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Case Report

Specific Test Design for the In-Depth Technique Analysis of Elite Karate Competitors with the Application of Kinematic Sensors

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Abstract: Karate fighters are under constant pressure to find adequate scoring solutions in ever-changing combat conditions. Thus, technique improvement at high levels of mastery demands a novel approach to key data acquisition and in-depth analysis of more than just the impact phase in punch execution. With the aim of describing the kinematic and temporal structure of a reverse punch in the developmental phase, two wireless sensors were used for the acquisition of selected quantities in ten modalities performed by a continental and world medallist. The results show that the timeline of kinematic parameters may be a reliable factor regarding the efficiency of the reverse punch. The obtained hand results show a tendency towards maintaining greater levels of stability in comparison to the body. Additionally, the differences between parameters in relation to applied tests that replicated training and combat conditions were noted. The highest acceleration values were obtained in sliding motion preceding RP, with a partner holding chest punch pad, both static (7.35 $\pm$ 0.47 g_0) and dynamic (6.99 $\pm$ 1.23 g_0) tests. The same applies for velocity (8.39 $\pm$ 0.14 and 7.30 $\pm$ 1.28 m/s). The obtained results indicate the need for specific testing and an individual approach in the analysis of the techniques of elite competitors, along with the use of sensors in data acquisition. Such an approach may help improve the training and competition practice of karate fighters.

Keywords: reverse punch; standardised testing; elite athletes; wireless technology

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1. Introduction

In constant pursuit of surpassing achieved results, elite athletes uphold high training standards. Such standards can be met by overcoming conventional training methods [1] based on the subjective evaluation of an individual athlete's coaches, and focused technique analysis may help the process. Stemming from the diversity of a methodological approach, in the broadest sense [2,3], the limiting factors in technique analysis of combat sports are numerous. Analysis of the reverse punch (RP), the most prominent karate technique, is no exception.

The distinguishing characteristic of karate combat at an elite level is the preference for variability in fighting conditions [4]. Despite the fact that direct attack accounts for the majority of points [5], it is not the only scoring modality [5–7]. Consequently, fighters are under constant pressure to find and apply adequate solutions [4,8]. Scoring efficiency depends on a fighter's ability to adapt accordingly [8] in restricted periods of fighting activity under high intensity [6,7,9]. Thus, it would be beneficial to research and analyse RP in realistic combat and training environments, addressing the issues which, due to their complexity, were considered separately in previous research [10–16].

The Internet of Things (IoT) could provide an appropriate solution for such a complex problem. This broad and rapidly evolving field of protocols and applications is based on highly developed, interrelated computer networks that provide real-time information to the consumer [17] and replace traditional testing techniques requiring expert knowledge and a great deal of expense [18]. Motion tracking, along with movement recognition systems adopting sensor technology, has proven to be very useful in the field of sports, but also in health monitoring and rehabilitation [17–22]. In general, studies show a diversity of approaches in human activity recognition, referring to automatic detection based on a series of observations [23]. However, it is important to understand that sports, especially elite ones, impose high demands compared to day-to-day activities [21,22]. Therefore, teaching technique in sports, especially changing the adopted motion patterns of high-level athletes, is a delicate job, and feedback is an essential part of the process [22].

Equipment and environmental constraints, especially laboratory settings, may have an impact on the motor skill being studied [1,24]. In addition, a marker-based optical system as a typical technology used to capture motion [24] requires a great deal of time and effort, as well as trained specialists to operate it [25]. However, the biggest issue is restricted capacity to precisely provide quantities such as velocity and acceleration throughout high-speed motion [24] such as punches. Such evidence imposes additional questions regarding the validity of results and applicability in training and competition practice.

Constraining factors in data acquisition and analysis of sporting techniques are numerous, and they originate from the requirement for assessment of the maximum level of performance during training or competitions [22,26]. Additionally, modifications in performance are constant and rapidly occurring, affecting the accuracy of the measurement [24]. In summary, the system is supposed to be ergonomic, appropriate for in-field use, wireless, applicable on any surface regardless of the environmental conditions, and should have sufficient power capacity, dynamic range, sampling frequency and/or accuracy [24,26,27]. Combat sports impose additional constraints on kinematic sensors (KS) use, which is arguably one of the reasons for the small number of studies applying KS in this field. Just 2.8% of the 286 studies in the review published by Camomilla et al. [26] featured combat sports. High acceleration levels, rapid and ballistic movements, multiple rotations of the employed segments of the kinetic chain, all of which are common to combat sports, are eliminating factors for most available sensors [3,15]. Bearing in mind that soft tissue is affected by the location and type of unit attachment, as well as the motor task and subject [26], the complexity of the topic becomes even more obvious.

