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Performance, Perceptual and Reaction Skills and Neuromuscular Control Indicators of High-Level Karate Athletes in the Execution of the Gyaku Tsuki Punch

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Abstract: This study aimed to investigate and compare the performance, perceptual and reaction skills and neuromuscular control indicators of sub-elite (SEG) and elite (EG) karate athletes during the execution of a Gyaku Tsuki punch. The study included 14 male athletes, equally divided into two subgroups according to their current competitive level. We analyzed the peak and mean linear velocity of the wrist, linear peak acceleration/deceleration of the wrist, braking time, pre-motor time, motor time, reaction time, movement time and co-contraction index between selected muscle groups. EG athletes presented higher values in almost all performance variables, with the exception of the mean linear velocity of the wrist, which was similar between the groups. In the perceptual and reaction skills, the EG athletes presented shorter time durations with the exception of the pre-motor time, which did not reveal significant differences. The only significant difference in the indicators of neuromuscular control were found during the deceleration phase, where the EG athletes presented a higher co-contraction index between the biceps brachii and the triceps brachii. In conclusion, the EG athletes, in addition to being faster to react, faster to accelerate the wrist, could perform the braking in less time than the SEG athletes, making the technique less perceptible to the opponent.

Keywords: kinematics; electromyography; reaction time; martial arts; punch

1. Introduction

Karate, a word of Japanese origin, means "empty hand" and is one of the arts of unarmed combat [1]. Like other martial arts, karate was created with an original intent to kill or dominate an opponent. Thus, to transform karate into a sporting modality, it was necessary to create rules and measures for the protection of the athletes [2]. Prior to 2001, attacks against the opponent had no restrictions whatsoever on the impact and the effects of the attack on the athlete who would receive the stroke. Currently, Article 8 of the rules of the World Karate Federation [3] lists several prohibited dangerous techniques. Furthermore, such rule changes have dramatically decreased the rate of injuries incurred during competitions by almost half [4]. However, changes in the rules inevitably generated changes in the characteristics of an attack execution. Previously, attacks had ballistic characteristics; that is, they were launched to hit the target with the greatest possible speed [5]. It has been suggested that ballistic movements are preprogrammed and once the central command is formulated and sent to the motor neurons, there is no change in the activation of the motor neurons based on peripheral feedback [6].

Under current rules, athletes need to control the velocity of the stroke so that it attains the highest velocity possible during the course of the punch but reaches the target with a velocity close to zero. Such a maneuver can make the performance of the technique easily perceived by the opponent if the stroke is not fast enough and if the time required for the braking process is not short enough. Lestienne [7] investigated the effect of various velocities, amplitudes and inertial loads in the flexion/extension braking process of the elbow joint and reported that the duration of agonist muscle activity and the onset of antagonist muscle activity were strongly correlated with peak velocity. In addition, increasing the inertial loads did not change the peak velocity, although it did increase the level of excitation of agonistic and antagonistic muscles without changing the temporal characteristics of the EMG bursts. Jarić et al. [8] found that stronger antagonists, conditioned by a training program, improved the performance of rapid elbow movements as they facilitate the braking of a movement in a shorter period of time. This provided a longer duration of the acceleration phase and a higher velocity peak of the movement. Sbriccoli et al. [9] investigated the mechanism of co-contraction in the frontal kick karate technique and pointed out that this mechanism might serve not only to protect a given joint but also as a mechanism of fine control of the movement.

Movement velocity is one of the main determinants and predictors of competitive karate performance [10]. However, success in this sport requires not only the efficient execution of motor patterns, but also a high level of perceptual capacity. High-level competitive sports are characterized by severe spatial and temporal constraints imposed on the athlete by the regulations and the opponent [11]. Karate is a good example of a competitive sport with high levels of temporal and spatial constraints, which require fast reactions. The need to strike and defend against the opponent requires karate athletes to develop their perceptual abilities, i.e., karate-specific perceptual skills and/or non-specific basic sensory functions [12].

