Journal of Physical Education and Sport ® (JPES), Vol 19 (Supplement issue 3), Art 121, pp 841 - 846, 2019
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

Potential of motion analysis technologies in the quantitative study of karate technique: an experimental approach for the jump of Unsu Kata.

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Published online:May 31, 2019
(Accepted for publication March 28, 2019)
DOI:10.7752/jpes.2019.s3121

Abstract
This study presents the results of quantitative analysis of the karate jump technique. The aim of the study is to investigate the correlation (r) between kinematic and kinetic parameters of the jump from the Unsu Kata. These parameters were identified during the initial phase of the jump (performance indicators), and critical elements were detected during the final phase of the jump (error indicators). The study involved an athlete with the Kata specialty. A six-camera opto-electronic system and two force platforms were used. Statistical correlation was determined between performance indicators and error indicators. The analysis and interpretation of the data reveal that contributions of the forces (ground reaction force and torque) are the most influential parameters on the other variables, which are involved in the evaluation of the jump during its final phase. It appears that the search for the adequate balance between the force components during the take-off phase, in particular the effects of the forces generated by the torque of the limbs on the body, can be considered as one of the most influential conditions for the success of the jump. The performed analysis of the only participant of the study and the complexity of the technique constitute a starting point for a future study.
Keywords: Karate, Technical evaluation, Unsu's leap, opto-electronic system.

Introduction

Introduced for the first time in the Olympic Games Tokyo 2020, karate begins to develop around the 18th century on the island of Okinawa. At that time the teaching of fighting techniques directly involved the teacher and the student, without the production of written sources, which is why it is still difficult to find precise information about it. The main interest was to obtain speed and effectiveness of gestures, without any aesthetic purpose, through exhausting and reserved training for a few, in an atmosphere of total secrecy. Gichin Funakoshi (Shuri, Okinawa 1868 - Tokyo 1957), founder of the Shotokan style, was the one who best defined karate in the most modern forms, initiating a greater diffusion (Funakoshi 2009; Kim 2016).

In karate, defense, attack, position, movement and landing techniques have been developed that involve the whole body in a rational and effective way. Subsequently, with the evolution of the competition rules and the accentuation of the competitive perspective, karate also took on more strictly sporting aspects, emphasized by the athletic preparation according to the specialization of karateka (Chaabène et al., 2012; Vidranski et al., 2015; Zago et al., 2015; Nikookheslat et al., 2016). In fact it is not uncommon today to observe athletes preferring the interpretation of Kata, a sequence of codified techniques that simulates a fight, or contend in Kumité, the real encounter between two athletes. This specialization, especially at a professional level, involves a different adaptation of the technique for the two different performance models, with the main purpose of achieving success in official sporting events. Kata requires concentration, orientation in space, modulation of strength and speed, harmony of movements, technique and harmony with breathing; in Kumité, on the other hand, the effectiveness of the technique is enhanced according to tactical strategies limited to the spectacular and correct execution, thus keeping alive the gestures and the rituals of combat, but minimizing the risk of suffering serious injuries (Cesari et al., 2008; Bajorek et al., 2011; Teixeira et al., 2016).

The aim of this work is to investigate some aspects related to the technical evaluation in karate through the use of motion analysis technologies in the study of the jump taken from the Kata Unsu. This acrobatic technique is estimated among the most complex, as well as being decisive in the overall assessment of performance in the competitive context. Jump techniques, when present in Kata, attribute added value to the performance if performed in compliance with some parameters. The detachment from the surface in fact generates a situation of strong instability, accentuated by the subsequent air phase as well as by the sudden shift of the center of mass upwards and in the direction of the next contact during landing. The preparation, the elevation and the final phases are therefore decisive in the correct reproduction of the gesture, above all for the correct maintenance of the directions and positions of the body segments, as well as the harmony in the phases of landing contact and the general intensity of the jump in terms of strength, speed, explosiveness and stability. However, the observations of the experts, although valid, can only attribute qualitative values to the execution of individual gestures or combinations of these. The technology used for the observation of human movement

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allows instead to analyze in detail the complexity of the actions performed during a given motor task (Juras et al., 2013;). In this study kinetic and kinematic variables of the jump were investigated, detected through the use of force platforms and optoelectronic system (Vastola, 2014; Vastola, 2016). This choice was made with the objectives of reducing the number of information available to the particular indicators useful for research and to deepen in the future the aspect closely linked to neuromuscular activation strategies, obtainable with the use of electromyography. Therefore, the main objective of the research path basically concerns the dependency ratios that the error indicators show in relation to the different performance indicators and demonstrate how much a quantitative analysis carried out on the components of the movement can be useful to better understand the elements that are more relevant during the execution of the gesture in competitive contexts.