Previous research in combat sport, focusing on different performance features, shows the diversity of device properties with the operating range of an accelerometer between ± 3 g and ± 2000 g; a gyroscope from 1000 deg to 4000 deg; and a sampling frequency of up to 5000 Hz. Different studies employed diverse models of sensor positioning, either applying one measuring device or using a full-body model [3]. The objective here was to propose a particular reference body point that might provide the explanatory data. Additionally, sensor-to-segment axis alignment is a critical feature that should be considered when predicting joint kinematics with inertial sensors [28]. However, obtaining such data is possible only if the positioning of the device has no impact on its output [3]. Put differently, kinematic quantities at the given body attachment location must not exceed the dynamic ranges of the device. This also means that the chosen location has to meet the criteria for secure attachment.

After reviewing different types of motion capture in combat sport, Wan Idris et al. [29] concluded that using marker-less estimation of motion involving upper and lower limbs is a "challenging task", especially emphasising the usage of a single computing unit in the utilisation, control and processing of more than one sensor concurrently. For this reason, this present study proposes a novel approach as a possible substitute for the common optical motion capture procedures, as well as for the previous solutions in sensor application. The approach is based on the application of sensors to specific chosen points on an athlete's body, testing the kinematic and temporal parameters with carefully designed tests [25,30].

Such an approach allows for in-depth analysis of technique execution in conditions the same or similar to training and competition and in an affordable and easy-to-use way.

These types of data are valuable feedback for elite karate athletes, given that each fighter at the highest level adds their own signature to the technique performance [31,32]. An analysis of exceptional individuals can contribute to a better understanding of the basis of their success [33]. Knowing that at high levels of mastery, technique improvement is a difficult and delicate job, reliable and valid key data obtained in selected phases of execution have specific value. Speaking from the standpoint of an individual approach, in-depth analysis of elite karate competitors should focus on the critical moments in technique execution. Although the authors do not oppose the significance of impact—indeed, it has been found to be the most important phase—there is a clear necessity to investigate what happens at the very beginning of punch execution. The isolated phases preceding impact can be considered developmental in terms of the progressive increase in kinematic quantities [30]. It is reasonable to expect that possible deviations in each (i.e., initial, developmental) phase of performance affect the final outcome and the quality of the performed technique. Ultimately, it is this that determines the difference between whether a punch will be scored or not.

Based on the above, there is a lack of knowledge of: (i) analysis of the developmental phase of the reverse punch; (ii) the individual approach of an elite karate athlete's performance; and (iii) recommendations regarding the application of wearable kinematic sensors in karate. Therefore, the aim of the current study was to: (i) obtain the relevant parameters for technique improvement with the application of specially designed tests; (ii) perform in-depth analysis of the developmental phase of the reverse punch as the foundation for an individual training programme; and (iii) propose specific sensors application based on the biomechanics of the punch. Thus, we hypothesised that (i) the kinematics in the developmental phase of the reverse punch differ between modalities; and (ii) that the appearance time of the kinematic events is structured in a recognisable pattern.

2. Materials and Methods

The elite karate competitor, a European and World Championship medallist, was tested and analysed in this case study. The participant (age—24 years; height—1.85 m; body mass—82 kg; experience—11 years) gave their written consent, was healthy and without injuries. The study was conducted following the ethical standards recognised by the Declaration of Helsinki and was approved by the Ethics Research Committee of the Faculty of Sport and Physical Education, University of Belgrade (Project III47015, Protocol No. 484–2).

2.1. Variables

The variable selection is based on the knowledge that highlights acceleration and velocity as important parameters of a punch [10,34], as well as the critical influence of the kinematic quantities' timeline on the sequential structure of the RP [11]. The kinematic and temporal quantities regarded as relevant for RP evaluation were:

- HA—maximum hand acceleration, expressed in g_0;
- tHAS—time for the onset of a hand acceleration;
- tHA—time for the maximum hand acceleration;
- HV—maximum hand velocity, expressed in m/s;
- tHV—time for the maximum hand velocity;
- BV—maximum body velocity, expressed in m/s;
- tBV—time for the maximum body velocity;
- tBAS—time for the onset of body acceleration;
- BRa—maximal body rotation angle, expressed in deg.

Of the kinematic variables, three were primary variables and one was derived. The velocity of the hand is integral to the acceleration of the hand (a_x), and it was calculated according to the model of movement in one dimension. The velocity samples were calculated from the acceleration (a_x) using the equation:

$$v_h[n] = v_h\,[n-1] + T_s\,g_0\,a_x[n] \tag{1}$$

where v_h is hand velocity; n is sample number; T_s is sampling interval; g_0 is gravity acceleration (equals 9.81 m/s^2); and a_x is hand acceleration (m/s^2).

