

Analysis of peak linear accelerations expressed in the technical gesture of gyaku-zuki in Karate/Kumite, comparing dominant and non-dominant limbs, including a complete review of the subject.

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Abstract

This study analyzes the "gyaku-zuki" punch in kumite, a controlled form of karate that emphasizes technique control to prevent trauma. The "gyaku-zuki" punch is preferred due to its speed and simplicity. The objective is to examine the peak acceleration of the punch using the K-Track instrument and investigate the correlation between the dominant and non-dominant limbs. By analyzing the physical elements of the punch, such as speed and acceleration, the study aims to gain insights into the balance and symmetry of punches executed by both limbs. This analysis contributes to a more harmonious and bilateral development of technical gestures. The results reveal that 75% of the athletes (6 out of 8) exhibited higher acceleration peaks in the dominant limb. However, two athletes showed opposing results, possibly due to factors like a preferred guard or variations in technical skills. While these factors are not extensively explored in this study, they influence the overall analysis.

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Introduction

Karate basically consists of two disciplines: Kata and Kumite. Kata involves multiple predetermined forms of offensive and defensive techniques and movements, while Kumite is a true encounter between two competitors according to strict rules (Chaabene H. et al., 2012). Karate has evolved from traditional karate, and Kumite in modern karate turns out to be driven by the ability to "control," thus avoiding, any contact for the safety of the contenders, unlike traditional karate, which instead allows full contact with no use of guards used nowadays in Kumite. In Kumite, the allowed techniques are fists, kicks, and projections, with corresponding different scores based on the criteria governing the combat, which despite its short duration, requires high intensities to be achieved by the athlete. Although the leg attack has a value of three points, many attacks are made using punches and especially the "gyaku-zuki," a technique that is faster and less complicated than a kick (Hofmann M. et al., 2008). Because of this frequency of use, it was considered necessary to start the studies from this fist in order to unequivocally establish clear physical parameters on which to refer in order to set up appropriate exercises for the real improvement of the investigated gesture and thus be able to monitor it in its performative succession. In karate technique, acceleration and thus speed are considered the factors that contribute to its greatest effectiveness (Vukovic V. et al., 2021), and for their measurement, we used the most advanced inertial sensor on the market (K-Track, K-Sport Ita. wearable devices).

In the scientific literature to date, the available analyses basically concern 3d systems and electromyography, which, however, have clear characteristics of laboratory that do not suit the dynamics of the competition and the dimensions of the different sports fields and thus, even on the Karate tatami, generate data with a high margin of error, not corresponding to the real characteristics of the sport under investigation. In this regard, as mentioned, the study aims to analyze the technical element of the gyaku-zuki fist and its peak acceleration, comparing the dominant and the "weak" limb moreover in a perspective of gesture "symmetry" with a bilateral performance that advantages the athlete with regard, especially to its greater unpredictability. As for what concerns the use of the wearable inertial sensors dedicated to sports performance, the few studies come mostly from our research group (ARGS), and only about 2.8% are dedicated to combat sports (Camomilla V. et

al., 2018). It is also important to note that the instrumentation used in these papers is now obsolete and, as previously mentioned, not appropriate for measurements on the ground. After a significant selection of 36 articles considered in this review, boxing appears to be the most studied combat sport, while only four of them analyze features of karate, among which only one uses wearable inertial sensors to generate scientific data. (Hachaj T. et al., 2017).

The gyaku-zuki fist was analyzed in one study using a VICON system (considered a gold standard in the 3D field) with eight infrared cameras at 200 Hz sampling rate, dwelling on the analysis of the various phases of the fist by detecting hip, shoulder and arm/hand velocities (Hofmann M. et al., 2008). An important aspect of karate training is the development of upper and lower limb power since it is assumed that it can positively impact the acceleration of techniques (Loturco I. et al., 2014). In this 2014 study, a 3D accelerometer was used to evaluate the peak acceleration of the gyaku-zuki fist and, subsequently, the height values of the Squat Jump, Counter Movement Jump, and the average power delivered both in the Squat Jump and on the bench press were also assessed to confirm the positive correlation between these values and the acceleration achieved by the fist, leading to the conclusion that, in this case, high power values (of both upper and lower limbs), lead to higher values of acceleration of the fist itself. Furthermore, in the same study, the relationship was analyzed on a single technical action starting from a static condition. A recent study of 2020 used a video recorder filmed at a frequency of 50 Hz and an inertial unit to calculate power output on bench press and squat (Quinzi F. et al., 2020). A 2021 study again used a combination of inertial and visual systems to analyze the kinematics of martial arts punching techniques in general, with an accelerometer (ICSensor model 3140) placed on the bag, Kinovea, and two GoPro Heroes. In karate fighting, in which the rule of control applies, fist techniques must be characterized by rapid movement in space, and, to understand such complexity, kinematic analysis would provide very useful feedback that could help to improve training, considering that acceleration in karate is clearly one of the factors contributing to its effectiveness, being the distances to the target very short (Izzo R., 2022; Vukovic V. et al., 2021).

This study just mentioned from 2021 analyzed the kinematics of the gyaku-zuki punch using two kinematic sensors and examination the performed technique in three variations. Both kinematic sensors were placed one between the second and third lumbar vertebrae (200 Hz) and the second on the upper side of the glove (100 Hz), revealing their good reliability in analyzing the variables, and maximum reliability in detecting the acceleration peak. It, too, however, points out how kinematic research, even to date, is mainly carried out in laboratory environments with the limitations described just above. A very recent paper aimed to determine the differences in the temporal structure of the gyaku-zuki in relation to the maximum reached hand speed, using a pair of IMUs (with 3D accelerometer, 100 Hz gyroscope, and 100 Hz magnetometer (Markovic S. et al., 2021). Basically, there are only two recent articles in the literature with the use of proper equipment, in our opinion, for the study of a combat sport. We mention them for the sake of the record even though they are from the same research group as this paper.

The first one, in chronological order, analyzed the "circular kick" of Muay Thai by finding the linear acceleration and angular velocity of hip, knee and ankle using K-Track (accelerometer, gyroscope and 3D magnetometer with sampling frequency of 4000 Hz with calibration at 100 Hz on each axis), which showed the division of the motory task studied into three phases (Socci M. et al., ARGS, 2020).

The second study, from 2022, equally uses a K-Track with the purpose of analyzing the dynamics of the technical gesture of the boxing jab to test the average accelerations of the blows and the average accelerations during upper body twisting while hitting on athletes of different levels, ages, and genders, allowing to establish specific and appropriate workload ranges, thanks to the punctual detections (Izzo R. et al., ARGS, 2022). Another aspect that will be analyzed later in this study is the comparison of the peak acceleration value between the dominant and non-dominant limb, as the bilateral development of techniques is, in our opinion, a crucial goal to be pursued to a greater extent in the future, certainly in many team and combat sports, likely in the youth training sector, to increase the offensive potential and the athletes' unpredictability.

