

# Coordinative intra-segment indicators of karate performance

## Authors' Contribution:

- A Study Design
- B Data Collection
- C Statistical Analysis
- D Manuscript Preparation
- E Funds Collection

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## Abstract

### Background and Study Aim:

Whether from the lower or upper limbs, intersegmental coordination is required at a high level in the blows of various martial arts modalities, with karate being no exception. In karate, precision, high speed, and technique are the hallmarks of attack, counterattack, and defence. The aim of this study was the phase relationship between the proximal and distal joints during the execution of two technique of stroke karate: the punch *gyaku tsuki* and the kick *mae geri*.

### Material and Methods:

The study included 14 male athletes, equally divided into 2 subgroups according to their current competitive level: sub-elite (SEG) and elite (EG). The karate stroke performance measure used was the linear velocity peak of the wrist and foot. In order to analyze the intra-segment coordination, it was applied the nonlinear dynamics approach named continuous relative phase (CRP). From the CRP curve it was obtained the peak as well as the time to reach the CRP peak. It was also compared the index of the coordinative patterns' variability, which was obtained by calculating the average of the CRP values and standard deviation.

### Results:

The EG group showed significantly higher values in the linear velocity peak of the wrist and foot when compared to the SEG. With respect to the CRP curve peak and the coordinative patterns variability, the SEG group presented significantly higher values, showing no differences in the time to reach the CRP peak.

### Conclusions:

The EG group presented a better intra-segment coordinative capacity during the execution of strikes. The stability of coordinative patterns seems to have an intimate relationship with the technical refinement. Thus, this variable can be configured also as a predictor of performance.

### Keywords:

gyaku tsuki • horizontal axis • mae geri • nonlinear dynamics • vertical axis

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Authors have declared that no competing interest exists

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**Coordination** *noun* the ability to use two or more parts of the body at the same time to carry out a movement or task [40].

**Neuromuscular** – *adjective* referring to both nerves and muscles [40].

**Motor** – *adjective* relating to muscle activity, especially voluntary muscle activity, and the consequent body movements [40].

**Performance** – *noun* the level at which a player or athlete is carrying out their activity, either in relation to others or in relation to personal goals or standards [40].

**Motor performance** – the observable production of a voluntary action, or a motor skill. The level of a person's performance is susceptible to fluctuations in temporary factors such as motivation, arousal, fatigue, and physical condition [41].

**Punch** *verb* to strike someone or something with the fist, e.g. in boxing or martial arts [40].

**Kick** – *verb* **1.** to strike a ball with the foot **2.** to strike something or somebody with the foot, e.g. in martial arts **3.** to make a thrashing movement with the legs, e.g. when fighting or swimming **4. (in cricket)** to bounce up high and quickly [40].

**Kick** – *noun* **1.** a blow with the foot, e.g. in martial arts **2.** a thrashing movement with the leg when swimming **3.** the striking of a ball with the foot [40].

**Technique** – *noun* a way of performing an action [40].

**Speed training** – *noun* training that uses exercises designed to improve reaction times [40].

**Dan (dan'ı)** – a term used to denote one's technical level or grade [42].

## INTRODUCTION

Whether from the lower or upper limbs, intersegmental coordination is required at a high level in the blows of various martial arts modalities, with karate being no exception. In karate, precision, high speed, and technique are the hallmarks of attack, counterattack, and defence [1].

Coordination is defined as the ability to manage the abundant or redundant degrees of freedom to produce a controllable system in the body movement [2] – see also glossary. Nonlinear dynamics and dynamical systems approaches are increasingly being implemented in biomechanics and human movement research [3]. Among these approaches stands out the phase relationships, which have been used as a measure of coordination and a way of quantifying intrasegmental coordination [4]. Among the techniques used to determine the phasic relationships between two or more joints, the continuous relative phase (CRP) stands out for simultaneously relating displacement and angular velocity of a given movement, thus providing important information in the investigation of motor control of multi-joint actions [5]. The CRP has been used to investigate coordinative patterns in cyclical actions [6, 7], as well in non-cyclical explosive actions [8-10].

Due to the specificity of sports gestures, the coordinative motor patterns (motor performance) become more consistent and controlled, presenting less variability of the coordinative characteristics of the technical gestures as the expertise in action increases [11]. The coordination variability has been analyzed using the CRP values dispersion [12, 13].

The *gyaku tsuki* is a punch executed with the advance of hand together with the advance of the contralateral lower limb, in *zenkutsu dachi* posture, in which the athlete is with one lower limb advanced and knee flexed and the other member with the hip and knee extended, both in contact with the ground [14, 15]. The *mae geri* is a frontal kick, considered a simple but very efficient technique and therefore one of the most used kick in competitions [16]. Among the most used strokes (“stroke” is an ambiguous concept – see in glossary) in the karate, the *gyaku tsuki* represents approximately 50% of the techniques used in an karate official combat [17].