Temporal variables are the time equivalents of the kinematic event. Their occurrence corresponds to the ideal time structure in the kinetic chain and has its own particular place in the sequence of connected events.

2.2. Procedure

After the warm-up session, the athlete received verbal instructions and practical demonstrations of the tests. The athlete was instructed to deliver a reverse punch with the dominant hand, aiming for the body, approximately 5 s after the audio signal. Three consecutive punches were delivered in two trials, with enough time to rest in between. The competitor was right-handed, and therefore stood in a left stance. The initial positions were: basic stance (zenkutsu-dachi) and combat stance (fudo-dachi). Both stances were characterised as front stances, on account of the body weight being shifted to the front leg with the knee flexed and positioned directly above the ankle of the front foot. The length of the stances corresponded approximately to two shoulder widths (slightly shorter in the case of fudo-dachi), and they were about one shoulder-width wide. The punch was tested in a total of 10 performance modalities. Apart from the first (RPNH: hip rotation excluded from RP execution) and second (RPH: hip rotation included in RP) tests, which were conducted without moving the feet, the remaining four tests were performed in two major conditions: static (S) and dynamic (D) starting positions:

- RPSM: sliding motion preceding RP;
- RPSMO: sliding motion preceding RP, with opponent as a target;
- RPSMP: sliding motion preceding RP, with partner holding chest punch pad;
- RPSMR: sliding motion preceding RP executed on a visual signal.

To ensure the athlete retained a scoring level performance (i.e., good form, sporting attitude, vigorous application, awareness, good timing, and correct distance) [35] during testing, three highly ranked, world-class referees administered the process. Only punches that met the criteria of competition rules were considered worthy of analysis.

2.3. Experimental Set-Up

Two KS attached to the hand and body were used in this study (Figure 1). Microcontrollers with WiFi communication modules integrated into the sensors enabled the reading of the KS data and their transfer to a separate LabVIEW for Loops application running on a laptop. The samples from both kinematic devices were read by the main program loop. The procedure was controlled and timed in cycles of 5 ms. Communication was established via User Datagram Protocol on a high loaded ISM band. Since packet diversity could result in data loss, error corrections were arranged so that the possible lost samples were replaced with previous values. The validity of the results was confirmed through channel quality monitoring.

Two cameras (Figure 1) were used to record the testing. The cameras were positioned 2 metres from the participant and placed laterally (left and right) relative to the athlete on a tripod that stood 1.3 metres from the floor. This provided enough space for the task to be performed within the field of view and for all stages of execution to be captured. The LabVIEW application received signals from multiple sensors timed with the video camera signal and recorded everything into files for further processing. This kind of approach has advantages over sensor-only application, such as combining images from two cameras at different viewpoints and recognising human action in a more comprehensive manner, allowing for the identification and distinction of the different phases of a movement.

Figure 1. The experimental set-up included two cameras and a laptop wirelessly connected to two sensors attached to the athlete.

The main advantage of the applied procedure is the combination of multiple sources and the heterogeneity of information such as images and inertial data. Four temporally synchronised data modalities were used in order to provide more accurate information. The applied method reduced uncertainty regarding the obtained data, as well as providing detailed analysis of technique. Given that the frame per second (FPR) of the cameras and the sampling rate of the sensors differed, the synchronisation of the beginning and ending of a movement was achieved using time stamps. This kind of synchronisation allowed an accurate assessment of the fixed time delay between the camera and the sensor devices. For each technique modality and each trial, the data were stored in two video (.avi and .MP4) files. The inertial sensor data were stored using the LabVIEW application as .tdms files.

2.4. Sensor Positioning

To our knowledge, there have been no comprehensive studies with particular recommendations of using wearable kinematic sensors for testing in karate. Therefore, several requirements were taken into account concerning the position of the sensors before the final positions were decided upon: (i) the kinetic chain of motion; (ii) eliminating sources of sensor disruption and connectivity problems; (iii) avoiding the disruption of an athlete's performance; and (iv) the most affordable and inexpensive solution. Of course, the main question was asked: which position would give the most satisfactory data? The decision was based on biomechanical facts and empirical knowledge, including:

Kinetic chain—The kinetic chain (Figure 2) represents the link between the superimposed body segments, including the ankle of the back leg, knee, hip, shoulder, elbow and wrist of a punching fist [10,36]. The joint sequence of the lower limb is connected to the joint sequence of an arm through pelvis rotation, i.e., the body. Therefore, this is the last reference point that includes all the relevant kinetic and corresponding temporal events of the lower part of the kinetic chain.