There are also significant gaps in the karate-specific literature in this area, although there are limited works analyzing laterality and asymmetries in some martial arts. Indeed, among these papers, a 2013 study aimed to compare dominant and non-dominant limb hand strikes of Kung Fu athletes under different circumstances of combat sports (Neto O. et al., 2013). We do not believe functional dominance in sports will be solved even by adjusting the training work plan, but what is strongly supported in this study is the usefulness of limitation, meaning shortening the gap between the two limbs ("symmetrization," Izzo R., 2015). In a case report by Maeda R. et al., 2014), expert athletes who spent a lot of time practicing with the non-dominant limb and novices who, on the contrary, did not spend time on it, all with right-hand preference were examined using a digital camera (with a sampling rate of 60 Hz), measuring the execution time of a specific technical gesture. The results show that, in specialists, less asymmetry exists between the two limbs, both in sports and in daily life, than in beginners, thus reducing the degree of hand preference. In sports, functional dominance is referred to as the preferential use of a limb or position based on its dominant use in motor functions as well as in specific situations (Grouios G., 2004). In a 2019 study, it was stated that left-handers have a distinct advantage during fighting because they can execute strikes from unexpected directions and at different angles than right-handers, recalling the phenomenon in fencing of "induced left-handedness" in students. Judo athletes who had performed

bilateral training and athletes who had instead performed training only with the non-dominant limb were examined, leading to the conclusion that lateral preference decreased in the group that had performed training only with the non-dominant limb (Mayo X. et al., 2019). Body asymmetries are the result of a predominant use of one limb over the other during sports practice as well as a neuromotor necessity. Martial arts and combat sports in general, are an example of disciplines that involve one side of the body over the other (Burdukiewicz A. et al., 2020). From a metabolic point of view, combat sports are defined as hybrid or mixed, which means that they involve all three energy systems and always require a combination of neuromuscular and metabolic capabilities, including strength, power, aerobic capacity, and endurance (Socci M. et al., 2020).

Thus, in this kind of sport, no single metabolic performance characteristic prevails (Beekley M. et al., 2006). Karate, a high-intensity sport, requires repeated explosive execution of technically demanding, striking techniques (Zago M. et al., 2017). Indeed, the performance model of the athlete must have significant motor skills, mainly explosive strength, speed, and coordination, to achieve excellent results (Blazevic S., Popovic D., 2006). With regard to the metabolic systems involved in this sport, as mentioned above, we can say that the decisive one, related to the explosiveness of the performing gestures, is the lactic acid anaerobic mechanism of duration within about 8 seconds. This is supported by the lactic acid one given the considerable repetitiveness of the gestures throughout the few minutes of karate competitions. As a consequence of all that has above been mentioned, the aerobic system assumes a subsidiary relevance as it helps endurance during competitions that obviously do not end with a single fight. For the assessment of aerobic metabolism in combat sports, the measurement of heart rate during the fight has so far been used as a marker of the aerobic system's requirements (Franchini E. et al., 2019).

Types of punches

The fists allowed during kumité are subdivided according to the technique and gesture that must be performed to reach an outcome. Some authors consider the lower body to be the main contributor to fist execution, as the ground reaction force being produced by the legs will be shifted to the upper body, giving power to the movement (Lenetsky S. et al., 2013). In Kumite, fists account for 43.7 percent of the points scored, body kicks for 15.3 percent, and head kicks for 37.9 percent, thus confirming that fist techniques play a significantly important role in competition and that careful observation during training with regard to the exercise patterns may therefore be useful for the performance requirements of the competition (Frigout J. et al., 2020). The types of fists used during a karate fight are: Kizami-zuki, Uraken uchi and Gyaku-zuki. The last one mentioned, the Gyaku-zuki, which is taken into analysis in this study, is a punch performed with the upper limb placed backward in the guard position.

The rotation of the pelvis transfers force to the arm involved in the punch, which will end, after a push of the lower limbs, with maximum arm extension and maximal pelvic turn. Unlike the techniques previously analyzed, the target of this fist can also be the torso or the face. The gyaku-zuki, turns out to be the most frequently used punch during competitions because of its versatility, as it can be used effectively either as a direct, anticipatory or counter attack (Markovic S. et al., 2021). The punches can be performed individually or in sequence, and an example we often can see from athletes is the combination of the kizami zuki, followed immediately by the gyaku-zuki technique. This combination leads to a greater speed of execution than the gyaku-zuki alone. This could be due the performance of the first punch that causes a rotation of the trunk in a direction opposite to the immediately following hit (gyaku-zuki), thus enhancing the lengthening-shortening action of the trunk muscles which contributes to a greater speed of the second fist (Quinzi F. et al., 2020).

Objective

This study aims at analyzing the gesture of a karate technical element (defined as gyaku-zuki), with a state-of-the-art device, by considering and verifying its peak acceleration reached. A careful evaluation to examine the technical act will be carried out with respect to movements, timing, and the chart corresponding to its trend. Subsequently, an analysis of the averages of accelerations between dominant and non-dominant limbs of the athletes will lead to an understanding of the importance of training that must always be set on the bilaterality of the body, and, above all, these analyses will allow a greater understanding of the relevance of studying technical gestures with state-of-the-art devices for a training update.

Means and Methods

The instrument used in this study, the K-track (Figure 1), is a state-of-the-art inertial sensor unit (IMU) (K-SPORT, Ita.). The sampling rate used in the IMU study was 100 Hz (instrument potential up to 8000 Hz), with a 3D 16G accelerometer set at 100 Hz (linear acceleration on the 3 axes), 3D gyroscope at 100 Hz (angular velocity on the 3 axes) and 3D magnetometer, set at 100 Hz (by sensor orientation). It weighs 13 g, with a size of 70*20*7 mm and a battery life of 3 hours, and its microstructure facilitated athletes to use it without bothering them, thus not altering the execution of the technical gesture and consequently the performance. In addition, K-fitness software (K-SPORT, Ita) was used for data storage and processing.



Fig. 1 K-Track-Real size.

Thanks to a USB (2.0) connection, data were easily and quickly transferred to the PC. The study took place at the gymnasium "Dinamica," in Montesilvano (Pescara, Abruzzo/ITA). The subjects examined by this study, which is considered as an approach, being an original to the used instrument, were 8 kumite athletes of the Senior category (age > 18 years), respectively 3 boys and 5 girls, all being part of the above-mentioned gym, obviously provided that having ascertained the applicative validity of the instrument, more appropriate statistical calibrations will have to be made with a substantial increase of the investigated sample. Anthropometric data and main characteristics of the athletes are reported below (Table 1):

Table 1. Age, anthropometry and upper limb length outcome data (mean $\pm$ SD) of the athletes included in the study (n = 8).

	Minimum	Maximum	Total*	p-value†
Age (y)	19.00	27.00	23.25 $\pm$ 2.43	0.880
Height (cm)	164.00	181.00	171.50 $\pm$ 6.00	0.793
Body mass (kg)	47.50	77.20	64.07 $\pm$ 9.21	0.905
Upper limb length (cm)	61.00	64.00	61.87 $\pm$ 1.12	0.036

*Mean $\pm$ Standard deviation; † Normality Shapiro-Wilk

The test was conducted on a tatami and the athletes wore karategi (typical clothing), barefoot, so as to replicate all the characteristics the sport under investigation requires in competition. The protocol consisted of a 15-minute warm-up made up of:

- - 5 minutes of light running to stimulate aerobic metabolism and low-impact plyometrics such as gaits, skipping and kicking.
- - 5 minutes of joint mobility training to target the joints and muscles involved. 5 minuti di riscaldamento specifico tecnico che consisteva nell'esecuzione di ripetuti pugni gyaku-zuki presi in esame, eseguiti a bassa intensità.