The *gyaku tsuki* and *mae geri* have great prominence among the karate techniques and has been examined in its various features, such as

kinematics, variability, muscle activation, adaptations of neuromuscular control, and others [1, 14, 15, 18-26]. However, studies describing their characteristics regarding intra-segment coordination and variability of coordinative patterns have not yet been conducted. Therefore, the important issue is knowledge about the phase relationship between the proximal and distal joints involved in the *gyaku tsuki* (shoulder and elbow) and *mae geri* (hip and knee) executions performed by elite and sub-elite karate athletes.

The aim of this study was the phase relationship between the proximal and distal joints during the execution of two technique of stroke karate: the punch *gyaku tsuki* and the kick *mae geri*.

## MATERIAL AND METHODS

### Sample

The study included 14 male volunteers, aged 18-35 years, competitive practitioners of karate, separated into two groups according to their competitive level. An elite group consisted of 7 individuals, black belts and competitors at the national or international level, including 2 national champions and three champions of various international competitions (age:  $26.300 \pm 6.900$  years; body mass:  $77.5 \pm 12.8$  kg; height:  $1.7 \pm 0.1$  m; fat percentage:  $12.6 \pm 6.7$  %). The sub-elite group consisted of 7 individuals, black belts and competitors at the regional or state level (age:  $27.5 \pm 6.1$  years; body mass:  $75.1 \pm 8.9$  kg; height:  $1.7 \pm 0.1$  m; fat percentage:  $15.1 \pm 5.9$  %).

The volunteer would be excluded from the study if he reported severe pain, severe soft tissue injury, concussion, or surgery in the six months prior to the study.

### Experimental Protocol

The strokes were performed on an instrumented target developed at the Biomechanics Laboratory of the São Paulo State University (UNESP). The target was equipped with LED to provide visual stimuli as well as a piezoelectric sensor whose function was to detect the end of the strike due to the touch of the hand or foot on the sensor (Figure 1, A and B). Both the LED system and the piezoelectric sensor were controlled by a micro controller board Arduino model “MEGA 2560”.

Five strokes were carried out unilaterally, and started according to the visual stimulus provided

by the LED system. The validity of the stroke was evaluated by a referee of the Brazilian Karate Federation.

### Data collection and processing

The kinematic data were obtained using a Vicon system consisting of seven cameras (T10 model) with a sampling frequency of 250 frames per second, operated by software. Vicon Nexus (Vicon®). The markers used to identify the anatomical points to be used for later reconstruction of the athletes' body movements were coupled to their body according to the recommendations presented in the Plug-in-Gait model for whole body (Vicon®).

The digital data were processed and analyzed through specific routines developed in software Matlab version 8.5.0.197613 (Mathworks®, Inc.).

The establishment of the optimal cut-off frequencies for signal filtering was performed using residual analysis [27], wherein the signal of the kinematic data was filtered with a recursive Butterworth lowpass 4<sup>th</sup> order with cutoff frequency of 6 Hz and the data of ground reaction forces with a recursive Butterworth lowpass 4<sup>th</sup> order with cutoff frequency of 95 Hz.

The movement onset was determined by the threshold method applied to the anteroposterior displacement curve of the center of pressure (COP) where the moment of onset is greater or equal to the mean plus 3 standard deviations calculated on the baseline.

The execution of the stroke comprises the interval between the movement onset and the hand or foot contact with the target.

### Data analysis

#### Kinematic data

The proximal and distal joints' angular position and angular velocity ( $\theta$ ,  $\omega$ ) were obtained from the displacement of the reflexive markers coupled to the limbs. Linear peak velocity of the wrist and foot were calculated as the maximum value of the resulting curve of the linear velocity of the lateral reflective marker of the wrist and lateral malleolus in the 3 axes.