Materials and Methods

Partecipants - For data collection was involved an experienced athlete in the specialty of Kata, 27 years old, 1.74 m tall and 64 kg body weight, member of the Italian Karate Association (IKA) sports group based in Grottaminarda (AV).

Measures - After recording the anthropometric measurements of the subject in accordance with the regular procedure of analysis, 22 retroactive markers were applied to the skin, 18 of which according to the Helen Hayes protocol (Kadaba et al., 1990; Davis et al., 1991) (C7, right and left acromion, sacrum, right and left a.s.i.s., right and left femoral bar, right and left lateral femoral condyle, right and left tibial bar, right and left lateral malleolus, point between the second and third metatarsal head of right and left foot, right and left posterior heel) and 4 additional ones, placed respectively on the right and left lateral humeral epicondyles and on the styloid processes of the right and left ulna. To reconstruct the three-dimensional position of the markers, a standard-D BTS system with six optoelectronic cameras calibrated at a frequency of 140 Hz were used. Two force platforms (60x40 cm), placed sequentially with respect to each other on the short side, to allow the subject to assume the starting position with both feet inside their surface, were used to assess ground reaction force and torques. Two cameras for the acquisition of the qualitative image, placed respectively on the frontal and sagittal plane, relative to the task, were used.

Procedures - The analysis was carried out at the Movement Analysis Laboratory of the University of Salerno and follows the setting of the pilot study "Comparison of two variants of Kata technique (Unsu): The neuromechanical point of view" (Camomilla et al., 2009), conducted at the University of Rome “Foro Italico”.

A brief warm-up routine was performed before the analysis, the subject was asked to perform a minimum of 10 tests, with 1 minute of recovery between each trial. In total 13 jumps were carried out, until the tests showed no errors related to fatigue. The subject has performed a total of 13 repetitions useful for the evaluation of the jump. The quantitative analysis of the data involved the processing of all 13 tests, carried out using BTS SMART Tracker and SMART Analyzer software, through which it was possible to extract the information useful for the purposes of the study. As in the reference article, the studied leap has been broken down into phases to define the gesture more precisely, and to conduct a detailed analysis of its parts.

A preparation phase (Phase 1) was distinguished, in which the subject assumed the typical defensive starting position in Fudo Dachi Tate Shuto Uke, placing both feet inside the surface offered by the force platforms. This phase begins at the last instant in which the velocity value of the "sacrum" marker (vector sum of the three components) is zero ("Start"), until the detachment of the right foot, identified when the value of the vertical component of the ground reaction force vector is zero ("Right detachment") The second phase, relative to the throwing of the right leg (Phase 2), elapses between the terminal event of the previous phase ("right detachment") and the event defined by the detachment of the left foot, determined at the instant when the vertical component of the ground reaction force is zero ("left detachment"). The third phase, corresponding to the flight phase (Phase 3), unlike the reference study, includes in this case both the ascending and descending flight condition and is defined between the terminal event of the antecedent phase ("Left detachment") and the next contact of the right foot at landing, when the velocity value (vector sum of the three components) of the marker placed on the second metatarsal of the right foot (marker "r met") is zero ("Right contact"). In this phase the marker placed on the sacrum, as an approximation of the CoM position, reaches the maximum height and the body changes its orientation in relation to the torque generated in the previous phase by the ground reaction forces, these factors allow air rotation.

In the last phase, defined between the terminal event of the previous phase ("right contact") and the event defined when the value of the total velocity of the sacrum is zero, before settling between ± 0.5 m / s, the landing phase is finally identified (Phase 4). The correlations between certain performance indicators and related error indicators were assessed, partly identified based on the reference article and partly re-established, in order to understand the type of relationship existing between the variables considered.

Unlike the reference study, the performance indicators identified were:

- anterior-posterior (A / P), vertical (V) and mid-lateral (M / L) components of velocity of the marker placed on sacrum at take-off (VSTO);
- peaks of the three components of the torque developed around the respective rotation axes (A / P, V, M / L) obtained on the force platform, at the contact of the left foot on it, as the pivot of the rotation during phase 2, until the take-off (TMTO);

‣ sum of the torques around the anterior-posterior (A / P), vertical (V) and mid-lateral (M / L) axes, generated by the three segments constituting the right leg (thigh, leg and foot), applied to the reference point identified on the sacrum at take-off (TLTO);

‣ peaks of the three components (A / P, V, M / L) of the ground reaction force in the phase preceding the take-off event (FMTO);

‣ elevation of the jump, referred to the maximum height reached by the marker placed on the sacrum during the flight phase (MSH).