Furthermore, all subjects were informed of the benefits and risks of the investigation prior to participate in the study. The data collection followed the principles outlined in the Declaration of Helsinki. The athletes were then briefed on the tests to be performed and made to rehearse the specific gesture a few times, also with high dynamics, while explaining them how the worn instrument works. Once the athletes declared to be ready to perform the test, they stood in front of the punching bag used in this study in a guarding position (stance), at a distance of about one meter, depending on the individual qualities of the athlete.

Contextually, the athletes were provided with a sensor placed on the wrist using a bandage so as to create the most stable conditions without causing impediments. In addition, the k-Track was placed in a longitudinal position, with the "tip" facing the fingers of the hand and thus placing the y-axis as the direction of the fist. Each athlete was required to perform eight fists, four with the right limb and four with the left one. Upon starting, the athlete would execute the first fist and return to the guard position, then after precisely 5 seconds, proceed to the second fist execution, following the same procedure and so on. After performing the 4 punches with the same limb, each athlete would take a 3-minute break as recovery and then perform the test with the opposite limb always at full intensity and according to the same procedure. This went on for the other athletes too.

Graphical analysis of the gesture

The graph taken under examination (Figure 2), represents the data filtered out by the instruments (K-track) from a fist performed by an athlete with the left limb. From the screened data, the graph, showing the acceleration trends in the 3 axes, was derived for a real dynamic analysis of the hit mechanics to better define in detail its efficiency. It is effective to us for the interpretation of the various executive moments the synchronized connection of the inertial track to the corresponding synchronized video frame. From this, it is possible to deduce the acceleration value and the movements that the athlete makes on the different axes at a specific moment of the gesture so that possible corrections and performative improvements can be made.

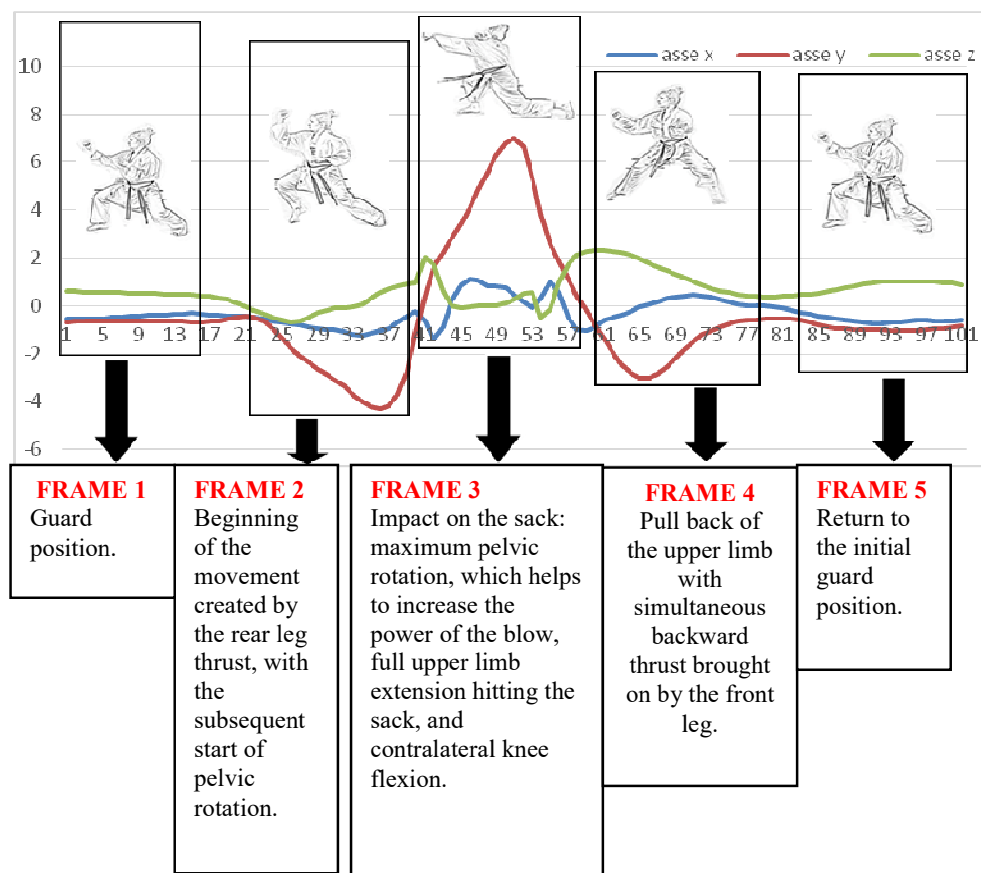


Fig.2; Frames description

Initial guard position (frame 1):

The proper guard position in competitive karate kumite significantly influences the execution of the technical gesture. Starting with hand strikes (fists), the hands should be kept closed, with the front arm placed at face level and the back arm slightly lower, defending the ribcage. The torso is erect, with the center of body gravity located in the midpoint of the two limbs, and considerable use of the "core" as the central element for posture stability as well as for the slight internal pelvic rotation that will convey dynamic energy and power to the hand, thus then carrying out the strike.

The legs are in a posture with a width, in the lateral direction, more or less equivalent to that of the pelvis, with the toes of the feet pointing forward in the direction of the thrust, the heel of the front foot will be on the ground, while the heel of the back foot will be slightly raised from the ground so as to be able to apply the thrust that will initiate the fist-phase and, in an eventual fight, allow the athlete to make rapid forward, backward and lateral movements. The feet are far apart longitudinally, but not excessively, because an excessive distance between them would not lead to an effective thrust. In addition, the back leg will have to be bent and heel raised to allow effective thrusting responsiveness while always keeping the center of gravity low.

Fist execution phase (frames 2 and 3):

This phase begins when the back leg performs a firm push. This transfers the body's center of gravity forward, and simultaneously, the front foot's heel will lift off the ground. Almost simultaneously, the pelvic rotation begins to rotate the hip, which proves to be fundamental in transferring power to the fist since it will allow the transmission of strength up to the limb involved in the technical gesture, that in this phase is fully extended. The pelvic rotation, however, must end at the moment of impact of the fist to the target, when reaching its maximum rotation. At this stage, the front leg will have its heel in contact with the ground and a 90° angle of flexion between leg and thigh, while the rear lower limb will result in having the tibia parallel to the ground and will be resting on the front of the foot. Finally, the hand that does not make a fist is covering the face, in case of a possible advance or counterattack by the opponent.

Return to the initial position (frames 4 and 5):

The rapid recall of the limb involved in the punch leads to an external retro-rotation of the pelvis, which, simultaneously with the thrust of the anterior lower limb allows the return to the initial guard position previously analyzed.