Reaction time (RT) is an important indicator of the speed of information processing and is defined as the time between the presentation of a stimulus and the beginning of the motor response [13]. RT can be subdivided into two periods: pre-motor time (PMT) and motor time (MT) [14]. The first one (PMT) corresponds to the time interval between the visual stimulus and the immediate change in the activation level of the muscle detected by EMG. The second (MT) refers to the time interval between the PMT and the beginning of a perceptible movement of the requested limb [15].

Among the strokes used in karate, the Gyaku Tsuki punch represents 50% of all techniques used in official karate combat [16]. The Gyaku Tsuki is a punch performed with the advancement of the hand along with the advancement of the contralateral lower limb, in the Zen Kutsu Dachi posture, in which the athlete has their front lower limb positioned with the knee flexed and the other limb with the hip and knee extended and both feet in contact with the ground [17,18].

Quantifying the possible variables that differentiate the elite from the sub-elite athlete has been the object of study in several modalities due to their potential effect on the development of the modality. To the best of our knowledge, there are no reports in the literature of studies that show biomechanical and neuromuscular differences when a Gyaku Tsuki punch is performed by sub-elite and elite athletes. In order to identify biomechanical and neuromuscular characteristics that differentiate sub-elite (SEG) and elite (EG) athletes, the aim of the present study was to investigate and compare the performance, the indicators of neuromuscular control and the perceptual and reaction skills of karate athletes during the execution of the Gyaku Tsuki punch. To achieve this objective, we investigated and compared kinematic, EMG and temporal parameters during the execution of the Gyaku

Tsuki punch technique between the EG and SEG groups. We hypothesized that elite athletes would execute the technique at a higher speed with a shorter reaction and movement time and are differentiated from the SEG group by a greater co-contraction of the selected muscles to control the speed of the stroke at the end of its execution.

2. Materials and Methods

2.1. Participants

Fourteen male competitive karate athletes volunteered to participated in the study, aged 18 to 35 years. They were divided into two subgroups, according to their current competitive level: the elite group (EG), composed of seven individuals who were at a black belt level and competitors at a national or international level (age: 26.3 $\pm$ 6.9 years; body mass: 77.5 $\pm$ 12.8 kg; height: 171.1 $\pm$ 7.7 cm; body fat: 12.6 $\pm$ 6.7%); and the sub-elite group (SEG), composed of seven individuals who were at a black belt level and competitors at a regional or state level (age: 27.5 $\pm$ 6.1 years, body mass: 75.1 $\pm$ 8.9 kg, height: 171.6 $\pm$ 6.2 m; body fat: 15.1 $\pm$ 5.9%). The criteria for exclusion of participants consisted of pain, fracture or severe injury in soft tissues in the 6 months prior to the study, as well as a history of cognitive, neurological, cardiovascular or respiratory disturbances. These criteria were investigated through an interview prior to the beginning of the evaluations. The present study was approved by the Local Ethics Committee, and all the participants signed the Informed Consent Term prior to participation in the study.

2.2. Data Collection Procedures

2.2.1. Anthropometric Evaluation

Regarding anthropometric data, the following were measured: body mass and height, as determined with a scale with a stadiometer (Sanny®, BL201PP, Sao Paulo, Brazil), and skinfolds of the thorax, abdominal and thigh [19], from which the percentage of body fat was calculated [20]. All anthropometric measures were performed by an experienced examiner, according to the ISAK guidelines.

2.2.2. Punch Evaluation

During the performance of the technique, the participant kept their dominant (back) foot on an AMTI® OR6-2000 force platform (AMTI®, Watertown, MA, USA) with a sampling frequency of 1500 Hz (Figure 1). The subjects used their experience to choose the distance at which the best possible execution of the technique would be ensured, taking into account their anthropometric characteristics and technical-tactical individualities.

A 16-channel wireless signal acquisition module (Noraxon®, Scottsdale, AZ, USA) was used to capture the EMG signals during the application of the punch. The EMG signal had a sampling frequency of 1500 Hz, with a total gain of 2000. Ag/AgCl surface electrodes were used in a bipolar configuration, with a capture area 1 cm in diameter and a 2 cm inter-electrode distance. The electrodes were positioned on the dominant side on the anterior deltoid (DA), posterior deltoid (DP), biceps brachii (BB), triceps brachii (TB), tensor fascia lata (TFL) and gluteus maximus (GM) muscles according to the SENIAM standards [21].