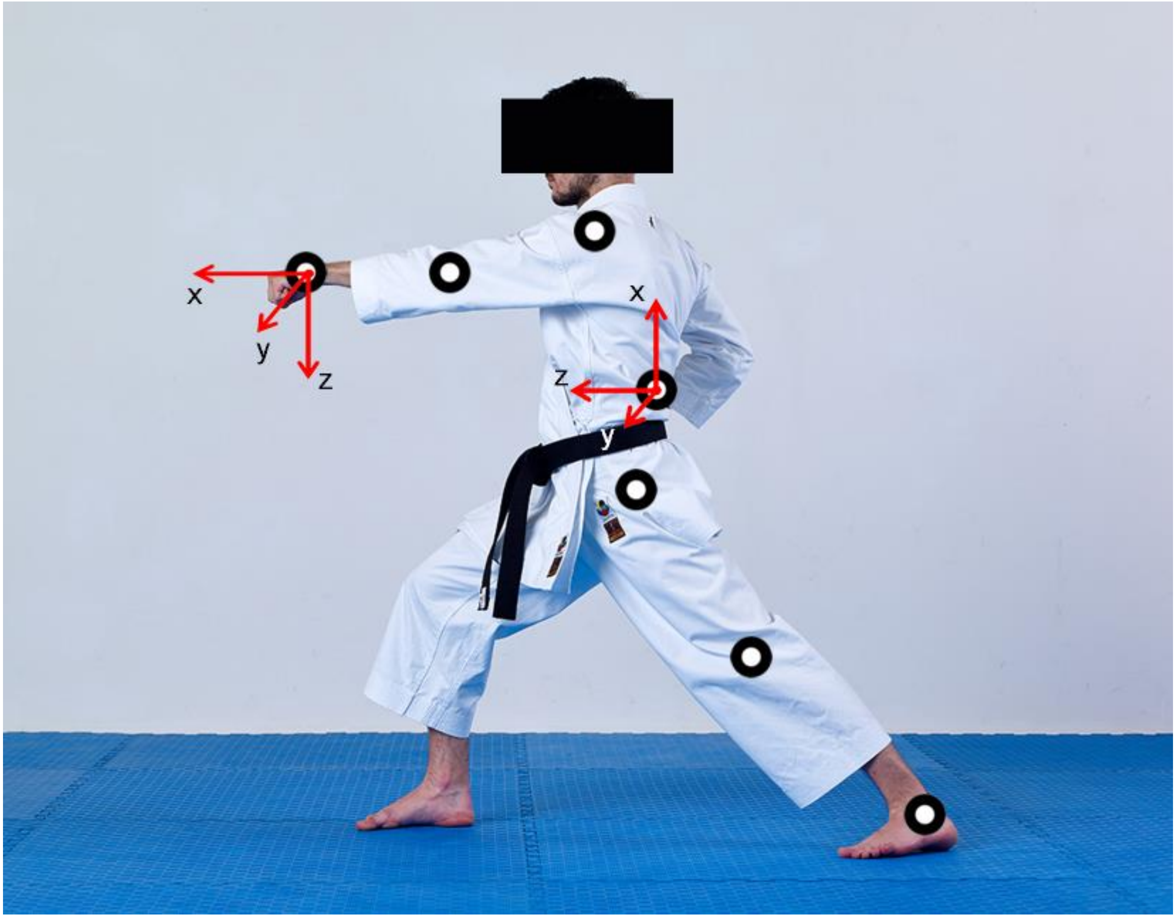

Figure 2. The kinetic chain of a reverse punch and the orientation of the sensors.

The most optimal point for the most representative data—The main idea of the presented method is getting the most accurate data through the simplest approach: placing as few sensors as possible on the most informative locations (i.e., the last optimal point in the kinetic chain for both the upper and lower parts of the body). For the upper limb, for obvious reasons, it is the fist. As for the lower part, it is the centre of gravity. The reasons for this are explained above.

Technique free from interference—The athlete has to feel free from disruption of any kind [37]. In other words, field research in realistic conditions is relevant only if each and every condition of execution is in accordance with the usual training and/or performance environment. In order to achieve this, it was necessary to determine appropriate sensor location empirically and get feedback from the athletes. The chosen location provided conditions in which wearable technical equipment was not obstructive to the athletes.

Sensor output—Sensors placement must not affect sensor output [3]. During test trials, no such problems occurred at the chosen location. The measured kinematic quantities at the selected body attachment point did not exceed the sensors' dynamic ranges.

Fixation—The location of the sensor has to be suitable for safe attachment and has to ensure fixation during the explosive movement. These conditions could be met by combining an appropriate fastening kit and the best sensor location. The security positioning and higher output production of sensors were ensured due to the usage of a waist belt with a tight-fitting pouch and a glove [38]. The particular fastening kit was chosen not only for reasons of secure attachment, but also because it allowed for the sensors not to be in direct contact with the athlete's skin during testing (i.e., not exposed to the effects of elevated body temperature or sweat).