Statistical analysis of the data

Normality of the distribution for each variable was examined using the Shapiro-Wilk normality test. Descriptive statistics including minimum, maximum, mean and standard deviations were calculated for the age,

height, body mass and upper limb length data. Paired two-sample t-tests were used to assess asymmetry between body sides (left fist versus right fist). Data were analysed with a Student's t-test for independent samples to assess possible differences in age, height, body mass, left fist, right fist and mean fist variables according to sex. In addition, the effect size was calculated for all variables according to Cohen or Hedges g. Effect size was No significant differences were found between left and right punches ($p \geq 0.727$; Cohen's $d \geq -0.128$ [trivial]) classified as trivial (< 0.2), small (0.2 to 0.59), moderate (0.6 to 1.19), large (1.20 to 2.00), very large (2.00 to 3.99) or extremely large (> 4.0) as previously described by Hopkins et al (2009). All statistical analyses were performed using IBM SPSS version 20 and the open-source statistical software JAMOV version 1.6.23 (The jamovi Project, Sydney, Australia).

Results

No significant differences ($p \geq 0.727$; Cohen's $d \geq -0.128$ [trivial]) were found between left and right punches (Table 2). According to sex, significant differences were found for the upper limb length ($p \geq 0.727$; Hedges's $g \geq -2.635$ [very large]). (Table 2. and 2.1.).

Table 2. Values of the resulting linear accelerations at the moment of impact of the eight punches and the values of the average of the four left and right punches.

	Minimum (n=8)	Maximum (n=8)	Total (n=8)*	p-value†
Left fist 1 (m/s ²)	3.77	6.71	5.40±1.03	0.420
Left fist 2 (m/s ²)	4.16	7.32	5.42±1.22	0.218
Left fist 3 (m/s ²)	3.75	7.08	5.46±1.17	0.558
Left fist 4 (m/s ²)	3.81	6.86	5.49±0.92	0.973
Mean left fist (m/s ²)	3.97	6.75	5.44±0.91	0.232
Right fist 1 (m/s ²)	4.09	6.42	5.45±0.89	0.333
Right fist 2 (m/s ²)	3.82	6.71	5.48±0.83	0.351
Right fist 3 (m/s ²)	3.02	7.34	5.37±1.35	0.736
Right fist 4 (m/s ²)	4.34	8.45	5.65±1.41	0.097
Mean Right fist (m/s ²)	4.47	6.87	5.48±0.82	0.762

*Mean±standard deviation; † Normality Shapiro-Wilk

Table 2.1 Values of the resulting linear acceleration s at the moment of impact of the eight punches and the values of the average of the four left and right punches according to sex.

	Female athletes (n=5)*	Male athlete (n=3)*	p-value†	Hedges g
Edad (y)	23.40±1.51	23.00±4.00	0.841	0.153
Height (cm)	168.80±5.31	176.00±4.58	0.100	-1.417
Body mass (kg)	61.00±8.92	69.20±8.66	0.251	-0.928
Upper limb length (cm)	61.20±0.44	63.00±1.00	0.011	-2.635
Mean left fist (m/s ²)	5.36±0.80	5.58±1.27	0.776	-0.218
Mean Right fist (m/s ²)	5.14±0.53	6.05±1.01	0.139	-1.244
Mean fist (m/s ²)	5.25±0.57	5.82±1.08	0.363	-0.719

*Mean±standard deviation

Discussion

After analyzing the data extracted for any athlete and filtering them (to mitigate the technological noise/margin of error), the peak acceleration values, corresponding to the phase of the fist contact with the bag, were analyzed. The formula applied to calculate the resulting linear acceleration vector was:

$A = \sqrt{(Ax^2 + Ay^2 + Az^2)}$ After identifying the peak, which precisely corresponds to the moment of impact of the fist to the bag, 50 values before and 50 after the same were considered and then plotted in the chart. This procedure was implemented for each athlete, for all 8 fists they went to perform, to identify the resulting individual acceleration values. Then, after identifying the peak acceleration values of each punch, the average of each athlete's 4 right and 4 left fists was evaluated to determine the most significant acceleration points of the two limbs at the moment of impact. Table 3 shows the average values of the peak accelerations of the right and left fists made by each athlete.

	AVARAGE FISTS RIGHT	AVARAGE FISTS LEFT
<i>Athlete 1</i>	5.66 m/s ²	5.79 m/s ²
<i>A2</i>	5.52 m/s ²	5.23 m/s ²
<i>A3</i>	6.00 m/s ²	5.49 m/s ²
<i>A4</i>	5.68 m/s ²	4.47 m/s ²
<i>A5</i>	4.33 m/s ²	4.92 m/s ²
<i>A6</i>	5.76 m/s ²	6.87 m/s ²
<i>A7</i>	3.97 m/s ²	4.74 m/s ²
<i>A8</i>	6.75 m/s ²	6.38 m/s ²

Tab.3.; Average Fist values

From the results, we can see that there is a difference in the average values of right and left fists, for each athlete, that obviously depend mainly on the laterality/dominance of the subject. These data comfort us on a basic formative methodological idea not only for this specific sport. It is that of the great performative utility of building an athlete as ambidextrous as possible, both for possible unpredictability and for greater efficiency of the two hemi laterals, reducing as much as possible the gap of the weak limb from the dominant one being, in our view, particularly effective for combat sports.

Athlete 1: Dominance: RIGHT

Chart 1 shows the patterns of four fists performed with the left limb by athlete 1, female. Chart 2 shows the patterns of four fists performed with the right limb by the same athlete.

ATHLETE 1 HITS

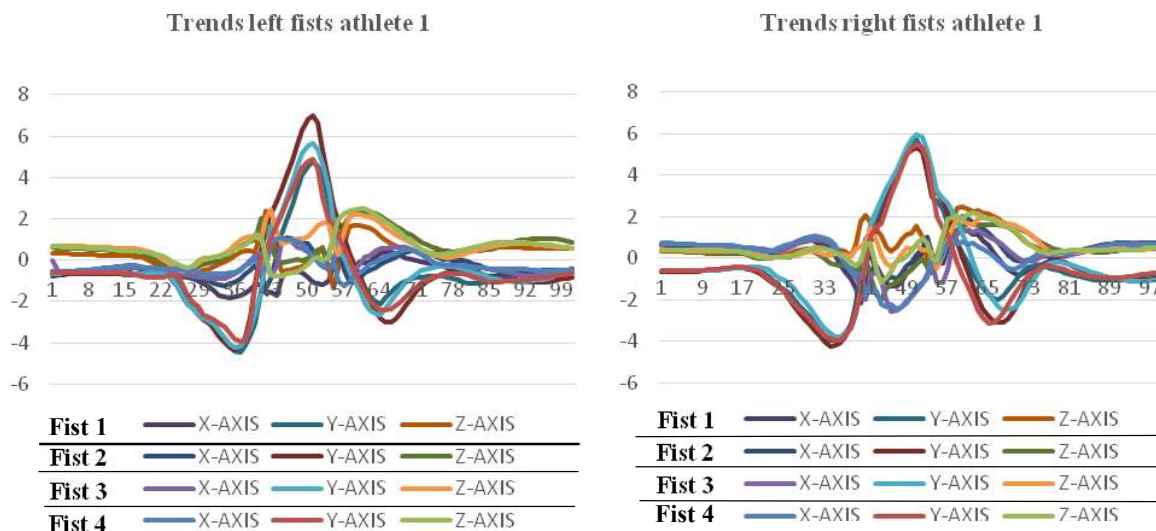


Chart 1: trends of athlete 1's left fists

Chart 2: trends of athlete 1's right fists

The following plots express linearity on the y-axis. Furthermore, a slightly greater presence of accelerations on the x- and z-axes of the right fists compared to the punches performed with the left limb, stands for a faster execution of movements on these axes, probably caused by a higher executional speed of the gesture with the right limb. Table 4 shows the peak acceleration values of the 8 punches performed by athlete 1 and the average of the four right and four left punches.