The collection of kinematic data was performed simultaneously with EMG data acquisition. Seven cameras, operating at 250 fps (Vicon®, New York, NY, USA), and Vicon® Nexus kinematic software were used. For the reconstruction of the movement, basic retro-reflective markers were fixed bilaterally, according to the Vicon® PluginGait model for the whole body.

Five punches were performed by the dominant upper limb on an instrumented target (Figure 2A) placed at an individualized distance chosen by the athlete, where they could execute the technique in a comfortable Zen Kutsu Dachi position. One light-emitting diode (LED) was placed on top of the target to give visual stimuli to the participant, who then delivered the punch to a contact sensor. This contact sensor was composed of one 30 mm piezoelectric sensor fixed to a block of ethyl vinyl acetate with dimensions of

24 cm × 27 cm (Figure 2B). Both the LED system and the contact sensor were controlled by a microcontroller (Figure 2C).

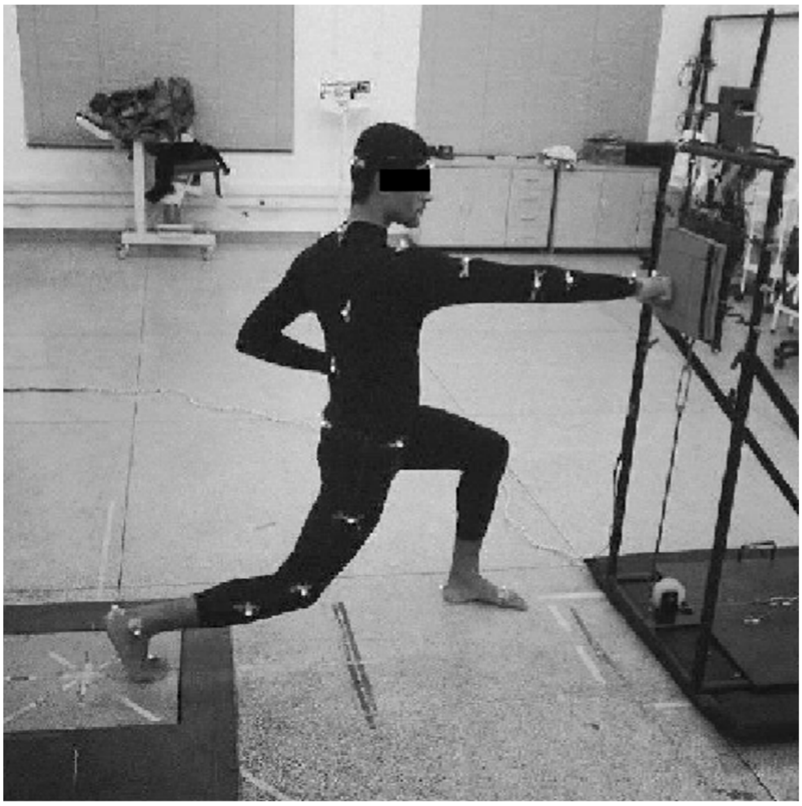

Figure 1. Gyaku Tsuki execution.