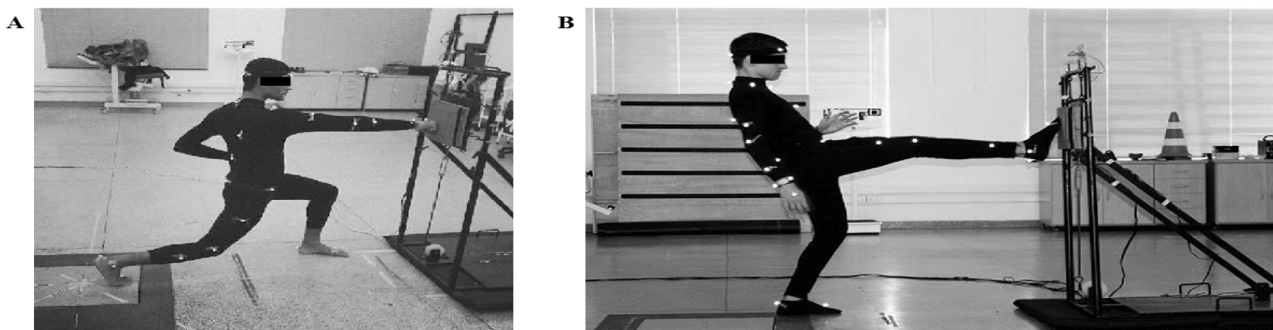
#### Phase of indicators

The phase of indicators were obtained from the kinematic data of the proximal and distal joints, obtained from each trial, and then they were interpolated to 2500 points using Spline Cubic functions. The interpolation procedure was performed so that all files had the same number of samples. Angular velocity values were plotted against the angular position values for the shoulder and elbow, and for the hip and knee joints, as respectively illustrated in figure 2A and 2B. Prior to calculating the phase angle ( $\varphi$ ), the data of angular displacement and angular velocity for each trial were normalized [7] in order to minimize the effects of different ranges of motion [28, 29]. The following equations were used to normalize the data:

- horizontal axis (angular displacement):

$$\theta_i = \frac{2 * [\theta_i - \min(\theta_i)]}{\max(\theta_i) - \min(\theta_i)} - 1,$$

where  $\theta$  is the angle of joint and "i" each data sample within each trial. This normalization sets the origin of the horizontal axis in the middle of the range, while normalizes the minimum value in -1 and the maximum in 1.



**Figure 1.** Illustrative picture of the final moment of blows A – *gyaku tsuki* and B – *mae geri*.

- vertical axis (angular velocity):

$$\omega_i = \frac{\omega_i}{R},$$

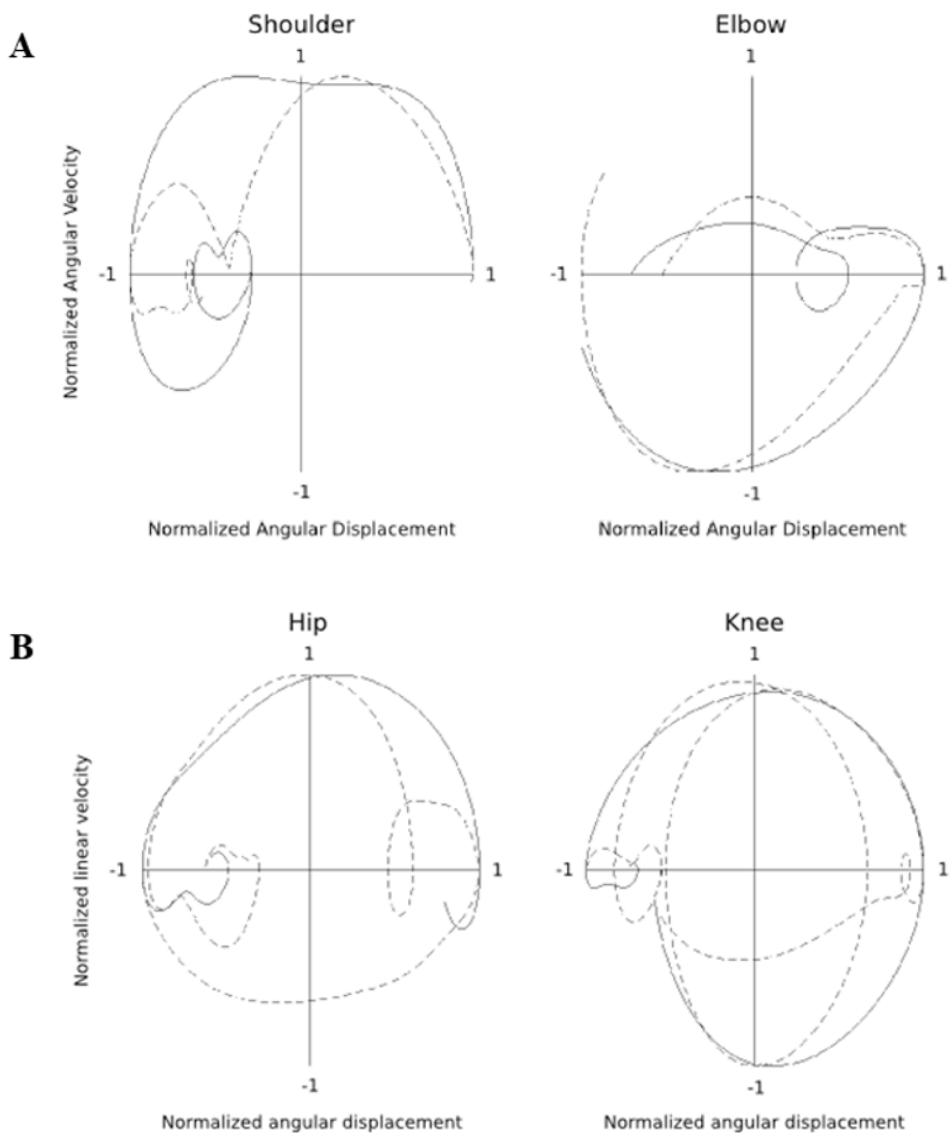
where R was calculated as: and  $\omega_i$  is the angular velocity of each sample "i" of data.