	LEFT LIMB	RIGHT LIMB
FIST 1	4.91 m/s ²	5.93 m/s ²
FIST 2	7.01 m/s ²	5.32 m/s ²
FIST 3	5.80 m/s ²	6.19 m/s ²
FIST 4	4.92 m/s ²	5.72 m/s ²
AVARAGE	5.66 m/s²	5.79 m/s²

Tab.4: Peak acceleration values of the four right and four left fists by athlete 1 and relative average

From the averages accelerations analysis of the blows, we note that the greatest value is that of fists performed with the right limb, leading to the confirmation of athlete 1's right limb dominance, which will therefore turn out to have a predominance of guarding with the left leg forward, despite the fact that in blows 2 and 3 there is a performance reversal, that is probably due to an error in the execution of the hits.

Athlete 2: Dominance: LEFT

Chart 3 shows the readings of the four punches performed with the left limb by athlete 2, female. Chart 4, on the other hand, shows the tracings of punches performed with the right limb by the same.

ATHLETE 2 HITS

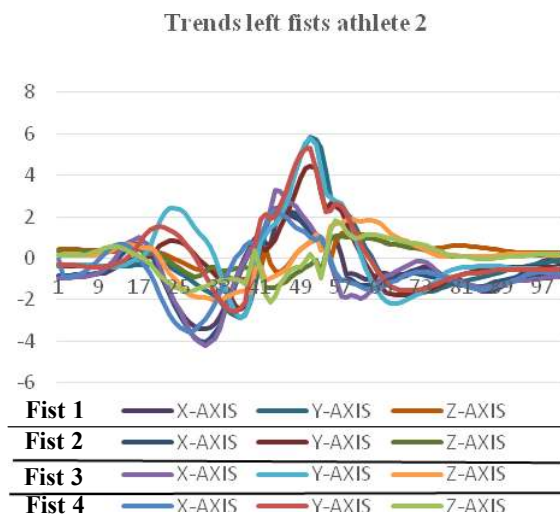


Chart 3: trends of athlete 2's left fists

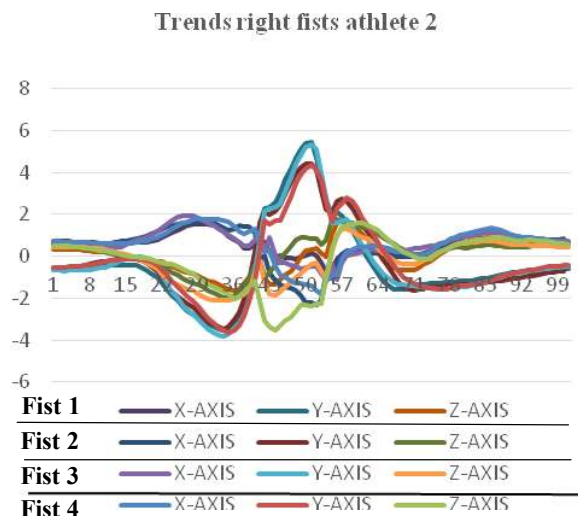


Chart 4: trends of athlete 2's right fists

The analysis of these findings showed that, athlete 2 compared with the first, in both right and left punches, has a less linear execution on all 3 axes, as it is noted that there are greater movements on the x- and z-axes and a less precise preloading and return phase of the fist on the y-axis. Table 5 shows the values of the resulting linear accelerations at the moment of impact, of the eight punches and the values of the average of the four left and right punches.

	LEFT LIMB	RIGHT LIMB
FIST 1	6.02 m/s ²	5.43 m/s ²
FIST 2	4.64 m/s ²	5.01 m/s ²
FIST 3	6.01 m/s ²	5.36 m/s ²
FIST 4	5.41 m/s ²	5.13 m/s ²
AVARAGE	5.52 m/s²	5.23 m/s²

Tab.5: Peak acceleration values of the four right and four left fists by athlete 2 and relative average

Analyzing these averages, the highest value turns out to be that of four fists performed with the left limb, confirming the left limb dominance of athlete 2, who therefore compared to the athletes with dominant right laterality detects a guard position with the right lower limb set forward.

Athlete 3: Dominance: RIGHT

Chart 5 shows the tracings of the four fists performed with the left limb by the third athlete, female. Chart 6 shows the tracings of the four fists performed with the right limb, also by the same athlete.

ATHLETE 3 HITS

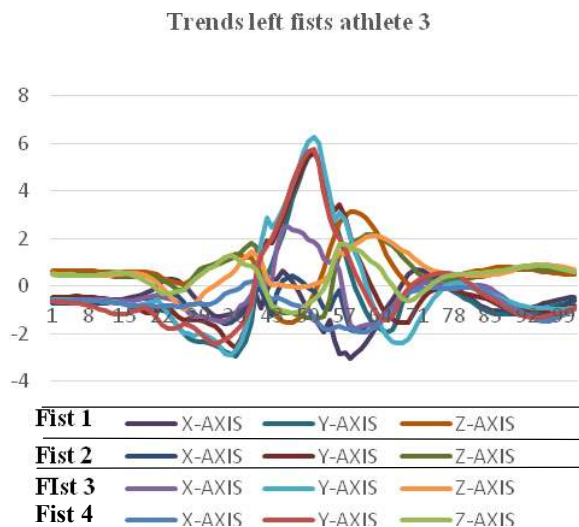


Chart 5: trends of athlete 3's left fists

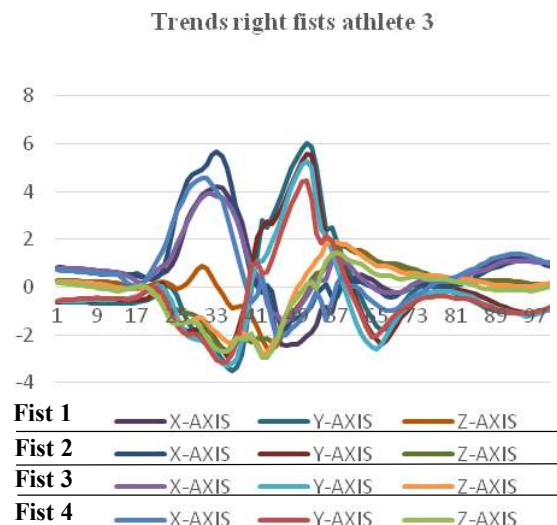


Chart 6: trends of athlete 3's right fists

What emerges from the analysis of the right and left fist traces of athlete 3 is the remarkable difference in the trend of the acceleration curve on the x-axis. Indeed, the athlete in the preload phase of the four fists performed with the right limb, in contrast to those performed with the contralateral limb, shows a significant acceleration value on the x-axis compared to the previous subjects due to an upward displacement of the device in this phase as a result of an upward thrust of the arm, probably caused by a compensatory movement. Table 6 shows the values of the resulting peak accelerations for each technique performed and the average for each limb.