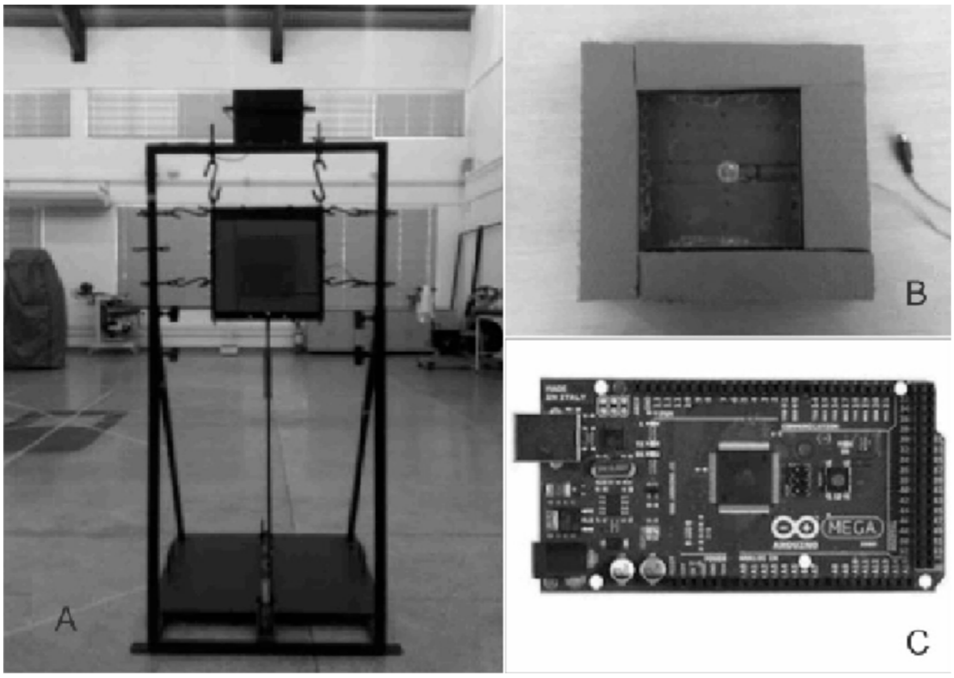

Figure 2. (**A**) Instrumented target; (**B**) contact sensor; (**C**) Arduino MEGA 2560.

Both the firmware allocated on the board and the software that commanded the LED system and contact sensor were developed in the C++ language. The signals from the instrumented target were synchronized with the biological signal acquisition system and the Vicon® analog–digital unit via analog inputs from the two systems simultaneously.

2.3. Data Analysis

Data were processed and analyzed using specific routines developed in the Matlab environment, version 8.5.0.197613 (Mathworks®, Inc., Natick, MA 01760-2098, USA). First, the optimum cutoff frequencies for signal filtering were established through residual analysis [22]. Then, the kinematic data were filtered with a low-pass recursive 4th-order Butterworth filter with a 6 Hz cutoff frequency. The kinetic data from the force platform signal were filtered with a low-pass recursive 4th-order Butterworth filter with a cutoff frequency of 95 Hz. The EMG signals were first high-pass-filtered at 20 Hz followed by low-pass filtering at 500 Hz.

In order to detect the onset of muscle activation, the EMG signal of the TFL and GM muscles were submitted to a non-linear energy operator (Teager–Kaiser), which enhances the activity of the motor units and thus provides a more robust onset detection methodology [23]. The onset of muscle activation was determined by the threshold method, where the onset instant has two conditions to fulfill, namely: (i) to be equal to or greater than the mean plus three standard deviations calculated at the baseline, and (ii) to keep the first condition by more than 50 samples (~0.033 s). The onset of muscle activation after visual stimulus was considered to be the shortest time between the onset of the TFL and the onset of the GM.

The onset of movement was determined by a threshold method applied on the antero-posterior displacement curve of the center of pressure (CoP) that was calculated from the force platform data. Movement onset was the instant at which the antero-posterior displacement of CoP was equal to or greater than the average plus three standard deviations above the baseline.

Reaction time (RT), pre-motor time (PMT), motor time (MT) and movement time (MOVT) were calculated as in Ervilha et al. [14] (see Figure 3).