For each point of the phase graphic, and for both joints, proximal and distal, the phase angle ( $\varphi$ ) was calculated as the inverse tangent of the normalized angular velocity and the normalized angular displacement, which is the angle formed between a line originating at (0, 0) to the point ( $\theta, \omega$ ) and the horizontal axis (Figure 2).

### Continuous Relative Phase (CRP)

CRP was set in the range of  $-180^\circ \leq \varphi \leq 180^\circ$ , as the difference between the phase angle of the proximal segment ( $\varphi_{\text{shoulder,or } \varphi_{\text{hip}}}$ ) and the phase angle of the correspondent distal segment ( $\varphi_{\text{elbow,or } \varphi_{\text{knee}}}$ ) for each data sample. CRP is therefore considered a measure of coordination between the proximal and the distal joints.

A positive CRP value reflects that  $\varphi_{\text{shoulder,or } \varphi_{\text{hip}}} > \varphi_{\text{elbow,or } \varphi_{\text{knee}}}$ . Reciprocally, a negative CRP value reflects that  $\varphi_{\text{shoulder,or } \varphi_{\text{hip}}} < \varphi_{\text{elbow,or } \varphi_{\text{knee}}}$ . A larger phase angle of a joint, in relation to the proximal or distal joint at the same limb, can be interpreted as the joint being moving slower or even having



**Figure 2.** A – phase graphic of shoulder and elbow joints of an elite athlete (solid line) and a sub-elite athlete (dashed line); B – phase graphic of hip and knee joints of an elite athlete (solid line) and a sub-elite athlete (dashed line).

made a movement of smaller amplitude than the other. It can also be interpreted as a simultaneous occurrence of these two factors, that is, slower movement and smaller amplitude.

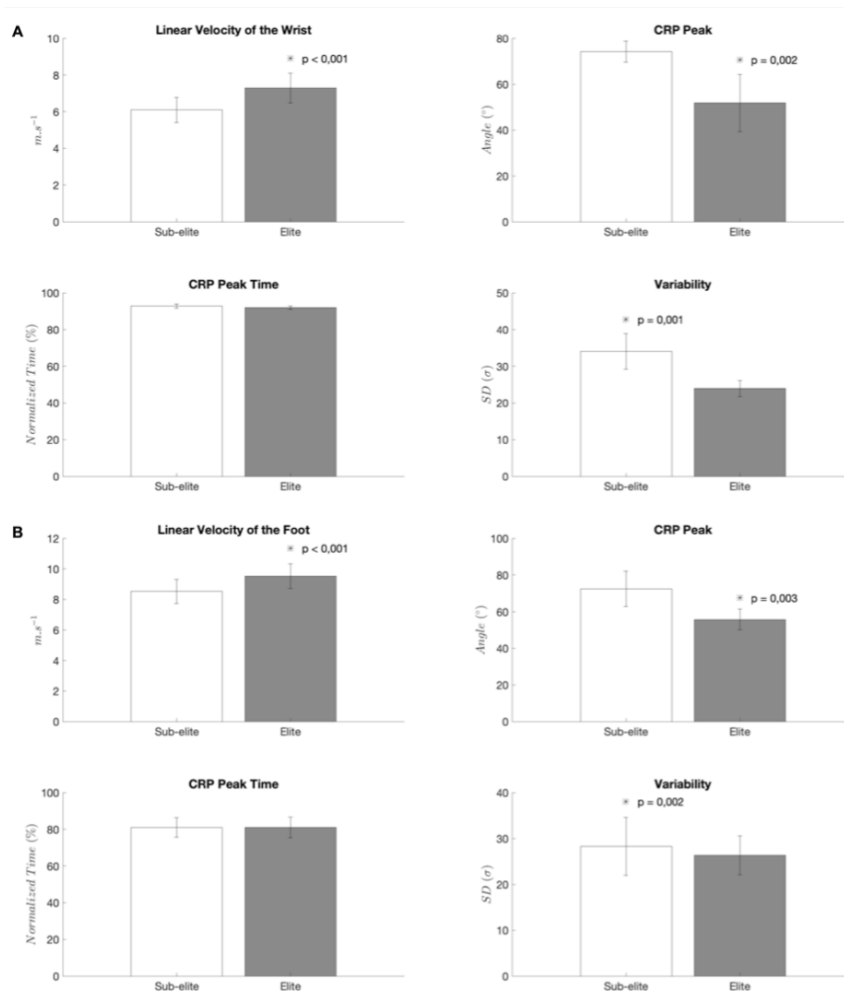
The average CRP curve of each subject was calculated as the average of CRP curves of the 5 trials. The peak of the average CRP curve of each subject was calculated as the maximum CRP value in the range comprising the maximum flexion of the elbow until the impact with the target, in this way, sought to investigate the coordination indicator in the flexion phase of the proximal joint and in the extension phase of the distal joint. The time in which occurred the peak of the average CRP curve was represented in a percentage of the stroke execution time. The average CRP curve of the group was calculated as the average of the average CRP curves of the subjects of each group.