These indicators mainly concerned the investigation of the torques generated by the right leg in the throwing phase, both on the left foot in contact with the ground and on the pelvis. Moreover, having reduced the number of markers useful for the three-dimensional reconstruction of the gesture, it was not possible to calculate the exact position of the CoM to evaluate the velocity and the elevation of the jump (Vastola et al., 2016; Vastola et al., 2016); this was remedied by considering the point corresponding to the marker placed on the sacrum, as a point integral with the pelvis. Finally, as in the reference article, the components of the ground reaction force were considered as other performance indicators. The following error indicators have been identified to quantitatively define the impact critical events, in relation to the landing:

‣ vertical displacement of the marker placed on the sacrum at landing, from the contact event to the ground of the right foot until the stop of its oscillation ("Cushion");

‣ average angular velocity around the anterior-posterior (A / P), vertical (V) and mid-lateral (M / L) axes of the reference system built on the shoulders in the landing phase, from the right foot contact event to the ground until the shoulders stabilize (AVSL);

‣ anterior-posterior ("In-plane") and mid-lateral displacement ("In-place") determined by the linear distance measured between the point identified on the right foot ("r met") in the contact event following the landing and the point located on the left foot ("l met") in the initial preparation position ("XZ Displacement").

Therefore, for the error indicators, the parameters relating to the information on the antero-posterior and mid-lateral displacement at landing and the parameters of cushioning of the pelvis have been re-proposed, while the calculation of the synchrony in the sequence of the landing pads is was replaced by the evaluation of the stability of the trunk, as the measurement of the average angular velocity of the reference system built on the shoulders, at the same final event. Moreover, through the software, it was necessary to reconstruct in advance three new different reference systems for the definition of performance and error indicators:

‣ The first reference system, reconstructed along the direction of the vector passing through the points identified on the heels stationed in the starting position, is fixed and oriented with the anterior-posterior axis (x-axis) facing forward. This reference system does not change over time and was used to calculate the coordinates of the forces recorded by force platform (TMTO and FMTO on the x, y and z axes), the velocity and height reached by the reference point identified on the sacrum.

‣ The second reference system has been reconstructed on the pelvis plane and is dynamic as it moves following its movement. Thanks to this the coordinates of the torques applied to the reference point identified on the sacrum at take-off were calculated.

‣ The third reference system has been reconstructed on the shoulders, it is also dynamic and has been useful to calculate the angular velocities reached at landing.

Analysis - The data obtained from the analysis of the 13 trials performed were exported on a spreadsheet, using the Microsoft Excel 2016 software, and shown below (Table 1.1 and 1.2).

The calculation of the correlation coefficients (r) between the performance indicators and the error indicators was obtained with the use of a spreadsheet (Microsoft Excel 2016) according to the statistical method proposed by Bravais-Pearson (Aiello, 2009). These correlations were also examined considering a qualitative evaluation with video-analysis done by a karate expert. Eight trials were selected through video analysis. The significance threshold for the correlation was set at ± 0.70. Positive values between 1 and 0.70 showed a strong direct correlation between the indicators. With the increase in the value of a performance indicator, the value of the relative error indicator also increases, on the contrary, with the decrease in the value of the first one, the second decreases. Negative values between -0.70 and -1 indicated a strong inverse correlation. As the value of a performance indicator increases, the value of the corresponding error indicator decreases and with the decrease in the value of the first increases the value of the second.

Results

The performance indicators identified were:

‣ anterior-posterior (A/P), vertical (V) and mid-lateral (M/L) components of velocity of the marker placed on sacrum at take-off (VMTO);

‣ peaks of the three components of the torque developed around the respective rotation axes (A/P; V; M/L) obtained on the force platform, at the contact of the left foot on it, as the pivot of the rotation during phase 2, until the take-off (TMTO);

‣ sum of the torques around the anterior-posterior (A/P), vertical (V) and mid-lateral (M/L) axes, generated by the three segments constituting the right leg (thigh, leg and foot), applied to the reference point identified on the sacrum at take-off (TLTO);

‣ peaks of the three components (A/P; V; M/L) of the ground reaction force in the phase preceding the take-off event (FMTO);

‣ elevation of the jump, referred to the maximum height reached by the marker placed on the sacrum during the flight phase (MSH).

The analysis shows an inverse correlation between the vertical velocity of the pelvis, peak value of the torque generated on the ground, around the anterior-posterior and mid-lateral axes, and the values of elevation of the jump with respect to the error indicator "Cushion" (vertical oscillation of the pelvis on landing) (table 1.1).