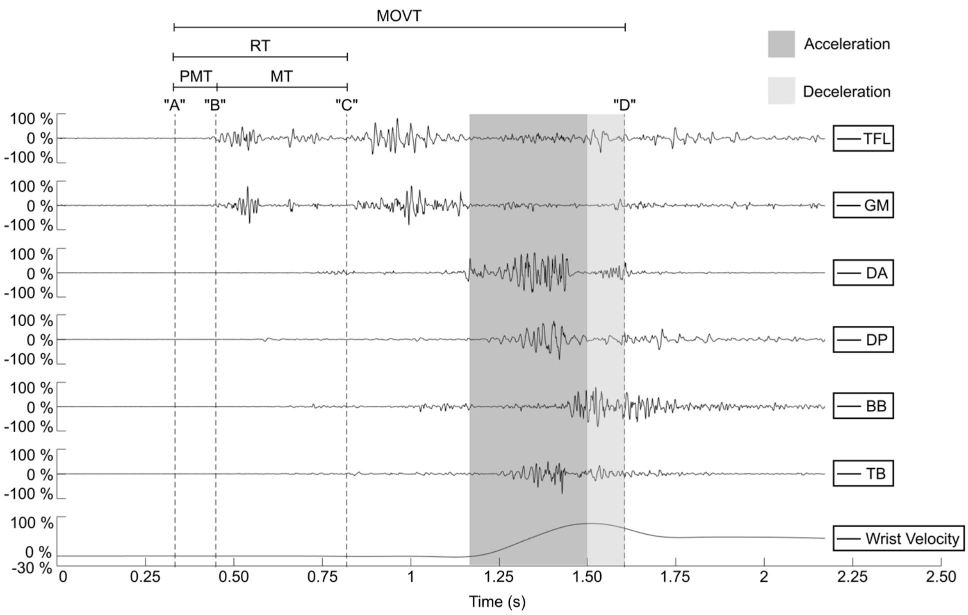

Figure 3. Example of the behavior of electromyographic and kinematic variables during the execution of the Gyaku Tsuki stroke. "A"—visual stimulus, "B"—onset of muscle activation, "C"—onset of movement and "D"—impact with target.

Peak linear velocity of the wrist, mean linear velocity of the wrist, peak linear acceleration of the wrist and the peak linear deceleration of the wrist were calculated from the kinematic data. These variables were calculated by differentiating the resultant from the linear displacement values of the lateral reflective marker of the wrist on the three axes. The interval between the linear velocity peak of the wrist and the minimum value of the linear acceleration curve (obtained between the linear velocity peak of the wrist and the target contact) constituted the braking time.

For the analysis of the co-contraction index, the EMG signal of the DA, DP, BB and TB muscles were first full-wave-rectified and then submitted to a low-pass recursive 4th-order Butterworth filter with a cutoff frequency of 6 Hz to create a linear envelope. After the envelope creation process, the EMG signal was normalized to the peak of the linear envelope of the EMG signal of the concerned muscle acting as an agonist during a maximal voluntary isometric contraction (MVC). MVCs were collected previously on a Biodex® System 4 PRO (Biodex Inc., New York, NY, USA). The following equation (Equation (1)) was developed and applied to the EMG signal of the pairs of agonist and antagonistic muscles of the flexion and extension movements of the shoulder and elbow:

$$\text{CoConIndex} = \frac{(\int \text{common to Muscle1 and Muscle2})}{(\int \text{Muscle1} + \int \text{Muscle2}) - (\int \text{common to Muscle1 and Muscle2})} \times 100 \quad (1)$$

The co-contraction index (CoConIndex) was calculated as a percentage in the acceleration and deceleration phases after the maximum flexion of the elbow joint during the execution of the Gyaku Tsuki punch. The pairs of muscles were AD-PD; BB-TB.

2.4. Statistical Analysis

Statistical analysis was performed using PASW statistics 18.0 software (SPSS®, Chicago, IL, USA). After verification of the normality of the data through the Shapiro–Wilks test; either a parametric t-test for independent samples was performed if the normality criterion was met or a Mann–Whitney U test for the non-parametric data was performed if the normality criterion was not met. For all statistical tests, the mean of the five trials for each participant was used. In all statistical tests, the significance level was set at $\alpha = 0.05$. The Common-Language Effect Size (CLES) indicates the probability that a score sampled at random from one distribution will be greater than a score sampled from some other distribution [24]. CLES was calculated for all tests. The post hoc power and effect size were also computed with the software G*Power.

3. Results

It was determined that no parameters, except peak wrist acceleration, met the normality criterion. Thus, group mean ± standard deviation is presented for the parametric parameter, while the median (interquartile range) is presented for the non-parametric data, as well the CLES values, post hoc power and effect size (Table 1).