## Variability

The individual group variability was calculated from the standard deviation (SD or  $\pm$ ) of the CRP measures. The results of these calculations indicates the variability in trial to trial and can be used to compare the stability characteristics of the system over the gesture performance standards [30]. The variation of CRP for each subject was calculated as the average of the SD ( $\sigma$ ) of each sample of the average CRP curve of each subject.

## Statistical analysis

According to the statistical power analysis (using the software G\*Power<sup>®</sup>, version 3.1.9.2) considering data from our previous pilot study, in order to achieve statistical power of 80% and effect size between 0.5 and 0.8 for test of differences between two independent averages (two groups), it was estimated a sample size of 14 athletes (7 in each group). This estimate was based on a



**Figure 3.** A – comparative graphics of the results between the groups during the performance of the *gyaku tsuki* strike; B – comparative graphics of the results between the groups during the performance of the *mae geri* strike.

detectable difference of 1.0, minimum correlation of 0.8 and alpha ( $\alpha$ ) of 0.05 considering four variables present in the present study [31, 32].

The statistical analysis was performed using IBM SPSS Statistics software 18 (IBM®). After checking the data normality by the Shapiro-Wilk test, it was performed the independent sample *t*-test in the parametric data and the Mann-Whitney *U* test in the non-parametric data, in order to verify differences between the groups in the variables of interest of this study. In all statistical tests it was adopted the significance level of  $p < 0.05$ .