	LEFT LIMB	RIGHT LIMB
FIST 1	5.79 m/s ²	6.39 m/s ²
FIST 2	5.76 m/s ²	5.69 m/s ²
FIST 3	6.53 m/s ²	5.30 m/s ²
PUGNO 4	5.93 m/s ²	4.59 m/s ²
AVERAGE	6.00 m/s²	5.49 m/s²

Tab.6: Peak acceleration values of the four right and four left fists by athlete 3 and relative average

Regarding athlete 3, the results do not lead to confirm the subject's right-hand dominance, as we can see that the highest average is in the punches made with the left limb, except for the first right fist, which is found to have a higher value than the left

Athlete 4: Dominance: RIGHT

Chart 7 shows the tracings of the four fists performed with the left limb by the third athlete, female gender. Chart 8 shows the tracings of the four fists performed with the right limb, also by the same athlete.

ATHLETE 4 HITS

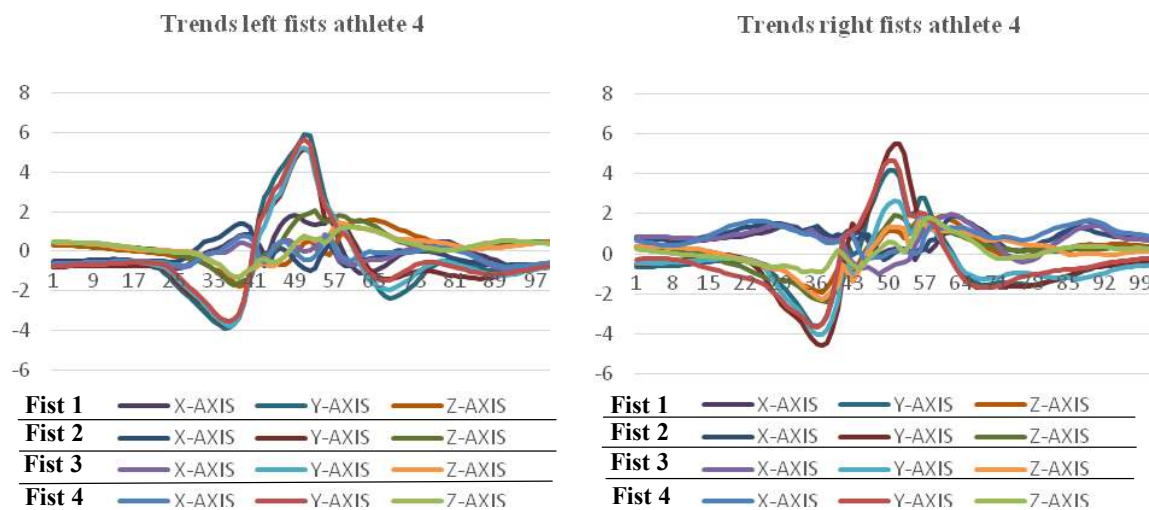


Chart 7: trends of athlete 4's left fists

Chart 8: trends of athlete 4's right fists

What emerges from the analysis of the fourth athlete's tracings is that in the fists performed with the left limb, there is less movement on the x- and z-axes, while in the fists performed with the right limb, besides showing less linearity on the y-axis, the accelerations on the remaining two axes are clearly greater and higher in frequency (probably due to the greater speed). As a final observation, we can observe that in the third right punch performed by the subject examined (the hit with the lowest acceleration), there is a much more "jagged" execution than in the other punches. This was later confirmed by video analysis, as there was more body instability in the forward and backward phases, and thus the execution of the gesture was incorrect. Table 7 shows the values of the resulting peak accelerations for each punch and their average.

	LEFT LIMB	RIGHT LIMB
FIST 1	6.15 m/s ²	4.34 m/s ²
FIST 2	5.57 m/s ²	5.83 m/s ²
FIST 3	5.29 m/s ²	3.02 m/s ²
FIST 4	5.71 m/s ²	4.72 m/s ²
AVERAGE	5.68 m/s²	4.47 m/s²

Tab.7: Peak acceleration values of the four right and four left fists by athlete 4 and relative average

In athlete 4, the same problem highlighted in the previous case is again found. In fact, even in this case, the greater average is that of fists performed with the left limb, with a greater difference than the one found in athlete 3.

Athlete 5 : Dominance: RIGHT

Chart 9 shows the tracings of the four fists performed with the left limb by the third athlete, female. Chart 10 shows the tracings of the four fists performed with the right limb, also by the same athlete.

ATHLETE 5 HITS

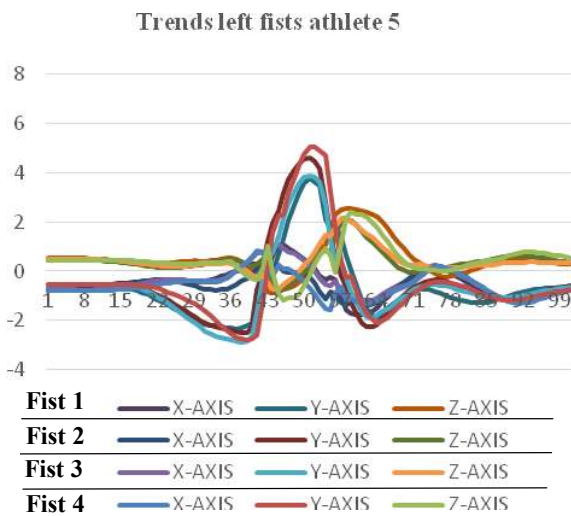


Chart 9: trends of athlete 5's left fists

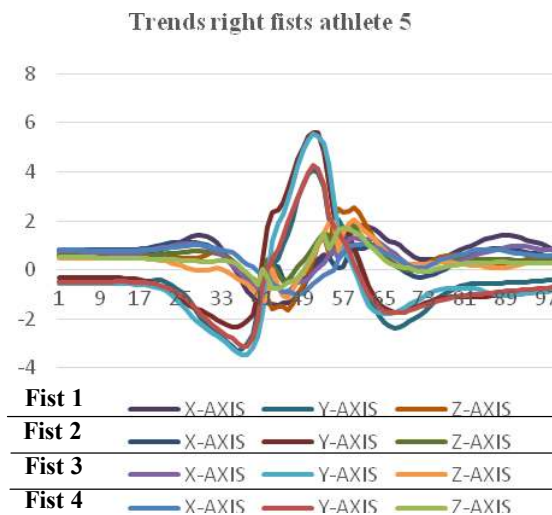


Chart 10: trends of athlete 5's right fists

As in some of the previous athletes' tracings, it is noticeable that in this athlete, linearity is often not observed on the x- and z-axes, while the y-axis, i.e., the direction of the fists, turns out to be quite linear, indicating a fairly precise movement. It is also observed that in strikes carried out with the right limb, there is greater acceleration on the y-axis in the preload phase, probably due to the athlete's dominant right laterality. Below, in Table 8, are the values of the peak acceleration results for each technique performed, and the averages of the right and left fists.