Both groups presented a very similar execution technique, reaching the target with the elbow semi-flexed, at a flexion angle of 44.66° ± 5.27° for the EG athletes and 40.62° ± 5.36° for the SEG athletes, without significant differences between groups ($p = 0.180$). Even so, all performance parameters, except for the mean velocity of the wrist, were statistically significantly different between the EG and SEG groups ($p < 0.05$). In each significant parameter, the EG group had what could be considered a better performance than the SEG group.

The two groups demonstrated statistically significant differences in several of the variables that configure the perceptual and reaction skills (motor time, reaction time and movement time), with EG athletes achieving shorter time intervals ($p < 0.05$). The exception was the PMT, which was similar between the groups ($p = 0.084$), however, the CLES value (76.91%) suggests a probable difference, which may have been suppressed by the sample size.

Only the co-contraction of the BB-TB muscles during the wrist deceleration phase was statistically different between the groups ($p = 0.022$). The EG group presented a significantly higher value in the percentage of coactivation between the triceps brachii (TB-"Agonist") and biceps brachii (BB-"Antagonist") muscles during this phase of the punch.

Table 1. Performance, perceptual and reaction skills and neuromuscular control parameters.

Variable	Sub-Elite	Elite	*p*	CLES (%)	Cohen's d	Power
Performance						
Wrist peak velocity (m.s^{-1})	6.09 (0.81)	7.20 (1.70)	0.000 *	75.33	0.89	0.98
Wrist mean velocity (m.s^{-1})	1.46 (0.33)	1.36 (0.28)	0.605	57.82	0.59	0.78
Wrist peak acceleration (m.s^{-2})	49.30 ± 11.68	63.03 ± 24.42	0.004 *	73.66	0.72	0.91
Wrist peak deceleration (m.s^{-2})	92.10 (22.49)	103.76 (28.00)	0.004 *	95.64	0.65	0.85
Wrist braking time (s)	0.09 (0.02)	0.08 (0.02)	0.013 *	89.75	0.59	0.79
Perceptual and reaction skills						
Pre-motor time (s)	0.13 (0.04)	0.12 (0.09)	0.084	76.91	0.42	0.53
Motor time (s)	0.23 (0.18)	0.10 (0.09)	0.003 *	96.34	0.6	0.8
Reaction time (s)	0.35 (0.11)	0.24 (0.07)	0.047 *	77.58	0.44	0.58
Movement time (s)	0.91 (0.10)	0.83 (0.15)	0.000 *	95.24	0.77	0.94
Neuromuscular control						
Cocon DA-DP accel (%)	42.67 (19.76)	40.89 (19.02)	0.738	55.05	0.4	0.07
Cocon DA-DP decel (%)	21.90 (28.28)	24.72 (35.76)	0.677	56.30	0.4	0.07
Cocon BB-TB accel (%)	25.78 (37.24)	19.14 (22.90)	0.499	60.24	0.18	0.18
Cocon BB-TB decel (%)	31.67 (21.23)	48.28 (36.35)	0.022 *	86.22	0.9	0.79

* Significant difference between groups ($p < 0.05$).

4. Discussion

This study compared athletes' performance, indicators of neuromuscular control and perceptual and reaction skills during the execution of the Gyaku Tsuki karate punch. We confirmed our hypothesis that elite athletes would execute the technique to a higher level, have more advanced perceptual and reaction skills and are differentiated from the SEG group by the best use of the co-contraction mechanism to control the speed of the stroke at the end of its execution.

Velocity is one of the main determinants and predictors of competitive karate performance, as shown in previous studies [10,25]. In agreement with the literature, we found that the linear velocity and acceleration of the wrist, during the performance of the Gyaku Tsuki punch, are higher when performed by elite karate athletes compared to sub-elite karate athletes. Our results also agree with those of Cesari and Bertucco [26], who compared karate athletes of different levels and verified higher values of upper limb velocity in athletes with a superior skill level.