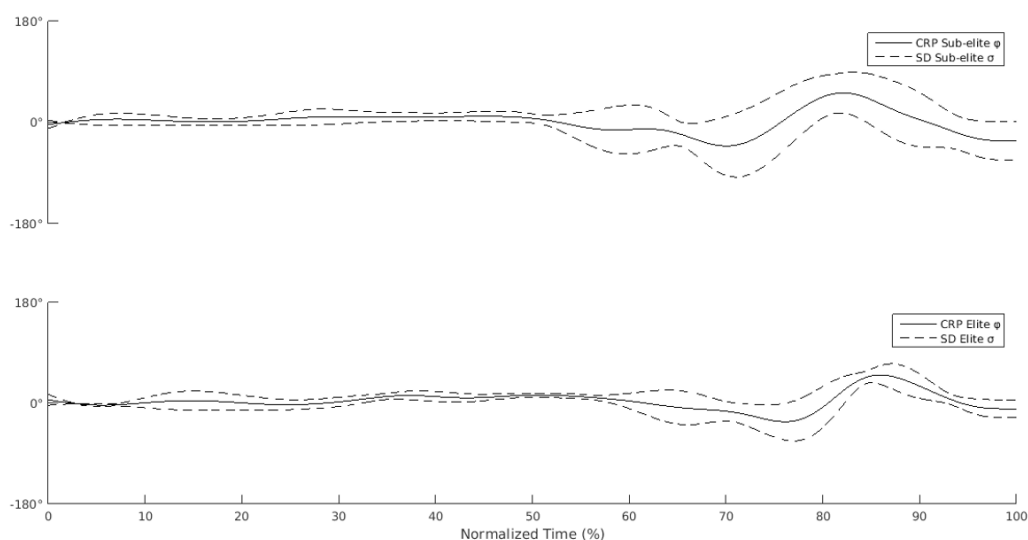
## RESULTS

### Linear velocity of the wrist

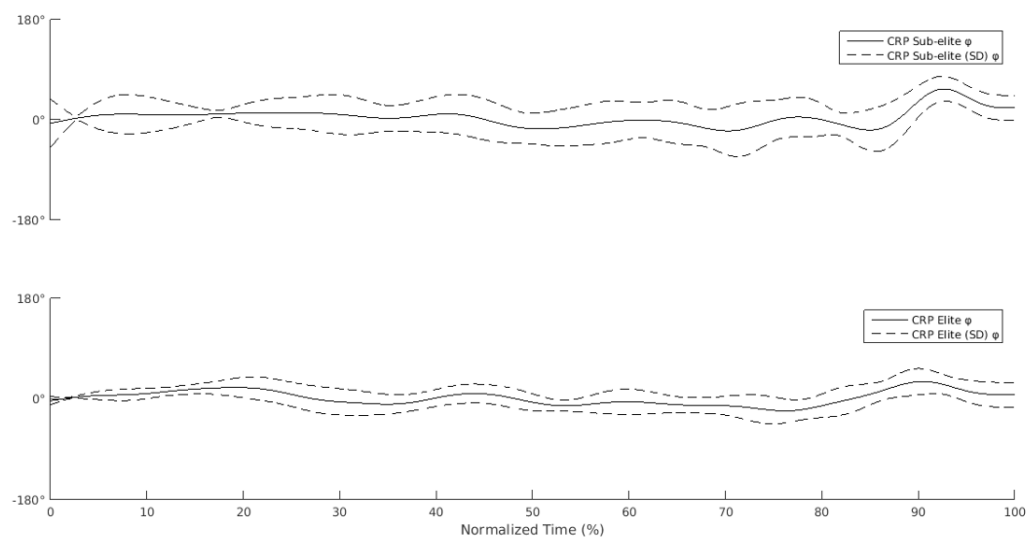
In the elite group, both linear velocity peak of the wrist and foot were significantly higher ( $7.3 \pm 0.8 \text{ m.s}^{-1}$  and  $9.5 \pm 0.8 \text{ m.s}^{-1}$ , respectively) than that presented by the sub-elite group ( $6.1 \pm 0.7 \text{ m.s}^{-1}$  and  $8.5 \pm 0.8 \text{ m.s}^{-1}$ , respectively) (Figure 3A and B).

### Continuous relative phase (CRP)

The average CRP curves of the sub-elite and elite groups performing *gyaku tsuki* and *mae geri* are shown, respectively, in Figure 4 and 5.



**Figure 4.** Average continuous relative phase (CRP) curve and standard deviation calculated from both groups during the performance of the *gyaku tsuki* strike (CRP was calculated from the shoulder and elbow phase angles).



**Figure 5.** Average continuous relative phase (CRP) curve and standard deviation calculated from both groups during the performance of the *mae geri* strike (CRP was calculated from the hip and knee phase angles).



It is possible to observe a positive peak near the end of the execution of the strokes *gyaku tsuki* and *mae geri*. This peak represents a higher proximal phase angle relative to the distal, which occurs due to a lower angular velocity and a smaller angular displacement of the proximal joint relative to the distal in this epoch of the stroke. The peak was significantly higher for the sub-elite group ( $74.2^\circ \pm 4.6^\circ$  in *gyaku tsuki* and  $72.4^\circ \pm 9.6^\circ$  in *mae geri*) than that presented by the elite group ( $51.8^\circ \pm 12.5^\circ$  in *gyaku tsuki* and  $55.8^\circ \pm 5.7^\circ$  in *mae geri*) (Figure 3A and B, top panel on the right).

The epoch time in which the CRP peak occurred was similar between the groups (Figure 3A and B, bottom panel on the left). This result represents the similarity between the groups in terms of controlling the striking limb, whether performing the *gyaku tsuki* or *mae geri*.

### Variability

The variability of CRP values between trials (Figure 4, bottom panel on the right) was significantly higher for the sub-elite group ( $34^\circ \pm 4.9^\circ$  in *gyaku tsuki* and  $28.3^\circ \pm 6.3^\circ$  in *mae geri*) than that presented by the elite group ( $23.9^\circ \pm 2.2^\circ$  in *gyaku tsuki* and  $26.3^\circ \pm 4.2^\circ$  in *mae geri*).

## DISCUSSION

The athletes who participated in this study presented similar anthropometry data even though they belong to different competitive levels. Similar anthropometry between groups guaranteed sample homogeneity, as shown in previous studies comparing the same variables [26, 33, 34].

The highest values of linear velocity peak presented by elite group corroborate with the fact that velocity is one of the main factors that determine or predict the performance in the competitive karate [35, 36].

Regarding to the CRP curve peak, the sub-elite group presented significantly higher values than the elite group. This fact represents that the less competitive level athletes have a worse coordinative pattern. The movement in positive anti-phase, indicates a smaller angular displacement and velocity of the proximal joint, which in this case is the shoulder or hip [37]. Thus, the difference presented in this variable between the groups is explained by the performance of proximal joint flexion.

Although differences have been shown in the coordinative pattern between the groups, no significant differences were found in the temporal indicator of CRP peak behavior. This finding can be explained by the fact that both groups are black belt and therefore have great ability to perform the techniques of striking.

The degree of variability in coordinative patterns is an important element in the understanding of movement dynamics [28]. A high degree of variability in the movement can be interpreted in one of two ways, namely: being beneficial if the action to be performed involves the need for adaptation of complex motor patterns [38], or harmful, if the task to be performed involves low complexity of movement and it is subject only to the slightest perturbations [39].