	LEFT LIMB	RIGHT LIMB
1° FIST	3.77 m/s ²	4.09 m/s ²
2° FIST	4.60 m/s ²	5.67 m/s ²
3° FIST	3.88 m/s ²	5.58 m/s ²
4° FIST	5.09 m/s ²	4.34 m/s ²
AVERAGE	4.33 m/s²	4.92 m/s²

Tab.8: Peak acceleration values of the four right and four left fists by athlete 5 and relative average

Analysis of the above values shows that punches performed with the right limb have a higher average, confirming the right-dominant laterality of the athlete examined.

Athlete 6: Dominance: RIGHT

Chart 11 shows the tracings of the four fists performed with the left limb by the sixth athlete, male. Chart 12 shows the tracings of fists performed with the right limb, by the same athlete.

ATHLETE 6 HITS

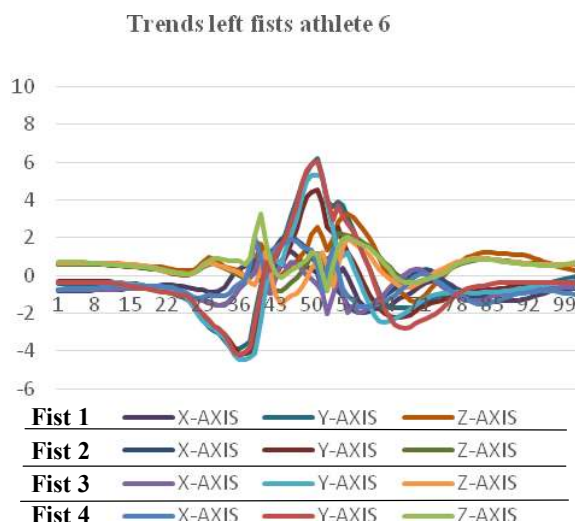


Chart 11: trends of athlete 6's left fists

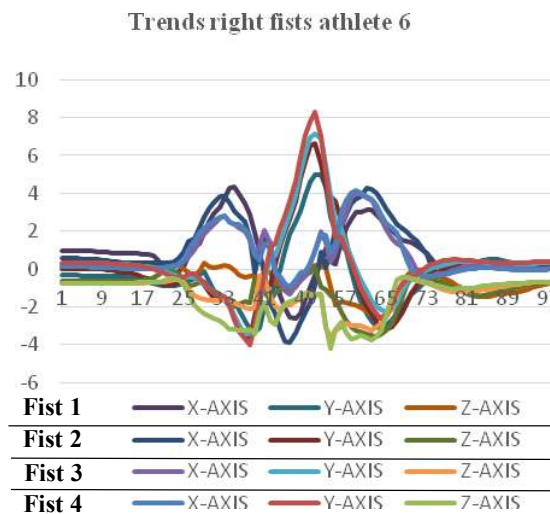


Chart 12: trends of athlete 6's right fists

This athlete shows a remarkable nonlinearity during the performance of the gesture. In fact there are considerable accelerations on the x- and z-axes, probably due to small and rapid movements of the same. Much like athlete 3, previously analyzed, we note how also, in this subject, there is substantial acceleration on the x-axis in the preload phase, with respect to the right fists. Table 9 below shows the peak acceleration values of the 8 techniques performed and the averages obtained from them.

	LEFT LIMB	RIGHT LIMB
FIST 1	6.71 m/s ²	5.01 m/s ²
FIST 2	4.72 m/s ²	6.71 m/s ²
FIST 3	5.41 m/s ²	7.34 m/s ²
FIST 4	6.22 m/s ²	8.45 m/s ²
AVERAGE	5.76 m/s²	6.87 m/s²

Tab.9: Peak acceleration values of the four right and four left fists by athlete 6 and relative average

The said athlete, turns out to have a higher average for fists performed with the right limb, confirming his right-hand dominance. In addition, the first right fist which results to have a significantly lower value even compared to some left fists, could be the cause of an error in the execution of the technique. In addition, among the subjects analyzed in the study, it is the athlete who achieved the highest average and therefore the high speed of the gesture, which could explain the nonlinearity of the movements on the axes found by the analysis of the tracings.

Athlete 7: Dominance: RIGHT

Chart 13 shows the tracings of the four fists performed with the left limb by the sixth athlete, male. Chart 14 shows the tracings of fists performed with the right limb, by the same athlete.

ATHLETE 7 HITS

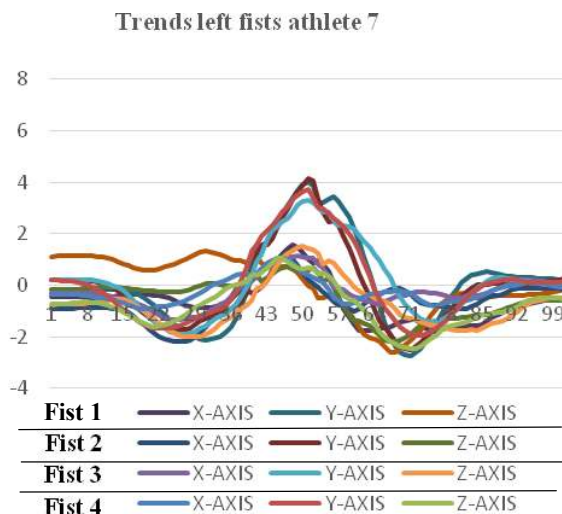


Chart 13: trends of athlete 7's left fists

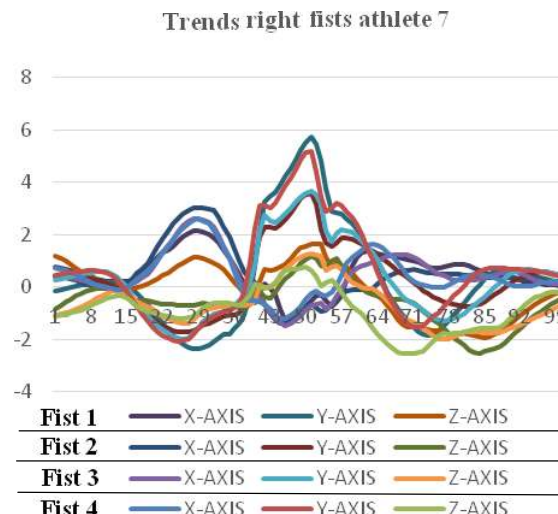


Chart 14: trends of athlete 7's right fists

In this athlete, it is evident that the phase before and after the moment of impact at the bag does not have linearity and, above all, has a longer duration than in previous athletes due to a lower speed in the execution of the gesture and the moment of return to guard. In right fists, there is a positive x-axis acceleration at the preload phase compared to fists with the contralateral limb, where it turns out to be even negative (this could therefore explain the different technical execution between the two limbs). Table 10 shows the resulting acceleration values of the eight strikes performed and the averages of the punches performed with the right and left limbs.

