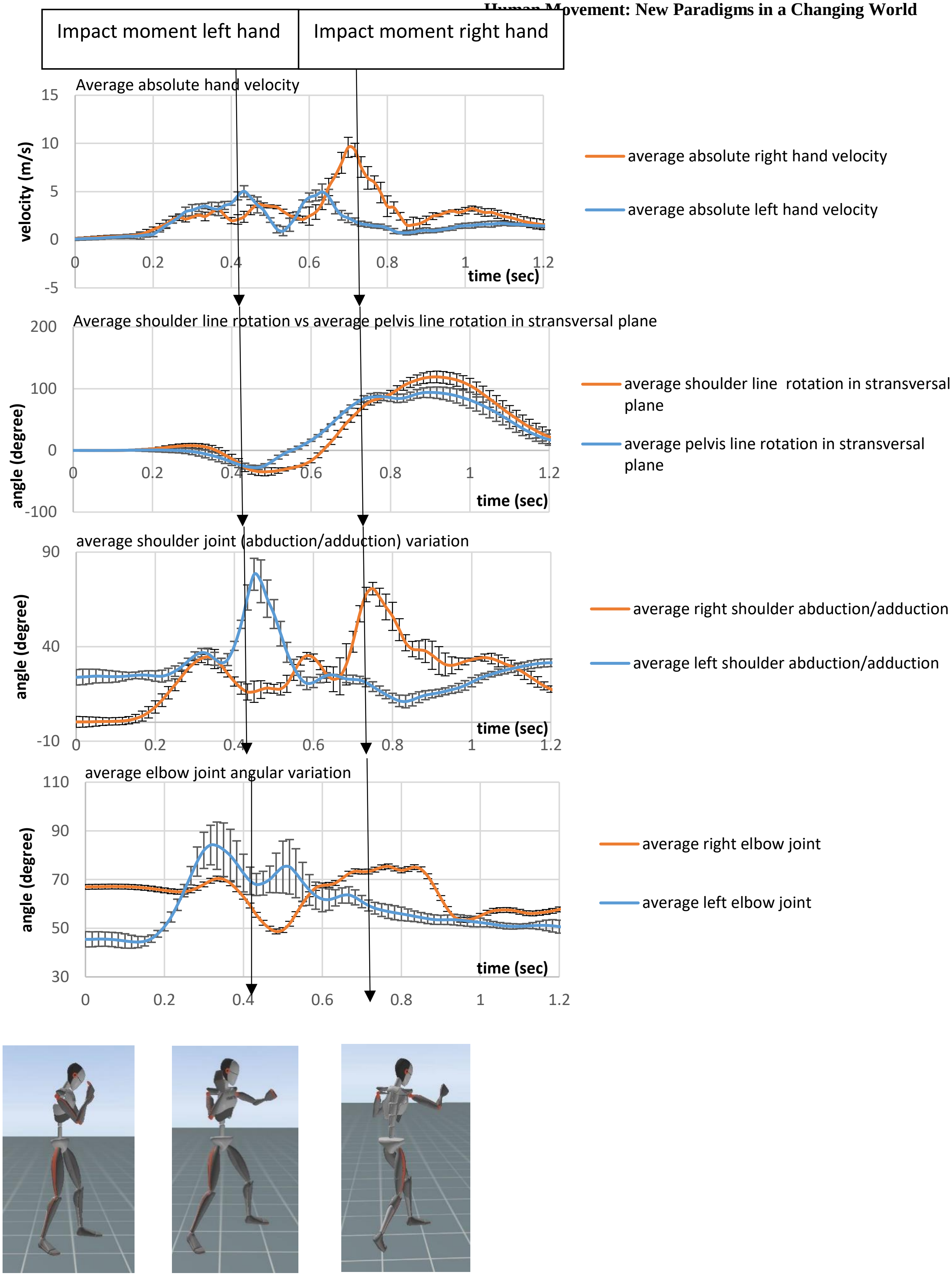

Figure 4. The evolution of the parameters during the technical executions of the first subject on dominant stance