N. TRIALS	PERFORMANCE INDICATORS												
	TAKE-OFF PHASE												**FLIGHT**
	VMTO [m/s]			TMTO [N*m]			TLTO [N*m]			FMTO [N]			MSH
	A/P	V	M/L	A/P	V	M/L	A/P	V	M/L	A/P	V	M/L	h [m]
1	0.81	1.91	-0.34	0.003	6.50	0.002	-2.99	-75.39	-82.13	71	1829	346	1.40
2	1.19	2.06	-0.10	0.004	11.58	0.003	-4.76	-52.42	-63.30	100	2044	341	1.38
3	1.40	1.98	-0.60	0.003	10.68	0.002	-17.30	-152.31	-107.85	87	1825	287	1.43
4	1.77	2.13	-0.01	0.004	11.48	0.005	-24.34	-185.88	-115.34	107	1925	266	1.42
5	1.73	2.27	-0.35	0.005	14.19	0.005	-10.07	-127.59	-111.59	108	1884	207	1.46
6	1.52	2.07	-0.17	0.004	10.79	0.003	-13.95	-138.42	-126.55	119	1968	177	1.46
7	1.73	2.14	-0.37	0.005	14.24	0.004	-2.00	-117.94	-125.12	122	1995	226	1.47
8	1.34	2.30	-1.11	0.006	8.92	0.006	-1.61	-137.22	-125.80	94	1866	229	1.52
9	1.14	2.40	-1.00	0.007	10.97	0.008	-1.75	-119.90	-105.43	83	1820	261	1.48
10	1.99	2.36	-0.53	0.004	9.51	0.005	7.42	-21.73	-38.51	123	1916	277	1.45
11	1.67	2.16	-0.53	0.004	5.99	0.004	-29.12	-176.58	-124.71	114	1995	146	1.50
12	1.37	2.40	-0.77	0.007	9.53	0.007	-21.48	-121.38	-77.28	114	1877	199	1.53
13	1.54	2.39	-0.84	0.006	11.59	0.006	8.86	-79.84	-109.68	116	1907	215	1.52

Table 1.1. Data related to the performance indicators obtained from the analysis of the jumping technique.

Were found significant correlations between the selected performance indicators and the error indicator "AVSL", there was an inverse correlation between the torque on the platform, around the mid-lateral axis (Torque leg on sacrum at take-off), and the angular velocity of the shoulders around the anterior-posterior axis to the landing. Further inverse correlations were found between the vertical and anterior-posterior components of the ground reaction force (GRF max at take-off) and the angular velocity of the shoulders around the mid-lateral axis at landing. The same correlation was recorded for the ground torque around the vertical axis (Torque max at take-off) and for the velocity around the vertical axis at the take-off. There was a direct correlation between the mid-lateral component of the velocity of the sacrum and the angular velocity of the shoulders around the vertical axis at landing (table 1.2). Regarding the error indicators relating to the anterior-posterior and mid-lateral displacement in reference to the starting position, the velocity of the sacrum has a direct correlation with the anterior-posterior displacement (XZ Displacement), and an inverse correlation with the displacement in the mid-lateral direction. As for "GRF max at take-off", its mid-side component has a direct correlation with the in-plane displacement and an inverse correlation with the in-place displacement. Its anterior-posterior component shows an inverse correlation with the in-place displacement.

ERRORS INDICATORS					
LANDING				**X-Z DISPLACEMENT**	
Cushion	AVSL [gradi/s]			in-plane (A/P)	in-place (M/L)
[m]	A/P	V	M/L	[m]	[m]
0.31	9.50	11.10	19.60	-0.050	0.480
0.33	5.60	47.70	7.10	0.012	0.349
0.31	8.90	11.90	8.10	0.228	0.155
0.27	10.60	26.60	6.30		
0.22	6.60	12.30	3.20	0.340	0.206
0.36	17.90	27.80	-0.20	0.348	0.079
0.27	19.40	12.50	1.50	0.445	0.109
0.27	14.60	-7.10	11.90	0.265	0.171
0.26	11.80	-10.20	18.40	0.266	0.342
0.30	12.60	24.20	3.90	0.534	0.324
0.33	36.50	42.10	-1.20	0.392	-0.049
0.23	9.40	23.40	8.60	0.222	0.105
0.25	13.00	-0.90	10.40	0.319	0.124

Table 1.2. Data related to the error indicators obtained from the analysis of the jump technique.

The peak of the torque generated on the ground at take-off shows a direct correlation between its vertical component and the anterior-posterior displacement (in-plane) at landing. The mid-lateral component of the torque of the leg on the sacrum has an inverse correlation with the anterior-posterior displacement. A direct correlation was found between the elevation of the jump and the anterior-posterior displacement, on the contrary the same parameter shows an inverse correlation with the medium-lateral displacement (in-place). (Tab. 1.3).