After much deliberation, the exact positions of the sensors (Figure 2) for measuring the kinematic parameters of GTC were: (a) between the 2nd and 3rd lumbar vertebrae, on the back of the athlete and (b) between the os metacarpal II and os metacarpal IV bones, on the dorsal side of the punching fist. In order to maintain the accuracy of the devices, the commonly used method to reduce bias was applied in the field before testing. The average bias measurement interval was 10 s. The sensors were calibrated in a laboratory.

2.5. Data Processing and Analysis

The athlete's technical performance was evaluated using accelerometer signals from both devices and gyroscope signals from the body-worn device: the principal aspect of hand acceleration in frontal movement; the absolute hand acceleration; the linear acceleration of the body; the absolute linear acceleration of the body; the rotation angle of the body in the dominant axis of movement; the rotation angle of the hand in the dominant axis of movement; the hand velocity originated from the principal aspect of hand acceleration; and the body velocity originated from the principal aspect of body acceleration. The time of their occurrence was also taken into account.

As previously explained, the performance of a punch is characterised by two main phases (before and after impact), each of which has several sub-phases in relation to acceleration, angular speed, rotation angle, etc. Although this study is dealing with the exact sub-phase and its time of occurrence, which occurs before impact, this specific moment of execution has been taken into account. A rapid change in acceleration with respect to time (i.e., the impact) was established by the threshold-triggering method. Based on the empirical data, the hand acceleration threshold value was set to 15 g_0. Considering that unfiltered absolute hand acceleration signal was used, analysis of the matching temporal events takes into account the filtering delay.

The data were post-processed and analysed using the MathCAD 7 numerical computation software. The signal analysis was performed using a Butterworth 5th-order order low-pass filter with a cut–off frequency of 40 Hz. In order to prevent false detection of the event, a different threshold was applied for acceleration and rotation speed. The maximum limit value was 5% [25,39]. The first step in calculating the variables defining technical performance was shifting the signals in the reference moment of analysis, which is an impact. Signal analysis was performed in a time window containing 120 samples, within a time interval of 0.6 s.

2.6. Statistics

Mean and standard deviations are used to present descriptive data. The data were calculated using Microsoft Excel for Windows .10.

3. Results and Discussion

The aim of this case study was to fill in the knowledge gap about the developmental phase of the reverse punch. The individual approach in the analysis was applied through ten specific tests and the use of sensors. The main finding of the study was the change in the kinematic and temporal parameters, evidence of which can be seen in the results of test modality (Table 1, Figure 3). Although the time of the appearance of the kinematic event was different in every modality, it is evident that the structure of the timeline stayed relatively stable, recording the maximum hand velocity (HV) last in the observed time sequence. Additionally, the least amount of time between the onset of hand acceleration (HA) and maximum acceleration elapsed in tests characterised by the lowest RP velocity.

Table 1. Hand and body temporal and kinematic parameters (MEAN ± SD) in the ten test modalities.

Test	tHAS (ms)	tHA (ms)	tHV (ms)	tBAS (ms)	tBV (ms)	HA (g0)	BRa (deg)
sRPNH	−120.83 ± 25.58	−60.83 ± 9.17	−20.83 ± 9.70	−135.83 ± 38.00	−61.67 ± 59.47	5.00 ± 0.23	14.65 ± 2.66
sRPH	−198.33 ± 9.31	−56.67 ± 7.53	−12.50 ± 4.18	−175.00 ± 22.14	−45.83 ± 7.36	5.39 ± 0.77	91.61 ± 1.47
sRPSM	−240.00 ± 18.97	−61.67 ± 6.83	−16.67 ± 6.06	−188.33 ± 16.33	−58.33 ± 4.08	6.09 ± 0.64	69.51 ± 10.08
sRPSMO	−235.83 ± 24.98	−73.33 ± 33.27	−25.83 ± 8.61	−186.67 ± 11.69	−60.00 ± 11.83	3.80 ± 0.71	50.09 ± 10.22
sRPSMP	−249.17 ± 8.61	−56.67 ± 6.06	−15.83 ± 4.92	−173.33 ± 11.69	−45.00 ± 7.75	7.35 ± 0.47	61.24 ± 1.59
sRPSMR	−245.00 ± 31.94	−80.00 ± 32.71	−29.17 ± 10.68	−143.33 ± 39.83	23.33 ± 40.33	4.69 ± 0.66	53.32 ± 4.10
dRPSM	−214.17 ± 12.01	−54.17 ± 3.76	−18.33 ± 2.58	−168.33 ± 82.02	39.17 ± 38.13	6.85 ± 0.50	65.27 ± 3.74
dRPSMO	−225.83 ± 19.60	−51.67 ± 2.58	−18.33 ± 4.08	−179.17 ± 75.33	−2.50 ± 12.14	6.10 ± 0.10	66.82 ± 4.03
dRPSMP	−226.67 ± 36.01	−75.00 ± 29.66	0.83 ± 28.18	−118.33 ± 29.94	10.00 ± 33.76	6.99 ± 1.23	72.89 ± 7.85
dRPSMR	−251.67 ± 23.63	−51.67 ± 2.89	−15.00 ± 5.00	−148.33 ± 10.41	20.00 ± 40.93	4.87 ± 1.17	61.29 ± 4.42