	LEFT LIMB	RIGHT LIMB
FIST 1	4.14 m/s ²	5.99 m/s ²
FIST 2	4.18 m/s ²	3.82 m/s ²
FIST 3	3.75 m/s ²	3.94 m/s ²
FIST 4	3.81 m/s ²	5.23 m/s ²
AVERAGE	3.97 m/s²	4.74 m/s²

Tab.10: Peak acceleration values of the four right and four left fists by athlete 7 and relative average

The athlete confirms his right-hand dominance, as the punches made with said limb are found to have a higher average. In addition, this examinee owns significantly lower values than the other athletes analyzed.

Athlete 8: Dominance: LEFT

Chart 15 shows the tracings of the four fists performed with the left limb by the sixth athlete, male. Chart 16 shows the tracings of fists performed with the right limb, by the same athlete.

ATHLETE 8 HITS

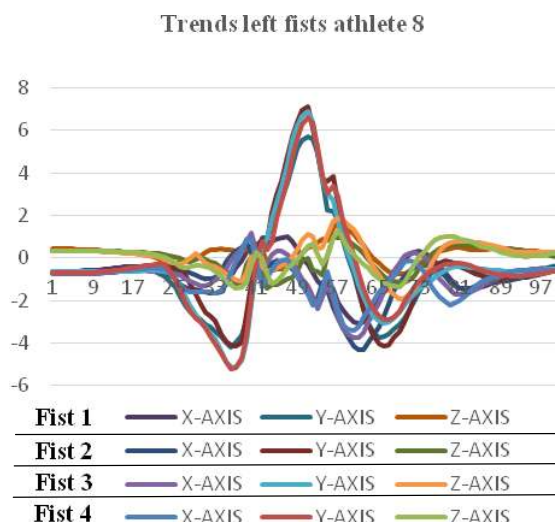


Chart 15: trends of athlete 8's left fists

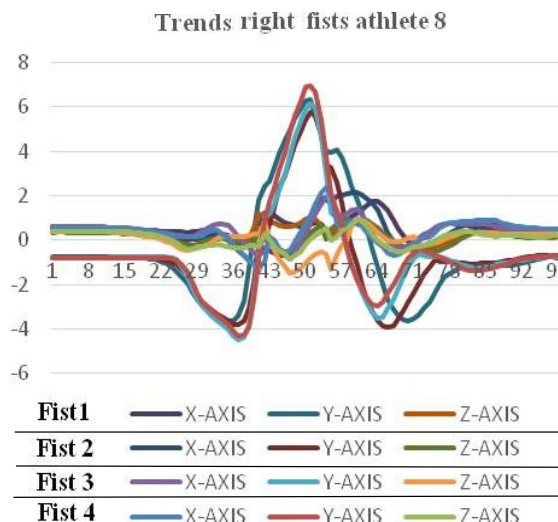


Chart 16: trends of athlete 8's right fists

In this case, we can see that there is a smaller range of variation in the values of the accelerations for the x- and y-axes, in the right fists, compared to the left ones. The y-axis negative acceleration in the pre-loading phase appears to be slightly higher in the left fists, and thus the athlete generated a faster loading phase due to his left dominant laterality. Table 11 shows the resulting acceleration values of each technique performed and the corresponding left and right limb averages, leading to confirm the athlete's left dominance.

	LEFT LIMB	RIGHT LIMB
FIST 1	5.75 m/s ²	6.42 m/s ²
FIST 2	7.32 m/s ²	5.82 m/s ²
FIST 3	7.08 m/s ²	6.23 m/s ²
FIST 4	6.86 m/s ²	7.05 m/s ²
AVERAGE	6.75 m/s²	6.38 m/s²

Tab.11: Peak acceleration values of the four right and four left fists by athlete 8 and relevant average

Conclusions

In this study we have analyzed a fist technique widely used in karate, the "gyaku-zuki", by means of inertial sensors of the latest wearable generation (K-track/K-sport, ITA), for a careful analysis of the gesture's accelerations, with the conviction that the study of the data obtained allows a rebalancing and improvement of the technique examined. This is thanks to an adequate revision of the proposed training aimed at increasing this gesture's performance. It should be pointed out that the small number of athletes and strokes performed will need

implementation in future studies, to comfort these first promising deductions, also with statistical significance, supported by satisfaction regarding the proven validity of the instrument used. Certainly interesting for a more in-depth future study will be the further verification of the acceleration peaks and, therefore, the hypothetical impact force of the blow, of both hands, to establish the gap between the two limbs, in order to prepare a strategic plan of reshaping the proposals in a training aimed at optimizing the weak limb so as to offer the athlete bilateral or almost bilateral tactical solutions, creating considerable difficulties for the opponent to predict the resulting attacks. It goes without saying that perfect symmetry will not be realistically achievable.

There will always be one side stronger than the other, or rather a preference of one over the other, but with a hopefully much smaller difference between the two limbs. Regarding the results obtained, the data analysis led to the conclusion that most of the subjects who participated in the study, were found to have a higher average peak acceleration for the dominant limb (6 out of 8 participants, i.e., 75%), although not as markedly as might have been expected. As mentioned, this may have been due to incorrect execution of the technique at the time of execution of the tests or poor performance of the movements in the few repetitions made for study, or even a level of technical refinement that was not yet good. It is clear that the above are all elements that must be taken into consideration when drawing final conclusions about the albeit indisputable instrumental findings. These elements mentioned above also led to confirm some studies on this topic, actually just a few, carried out in previous years, which observed that right-dominant subjects, for example, had a left-leg forward main guard and were therefore found to be more proficient in pulling the gyaku-zuki with the right arm.

In conclusion, we must point out two anomalies in the following study concerning the two female athletes. They, despite being right-handed, showed higher average acceleration and stroke velocity data with the left limb. After analyzing the data, questions were asked to the two female athletes, who stated that they possessed a prevalence of right-leg forward guard, with the result that the punch examined, was found to be faster with the left limb, as it was more used and trained due to the more commonly used guard. Moreover, their same background of training (same gymnasium) led them to assume such type of guard technique. We are definitely at the beginning of such in-depth studies on the subject with this equipment that is bound to contemplate, as stated, surveys and analysis not only of more sustained sample numbers but also of athletes of different ranks up to the excellences of the sport investigated that may lead the trends of technique to variations as has already happened in many other sports, to begin with football that has greatly altered, if not overturned, both its physical and technical-tactical preparation, particularly at the high level where instrumental analysis is now a consolidated working practice.

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Investigation: Febo M., Hosseini C.,

Data curation: Izzo R., Febo M., Cruciani A., Crudelini E., Hosseini C.

Statistical analysis: Cejudo A., Febo M.,

Writing, original draft preparation: Izzo R., Febo M.

Writing, review and editing: Izzo R., Febo M., Hosseini C.

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