				Pearson correlation coefficient					
				ERROR INDICATORS					
				LANDING				X-Z DISPLACEMENT	
				CUSHION	AVSL			IN-PLANE (A/P)	IN-PLACE (M/L)
					x	y	z		
PERFORMANCE INDICATORS	TAKE-OFF PHASE	VSTO	x	-0.4	0.53	0.08	-0.82	0.88	-0.92
			y	-0.84	0.25	-0.4	0.03	0.54	-0.46
			z	0.6	-0.19	0.77	-0.41	-0.49	0.34
		TMTO	x	-0.82	0.29	-0.39	0.08	0.52	-0.38
			y	-0.16	0.56	0.05	-0.76	0.76	-0.61
			z	-0.84	0.23	-0.41	0.14	0.47	-0.29
		TLTO	x	0.06	0.34	-0.44	0.29	0.13	0.23
			y	0.35	-0.2	0.13	0.29	-0.57	0.53
			z	0.4	-0.78	0.57	0.29	-0.84	0.5
		FMTO	x	-0.49	0.49	0.21	-0.8	0.67	-0.82
			y	0.28	0.11	0.68	-0.7	0.08	-0.17
			z	0.91	-0.58	0.38	0.37	-0.84	0.84
	MSH			-0.91	0.46	-0.53	-0.06	0.7	-0.7

Table 1.3. Framework of significant correlations between the performance and error indicators according to the Bravais-Pearson correlation coefficient.

Discussion

The interpretation of the results obtained revealed the existence of correlations between isolated performance and error indicators, especially about the correspondence between the directions of the components of each parameter.

In fact, in the initial phase of throwing (the leg), it is shown that a faster vertical displacement of the pelvis at take-off in the same direction of the rotation of the jump causes greater vertical stability of the pelvis at landing. In the same way, the sum of the torques generated by the right leg applied to the sacrum around the mid-lateral axis leads to a rotation that is favorable to avoid large displacements of the shoulders around the anterior-posterior axis at landing. This is favored by the peaks of the torques around the anterior-posterior and mid-lateral axes recorded on the platform, with effects on the maximum height reached in the jump. Thus, probably, the greater availability of time obtained determines a better organization of the movement in its aerial phase and less need of cushion at landing. The same direction of the forces involved also reduces the anterior-posterior and mid-lateral displacements in reference to the starting position. On the contrary, it is plausible that detecting a peak value of force expressed on the ground more in the medium-lateral direction may have a negative influence on the cushion, due to the direction not consistent with the jump in the final phase, generating instability. On the other hand, high values of forces and torques expressed in different directions respect to those considered correct seem to show greater criticality in the final landing phase, to the detriment of a positive overall assessment of the gesture. The search for the adequate balance between the forces expressed in the take-off phase at the time of the detachment, especially torques, determines the body rotations in air during the Unsu jump, could therefore be considered one of the most influential conditions to get a positive evaluation of the gesture.

However, the availability of a single subject for the quantitative analysis and the evident complexity of the technique under study widen the possibilities of analysis on other specific aspects for future investigations.

Conclusion

Modern karate, as a sporting discipline, is the result of an evolution that has produced variations in styles and purposes over time. These transformations have also influenced the interests of those who choose to walk the "Way of the empty hand" both from the point of view of sports practice and the possible objectives of a scientific investigation on its decisive aspects (Blazevic et al., 2006; Katic et al., 2009; Katic et al. 2010; Pop et al., 2013; Magnani et al., 2016). The contribution of technology in scientific research in sports is currently an indispensable contribution (Sforza, 2007; Sforza et al., 2000; Sforza et al. 2001; Sforza et al., 2002; Shirai et al., 2005). In this regard, in the panorama of the various sports disciplines, modern karate presents important complexities linked to its performance models and closely related to the two different specialties presented by Kata and Kumité (Vastola et al., 2010). The interpretations of the data obtained from the analysis of the jump of the Unsu Kata represent, therefore, the result of an experiment born from the general interest to increase the knowledge on the technique in karate and to further expand the proposals to start new investigations. The available statistical unit has produced only an argument on some of the movement organization strategies implemented by the same subject. This methodology could therefore be favorably applied to subsequent studies with the aim of verifying the changes made by a planned training over a longer period or to investigate intersubjective differences with the analysis of a larger sample. Since the results obtained, it is concluded that the quantitative research carried out on the sports movement can represent a powerful analytical tool of investigation, useful for the deepening of common knowledge and to propose new research objectives.

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