Note: RPNH—hip rotation excluded from RP execution; RPH—hip rotation included in RP; RPSM—sliding motion preceding RP; RPSMO—sliding motion preceding RP, with opponent as a target; RPSMP—sliding motion preceding RP, with partner holding punch pad; RPSMR—sliding motion preceding RP executed on a visual signal; s—static; d—dynamic.

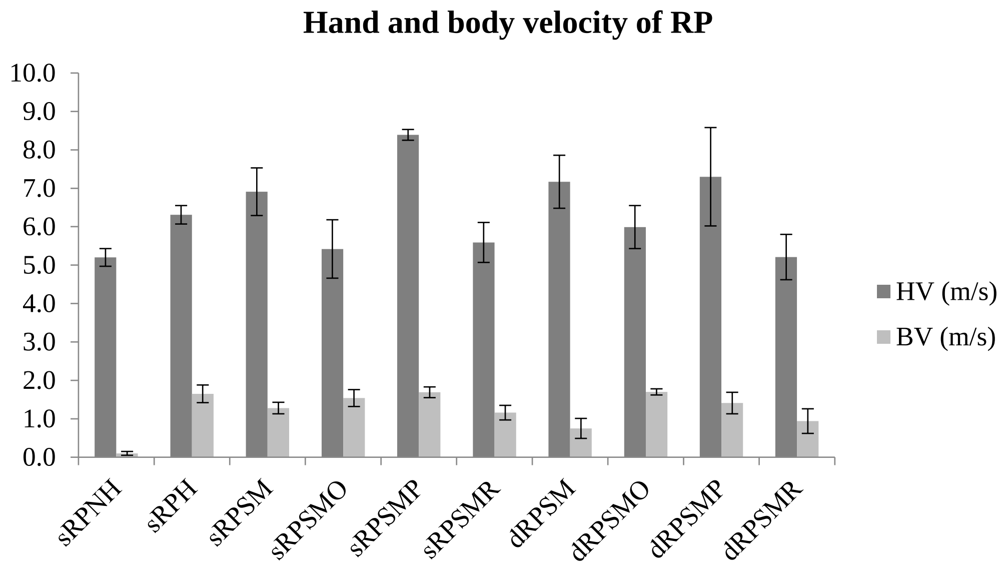

Figure 3. Change in maximum hand and body velocity (m/s) in the ten test modalities of reverse punch.

The results of the two tests, sRPNH and sRPH, explain the basic requirements in the technical performance and the ability of the athlete to successfully apply them. Apart from stability, one of the main requirements for a good stance is smooth hip rotation providing adequate energy transfer and correct technique form [40]. The study confirmed that the observed quantities increased, ultimately influencing hand velocity. The major objective of testing particular motor functions of karate athletes is to identify the causes of technique variations. The two tests clearly show a change in the athlete's performance consistency in regard to time. As the optimal value of acceleration or velocity will most likely be reached on account of an athlete's adaptation capability, it is interesting to find out to what extent the timeline stays rigid. Applied sensor devices detected time deviations in the test modalities. This is consistent with previous findings [30] and indicates that sensors are sensitive enough to detect the movement pattern changed by the complexity of the performed modalities. When a punch is executed in a way that deviates from the desired model of performance, the results reveal that tHV and tBV change positions at the end of the timeline. This property of measuring wearables is indeed important because it is often a difference measured in milliseconds and, most likely, such a difference can be detected thanks to the careful positioning of the sensors.