During the execution of Gyaku Tsuki punch, the participants of the elite group exhibited a significantly shorter motor time, reaction time and movement time. However, pre-motor time was similar between the two groups, although there was an apparent effect of the reduced sample size. Regarding our finding on the comparison of the PMT, it is in agreement with a study by Chung et al. [27], who investigated the EMG onset of a large muscle of the lower limb (rectus femoris), as in our case (TFL or GM), and found no differences in pre-motor time among professional Taekwondo (TKD) athletes, amateur TKD athletes and non-athletes. As to simple reaction time, Layton [28] did not find significant differences when comparing athletes of different competitive levels, but points out that black belts have shorter times than beginners. Mori et al. [12] demonstrated that experienced athletes are superior in making quick and accurate decisions, while Scott et al. [29] compared a choice reaction time task performed by experienced and beginner karate practitioners using specific stimuli, and found that experienced athletes responded more quickly, both verbally and with gestures of defensive actions. Pieter and Pieter [30] evaluated high-level Taekwondo athletes and found that for these athletes, movement time to strike a target was less than the reaction time to dodge an attack. Milazzo et al. [31] verified that perceptual training without feedback through video is capable of improving the decision making of elite karate athletes. In each of the previous studies, as in the current study, the preparation and speed of the movement were influenced by the skill level of the performer.

Like other authors who investigated neuromuscular aspects of the execution of karate techniques [6,9,32], we compared co-contraction indexes in both the acceleration and deceleration phases of the punch. However, in our study, the significantly higher co-contraction index presented by the elite athletes occurred in the deceleration phase and can be explained by the fact that higher-level athletes are able to slow down the movement in a more controlled manner. Controlled deceleration is critical in order to follow the rules of karate that require the attacker to restrict the impact of the punch. Quinzi et al. [32] reported similar findings when comparing experienced and amateur athletes in the performance of Mawashi Geri (roundhouse kick) in two situations, with and without impact with the target. When compared to our study, in the non-impact task, the experienced athletes had higher agonist/antagonist coactivation rates of the musculature responsible for the movements of the distal joint (knee flexion/extension). In our study, the differences found also occurred in the musculature responsible for the movements of the distal joint (elbow flexion/extension).

It is possible that one of the main effects of high-level training in karate is the development of faster movements due to the improvement and optimization of perceptual and reaction skills as well as neuromuscular control, allowing for improved decision making and consequently faster reactions as demonstrated in the elite athletes performing the Gyaku Tsuki punch. In each timing parameter, the elite group responded much faster than the sub-elite group, which is not surprising and possibly explains why these athletes are considered elite.

5. Conclusions

In conclusion, clear differences in performance and reaction skills were evident between the two groups even though both groups were at the highest level in karate. What differentiated the two groups were the velocity of movement and the reaction to the stimulus presented. It was also apparent that the elite group could control co-contraction during the deceleration phase to ensure the safety of their opponent according to karate rules. The results of the parameter analysis presented in this study show a differentiated performance, perceptual and reaction skill and neuromuscular adaptation by elite karate athletes, possibly as a result of a greater technical refinement.

The results of this study can be applied to develop training protocols for coaches and trainers. These results show that even at the highest rank of karate, there are differences between performers. To facilitate athletes' progression to the very highest level of athleticism, a training program could be instituted to develop athletes' reaction to a stimulus in the form of the Gyaku Tsuki punch and increase their speed of movement to that necessary for a completed punch. Because the deceleration phase of the wrist is critical in controlling the outcome of the punch, developing a training protocol to increase the co-contraction of the triceps brachii and biceps brachii muscles would be beneficial, possibly more so if movement techniques as in Tai Chi are used.

Enhancing our understanding of motor performance distinctions between elite and sub-elite athletes could potentially contribute to advancing the overall quality of the sport. However, it is crucial to recognize the limitations of the present study. Firstly, precise data regarding the athletes' practice time were not available, although the participants were divided into two subgroups: the elite group, composed of individuals competing at national or international level, and the sub-elite group, composed of individuals competing at a regional or state level. Additionally, the sample collection method was based on convenience, as we aimed to maximize the recruitment of elite athletes in the region where the study was conducted. In this way, the scope of the study was limited by a relatively small number of participants in each group.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data will be available under reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

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