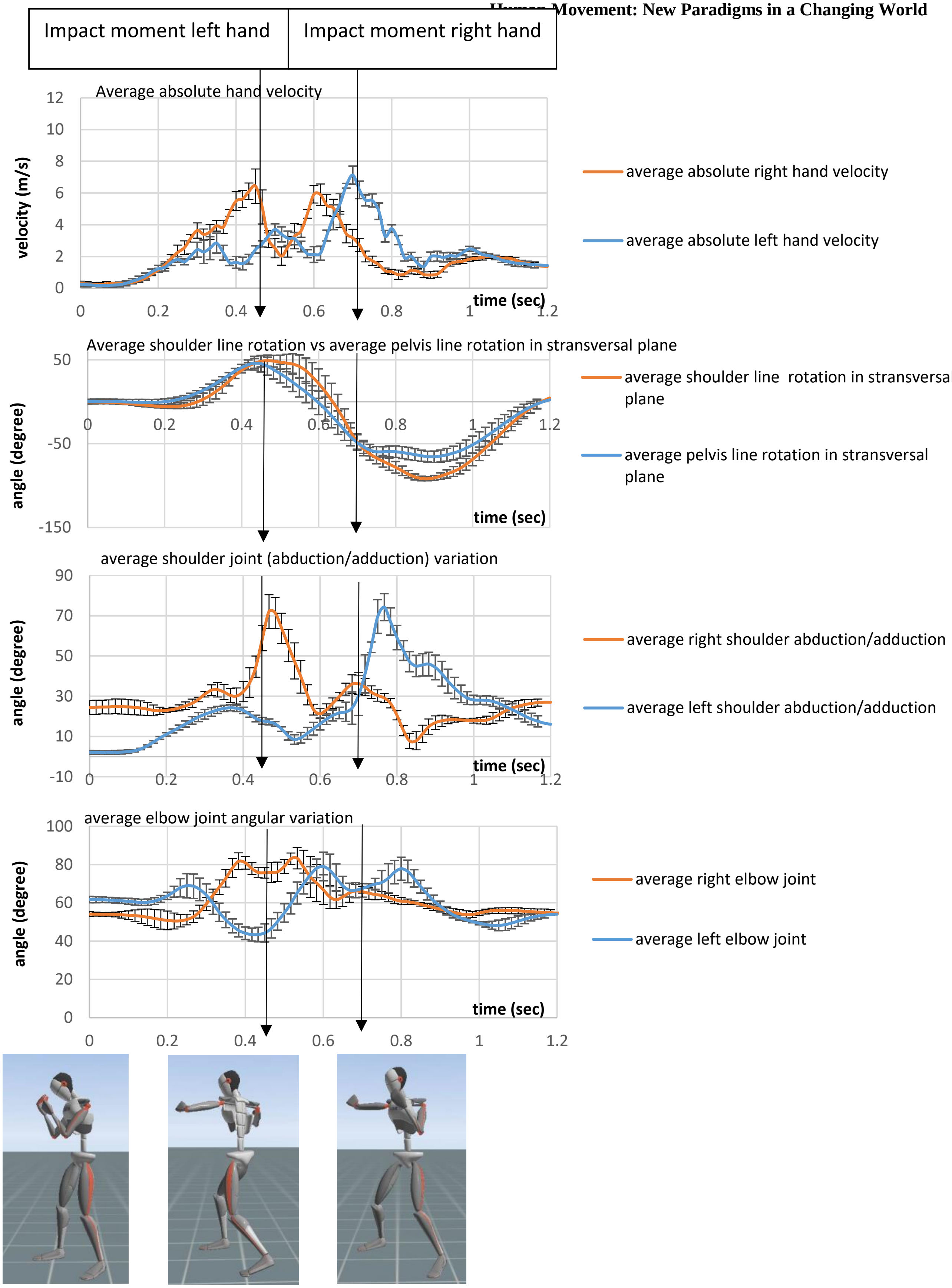

Figure 4. The evolution of the parameters during the technical executions of the first subject on non-dominant stance

Conclusions

We consider the hypothesis confirmed, namely extracting key parameters that would make possible an objective evaluation of the executions of the athletes individually and also to facilitate comparisons between them if needed.

The MVN equipment presented offers us the possibility to obtain objective information in the evaluation of kickboxers, being determining factors in the training of practitioners in this discipline.

The technical executions shown in this case study were not meant to be judged from a performance point of view by us, but to be presented objectively to the persons responsible of the training, in order to adjust or not the technical training. For instance, some coaches may adapt the exercises and means to improve the executions also performed by the non-dominant side or on non-dominant stance (reversed guard) or others would consider changes in tactics.

This case study is meant to target high performance athletes and we have to take in consideration their style. At this level, they might perform some techniques considerable different solely based on their preferences, thus their style. If some differences occur, whether they are mistakes, details that need adjusting or they are considered parts of the athletes' way of executing would be up to the coaches or the other persons involved in the training to decide.

In future studies, athletes who are members of national teams or top private club can be measured and evaluated and based on their combined results it will be possible to create a standard, used for selection taking in consideration weight category, competition rules and other criteria. Also, if one practitioner would register relative better results than the others at approximately the same age and weight category, but their competition results are below expectations, might reflect a tactical or psychological issue in their performance, thus adjusting the preparation accordingly.

In order to achieve great results in high level competitions, trainings adapted to the characteristics, skills, strengths and weaknesses of the athletes are necessary and we consider that with such kinematic analysis the process of individualization is enhanced.

Other key parameters might be considered for analyzing after discussions with persons involved in the training of athletes.

The study aims to open new research directions to other people interested in the field of martial arts or even other sports and desires to present an efficient way to use modern technology in such areas.

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