The same tendency is observed in the tests that follow, but only to some extent. In order to understand the complexity of the problem and interpret the results in the proper context, the group of static tests (sRPSM, sRPSMO, sRPSMP and sRPSMR) should be observed together. Although they represent a logical continuation of the previous ones, and reflect the gradual rise in the complexity of combat (training and competition) situations, they indicate that HA and HV do not necessarily increase, which is in accordance with previous findings [10,11,41]. When performing a punch in the air or on the punching pad, the athlete reaches the highest values of HA and HV. On the contrary, there is an obvious drop in hand acceleration and velocity in the initial phase of the punch when RP is executed while aiming at an opponent or reacting to a visual signal. The reason for such results could be explained by the test organisation, which implies certain goal orientation. Tests sRPSM and sRPSMP replicate the training set-up, where a direct threat from an opponent is reduced to zero. Even so, the apparent difference in kinematic parameters speaks in favour of RP executed on the punching pad. The same pattern is repeated in the results of the dynamic tests. Such evidence is supported by previous studies pointing out that changing the condition of execution (whether it be a task or goal orientation, opponent's activity, rules, etc.) [10,11,42,43] will influence an athlete's performance. It was found that changing the distance or aiming for a higher impact affects acceleration [10,11], and our results are in line with such data.

In contrast with the previous tests, the kinematic values obtained in tests sRPSMO and sRPSMR are lower. This is presumably because these tests simulate real combat situations and engagement with an opponent to some degree [43]. It is true that the opponent activity is non-threatening, but it can be assumed that this type of setting activates learned patterns of execution. Such patterns involve the controlled use of force against an opponent, as well as alertness and anticipation of a potential reaction from the opponent. Taking into account the findings of Loturco et al. [10], with caution, it can be assumed that these tests emphasise the necessity for the fighter to be fast and not to generate a high impact. The same intention is observed in the dynamic tests: the athlete achieved higher HA and HV in dRPSM and dRPSMP than in dRPSMO and dRPSMR. Interestingly, body kinematics do not necessarily follow this pattern. Additionally, it was expected that the results of the dynamic test would show an increase in HA and HV, but that is not what happened in all cases. Regarding HA, this intention is observed in all tests but dRPSMP, where the achieved value was lower by 0.39 g_0 and the punch was slower by 1.09 m/s. The probable cause of such an outcome is a combination of training and real combat conditions. It is not surprising that the lowest HA and HV are identified in the test RPSMR, regardless of a static or dynamic starting position. This test has the most complex structure and demands the fighter be highly concentrated on the opponent, simultaneously anticipating their activity and reacting to it. To some extent, this test in the suggested conditions can be considered as a task mixture, combining the anticipation and reaction of the athlete. The importance of reaction time in karate has been questioned in several studies [12,13,44–46] but, to our knowledge, kinematic and temporal parameters of RP under the proposed conditions have never been investigated. The results confirm that the desirable time pattern of kinematic events is achieved in less variable conditions—i.e., the static test. Such a timeline implies the time of occurrence closest to the impact, whether it is tHA, tBV, or tHV [11].

Limitations of the Study

Although the aim of our study was to assess the developmental phase of RP in different test modalities performed by an elite athlete, the underlying kinematic and temporal structure of impact would provide additional insight and might help to provide a more comprehensive understanding of RP. Although the analysis of outstanding individuals provides valuable feedback on key technical components and helps us to understand the specifics of a successful performance, the next research step should include a larger and more diverse sample that could provide more general conclusions. It would be noteworthy to study the differences between male and female fighters, as well as differences in age or competitive level. When it comes to analysing exceptional individuals, attention should be focused on a limited number of variables, and a punch performed in a larger number of repetitions, so that the sample is representative for a more complex statistical analysis. Such an analysis should take into consideration only the most representative punches (i.e., the ones with the highest kinematic values). A more discriminative approach should also take into account anthropometric, physical performance profiles, physiological profiles, etc. For such an analysis, it would be beneficial to limit and carefully select the number and type of tests. It is also recommended to compare competitors in different weight categories, while respecting the above conditions. On the other hand, a more comprehensive analysis could focus on a wider set of variables, emphasising the study of the relationship between the kinematic quantities and their possible influence on the execution of the punch. In a final step, the impact phase of the punch should be analysed as well.

4. Conclusions

This case study provided in-depth analysis of an elite karate athlete and demonstrated the necessity for an individual approach to the training and competition issues in elite combat sport. The obtained data confirmed the change in kinematic parameters between the tests. The acceleration values and velocity of a punch changed, reflecting the athlete's response to the specifics of the tests. The highest acceleration and velocity values were obtained with RPSMP in both the static and dynamic tests. Regardless of the test modality, the time structure of the punch stayed relatively stable, implying that consistency in the timeline sequence of the kinematic events can be used to predict an athlete's potential efficiency. Yet, an increase or decrease in HA and HV suggests different strategies of punch execution probably relate to the type of target. The presented findings justify the need for specific testing, as well as the use of sensors in data acquisition. The proposed approach is based on the biomechanical and practical knowledge specific to karate combat, which considers the key points of the punch execution: (i) the kinetic chain; (ii) the type of starting position; (iii) the type of stance; (iv) the distance; (v) the target; (vi) the visual signal; and (vii) the performance complexity. Furthermore, the study demonstrated a practical, inexpensive and easy-to-use method that uses only two sensors in realistic conditions and overcomes the limitations imposed by a common laboratory approach, thus reducing the preparation and testing, as well as the necessary logistics. The obtained data described the technique performance with richness that provides valuable information for practice improvement in relation to different training and combat situations.