Elite athletes have an exceptional mastery of his movements, and if they enjoy full physical and training conditions, they show high degree of reproducibility of the movement in the performance of basic actions [39]. Karate athletes with higher degrees of black belt (higher dans) have greater repeatability in performing the *oi tsuki* (lunge punch) and the *choku tsuki* (straight punch) [21, 22]. Likewise, Pozo et al. [26], when comparing the variability during the execution of *mae geri* in Belgian karate athletes of national and international level, found that international level athletes have lower variability in movement indicators in the hip, knee and ankle joints. In our study we found a similar situation, where the athletes with lower competitive level, sub-elite group, showed a degree of coordinative pattern variability significantly higher.

## CONCLUSIONS

The differences in the coordinative indicators between sub-elite and elite athletes identified in the present study might explain the difference in the stroke performance, measured by the peak linear velocity of the wrist. Despite the technical gesture to be similar between the groups, the elite group gets higher performance through the implementation of an optimized kinetic chain.

The results of this study indicate that in any case the shoulder flexion movement is primarily responsible for the anti-phase behavior during the execution of *gyaku tsuki*. Elite athletes can minimize this effect, performing a faster technique and thus obtaining better competitive results.

Elite athletes are also distinguishable from sub-elite athletes because they present less variability in coordinative indicators. The stability of coordinative patterns seems to have an intimate relationship with the technical refinement. Thus, this variable can be configured also as a predictor of performance.

This study provides critical information to coaches and athletes of the sport, pointing substantial differences between competitive levels with regard to the coordinative indicators during the execution of the *gyaku tsuki* punch. However,

future studies are needed on this same theme but involving more complex motor actions, so that we can understand in more depth how the motor control system is specialized in tasks closer to the reality of the combat sports.

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## REFERENCES

- Sbriccoli P, Camomilla V, Di Mario A et al. Neuromuscular control adaptations in elite athletes: the case of top level karateka. *Eur J Appl Physiol* 2010; 108(6): 1269-1280
- Bernstein NA. *The Coordination and regulation of movement*. London: Pergamon; 1967: 196
- Van Emmerik REA, Rosenstein MT, McDermott WJ et al. A nonlinear dynamics approach to human movement. *J Appl Biomech* 2004; 20(4): 396-420
- Hamill J, Haddad JM, Van Emmerik RE. Using Coordination Measures for Movement Analysis. In: XXIII International Symposium on Biomechanics in Sports. Beijing, China; 2005: 33-38
- Burgess-Limerick R, Abernethy B, Neal RJ. Relative phase quantifies inter joint coordination. *J Biomech* 1993; 26(1): 91-94
- Heiderscheit BC, Hamill J, Van Emmerik RE. Q-angle influences on the variability of lower extremity coordination during running. *Med Sci Sports Exerc* 1999; 31(9): 1313-1319
- Li L, Van Den Bogert ECH, Caldwell GE et al. Coordination patterns of walking and running at similar speed and stride frequency. *Hum Mov Sci* 1999; 18(1): 67-85
- Temprado J, Della-Graza M, Farrell M et al. A novice-expert comparison of (intra-limb) coordination subserving the volleyball serve. *Hum Mov Sci* 1997; 16: 653-676
- Tomioka M, Owings TM, Grabiner MD. Lower extremity strength and coordination are independent contributors to maximum vertical jump height. *J Appl Biomech* 2001; 17(3): 181-187
- Kim YK, Kim YH, Im SJ. Inter-joint coordination in producing kicking velocity of taekwondo kicks. *J Sports Sci Med* 2011; 10(1): 31-38
- Wilson C, Simpson SE, van Emmerik RE et al. Coordination variability and skill development in expert triple jumpers. *Sports Biomech* 2008; 7(1): 2-9
- Van Emmerik REA, Van Wegen EEH. On variability and stability in human movement. *J Appl Biomech* 2000; 16(4): 394-406
- Stergiou N, Decker LM. Human movement variability, nonlinear dynamics, and pathology: Is there a connection? *Hum Mov Sci* 2011; 30(5): 869-888
- Emmermacher P, Witte K, Hofmann M. Acceleration Course of Fist Push of Gyaku-Zuki. In: XXIII International Symposium on Biomechanics in Sports. Beijing, China; 2005: 844-847
- Witte K, Emmermacher P, Hofmann M et al. Electromyographic Researches of Gyaku-Zuki in Karate Kumite. In: XXIII International Symposium on Biomechanics in Sports. Beijing, China; 2005: 861-865
- Dworak LB, Dziewiecki K, Maczynski J. Characteristics of Kinematics and Kinetics of Strokes in Karate – Biomechanical Approach. In: XXIII International Symposium on Biomechanics in Sports. Beijing, China; 2005: 109-112
- Chaabène H, Mkaouer B, Franchini E et al. Physiological Responses and Performance Analysis Difference between Official and Simulated Karate Combat Conditions. *Asian J Sports Med* 2014; 5(1): 21-29
- Stull R, Barham JN. An Analysis of Movement Patterns Utilized by Different Styles in The Karate Reverse Punch in Front Stance. In: VI International Symposium on Biomechanics in Sports. Bozeman, Montana; 1988: 233-243
- Stull R, Barham JN. An Analysis of Work and Power Produced by Different Karate Styles in The Karate Reverse Punch in Front Stance. In: VI International Symposium on Biomechanics in Sports. Bozeman, Montana; 1988: 225-231
- Sørensen H, Zacho M, Simonsen EB et al. Dynamics of the martial arts high front kick. *J Sports Sci* 1996; 14(6): 483-495
- Sforza C, Turci M, Grassi G et al. The repeatability of choku-tsuki and oi-tsuki in traditional Shotokan karate: a morphological three-dimensional analysis. *Percept Mot Skills* 2000; 90(3 Pt 1): 947-960
- Sforza C, Turci M, Grassi GP et al. Repeatability of Choku-tsuki and Oi-tsuki in Shotokan Karate: A 3-Dimensional Analysis with Thirteen black-belt karateka. *Percept Mot Skills* 2001; 92: 1230-1232
- Sforza C, Turci M, Grassi GP et al. Repeatability of Mae-Geri-Keage in Traditional Karate: a three-dimensional analysis with black-belt karateka. *Percept Mot Skills* 2002; 95: 433-444
- Hofmann M, Witte K, Emmermacher P. Biomechanical Analysis of Fist Punch Gyaku-Zuki in Karate. In: XXVI International Conference on Biomechanics in Sports. Seoul, Korea; 2008: 576-579
- Suwarganda EK, Razali RA, Wilson B et al. Analysis of Performance of the Karate Punch (Gyaku-Zuki). In: XXVII International Conference on Biomechanics in Sports. Limerick, Ireland; 2009
- Pozo J, Bastien G, Dierick F. Execution time, kinetics, and kinematics of the mae-geri kick: comparison of national and international standard karate athletes. *J Sports Sci* 2011; 29(14): 1553-1561
- Winter DA. *Muscle Mechanics*. In: *Biomechanics and Motor Control of Human Movement*. Second Edi. Waterloo, Ontario, Canada: John Wiley & Sons, Inc.; 1990
- Hamill J, Haddad JM, McDermott WJ. Issues in Quantifying Variability from a Dynamical Systems Perspectives. *J Appl Biomech* 2000; 16: 407-418
- Lamoth CJC, Beek PJ, Meijer OG. Pelvis-thorax coordination in the transverse plane during gait. *Gait Posture* 2002; 16(2): 101-114
- Van Emmerik RE, Wagenaar RC. Effects of walking velocity on relative phase dynamics in the trunk in human walking. *J Biomech* 1996; 29(9): 1175-1184
- Cohen J. *Statistical Power Analysis*. *Curr Dir Psychol Sci* 1992; 1(3): 98-101
- Faul F, Erdfelder E, Lang A-G et al. G\*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav Res Methods* 2007; 39(2): 175-191



33. Imamura H, Yoshimura Y, Uchida K et al. Maximal Oxygen Uptake , Body Composition and Strength of Highly Competitive and Novice Karate Practitioners. *Appl Hum Sci - J Physiol Anthropol* 1998; 17(5): 215-218
34. Giampietro M, Pujja A, Bertini I. Anthropometric features and body composition of young athletes practicing karate at a high and medium competitive level. *Acta Diabetol* 2003; 40 (Suppl 1): S145-148
35. Ravier G, Grappe F, Rouillon JD. Comparaison de deux méthodes d'analyse des variables maximales de vitesse, force et puissance dans l'évaluation fonctionnelle en karaté. *Sci Sports* 2003; 18(3): 134-140 [in Portuguese]
36. Blazević S, Katić R, Popović D. The effect of motor abilities on karate performance. *Coll Antropol* 2006; 30(2): 327-333
37. Hamill J, Van Emmerik RE, Heiderscheit BC et al. A dynamical systems approach to lower extremity running injuries. *Clin Biomech* 1999; 14(5): 297-308
38. Button C, Davids K, Schollhorn W. Coordination Profiling of Movement Systems. In: Davids K, Bennett S, Newell K, editors. *Movement System Variability*. Champaign, IL: Human Kinetics; 2006: 133-152
39. Preatoni E, Hamill J, Harrison AJ et al. Movement variability and skills monitoring in sports. *Sports Biomech* 2013; 12(2): 69-92
40. *Dictionary of Sport and Exercise Science. Over 5,000 Terms Clearly Defined*. London: A & B Black; 2006
41. Schmidt RA, Wrisberg CA. *Motor Learning and Performance. A Situation-Based Learning Approach*. 4th ed. Champaign: Human Kinetics; 2008
42. *Budō: The Martial Ways of Japan*. Tokyo: Nippon Budokan Foundation; 2009

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