5. Patents

The basic idea of the presented testing approach lies in the assumption that kinematic parameters will change due to different levels of technical complexity. That is to say, the inclusion of a larger number of body segments will influence acceleration and velocity, i.e., the RP performance. Until now, research provided enough evidence to assume that the involvement of a specific task or a target [10–12,41] may affect the parameters of interest as well. From a biomechanical point of view, the complexity increases from the RPNH to the RPSMR, and is followed by the initial stance. With insightful sensor placement, the proposed system is reliable, ergonomic, optimal and easy to use in a realistic environment.

Tests were performed in accordance with several requirements and two starting positions. A static position implies that the athlete stood still, with their feet firmly on the floor in one out of the two initial stances. The athlete was free to choose the distance and take in the starting position when they felt ready. However, once settled, the athlete should not make any additional movement besides the one defined by test. The dynamic position implies that the athlete taking in fudo-dachi is free to move in a manner characteristic of a sport's combat. Three consecutive punches are performed in one trial. The reason for this lies in the athlete's necessity to adapt in the shortest time. As a consequence, fighters often perform continuous and time-limited actions consisting of one or more punches [5]. The trial is regarded as correct if all three punches meet the scoring criteria. It is probable that some of the performed techniques will be not as good as they could be. It is, however, important to take them into account, because they speak in favour of a fighter's ability to make the right choices and execute efficient technique with the fighting constrains. The proposed tests are:

1. RPNH (reverse punch, no hip included): Zenkutsu-dachi is the initial stance adopted in the first test. ZD requires straightening the rear leg and positioning both hips 90 degrees relative to the stance direction. This particular positioning of the hips is known as a front position. This kind of set-up suspends the lower part of the kinetic chain from participating in and influencing the punch. The left arm rests alongside and next to the body in order to prevent any additional movement coordinating the opposite arm, which might affect the acceleration of the punch. The elbow of the right arm is flexed at an angle of 90 degrees and rests on the body. The punch is executed in the air.
2. RPH (reverse punch, hip included): In the remaining test modalities, the initial stance is fudo-dachi. In FD, both legs are flexed at the knee joint, while the hips are positioned at an angle relative to the stance direction (in karate terminology, this is referred to as an *open position of hips*). Both arms are in a position of readiness to fight (i.e., *guard position*). The particular set-up allows for the inclusion of the entire kinetic chain in the punch execution. RPH implies that an athlete performs RP including hip rotation, but retaining a static position. The punch is executed in the air.
3. RPSM (reverse punch in motion): In the third test, RP is performed in motion. The motion adopted is the common pattern motion combined with the reverse punch [5]. It consists of a front leg sliding forward during the punch and sliding back after the punch has been executed. In this way, the path of the punch execution is longer. The punch is executed in the air and there is no target or a marker defining the distance.
4. RPSMO (reverse punch in motion against an opponent): This test builds on the previously adopted conditions, static position and sliding motion, but involves an opponent as a target. This requires the athlete to adjust the distance in relation to the target and make controlled contact with the opponent's body. The opponent stands still in FD, in a position of readiness to fight. After the punch execution, the athlete slides back to the initial position.
5. RPSMP (reverse punch in motion against the chest punching pad): The difference between this test and RPSMO is the type of target. In this test, the opponent is standing still in FD, holding a chest punch pad. This type of target allows for excessive contact and no control. The competitor is still required to return to the starting position after the punch.
6. RPSMR (reverse punch in motion as a reaction to a visual signal): The last test from a static position with sliding movement preceding the RP is also performed with an opponent. Unlike the previous tests, where the athlete executed a punch when they felt ready, in RPSMR punch is executed on the visual signal of the opponent. The opponent is standing in FD, in a position of readiness to fight. Whenever they feel ready, the opponent lifts their front arm vertically up as a visual signal. As a reaction to the visual signal, the athlete executes RP before sliding back to their initial position.

7–10. Tests 3–6 are also performed from a dynamic position. The logic behind this is that free movement allows an athlete to find the appropriate distance for an attack by making the necessary adjustments. More importantly, a dynamic starting position is a precondition for the generation of higher ground reaction forces enabling higher punch efficiency [10,47]. In the dynamic test requiring a target, only the athlete performing the punch is allowed to move freely. The opponent, whatever their role is, always takes a static stance with their feet firmly on the ground.

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