SEX DIFFERENCES IN ELECTROMECHANICAL DELAY DURING A PUNCH MOVEMENT

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Summary.—This study assessed how sex of participant is related to electromechanical delay during a karate punch. Ten male ($M$ age = 25.00 yr., $SD$ = 3.02; $M$ height = 174.9 cm, $SD$ = 6.3; $M$ weight = 71.13 kg, $SD$ = 9.35) and 8 female ($M$ age = 27.4 yr., $SD$ = 6.0; $M$ height = 161.4 cm, $SD$ = 5.1; $M$ weight = 59.09 kg, $SD$ = 7.00) karate athletes performed 10 ballistic punches to a target as hard as possible. Kinematic analysis and surface electromyographic (EMG) activity of the upper-limb muscles were recorded. Men had a significantly shorter electromechanical delay in the anterior portion of the deltoid, showing a larger effectiveness in the transfer of the contractile force for the beginning of movement. Agonist and antagonist relationships show intermuscular coordination differences between the sexes. Results revealed the existence of a different neuromuscular coordination pattern of motor control between men and women, although a similar kinematic pattern was expected due to karate practice.

A powerful karate technique is characterized by high precision and high movement velocity, where the goal is to attain the maximal velocity of the distal segment. Thus, an optimal intermuscular and intramuscular coordination is important. Training, seen as improving alterations in the internal processes that determine an individual capacity to produce a motor action after practice (Schmidt & Wrisberg, 2008), increases the quality and the efficacy of the karate techniques (Nakayama, 1983). Biomechanical studies regarding sex differences in karate performance are limited. Kim and Petrakis (1998) found that female karate athletes had a faster visuo perceptual speed than male karate athletes. The authors suggested that men tend to emphasize strength and speed while women pay more attention to technique. Doria, Veicsteinas, Limonta, Maggioni, Aschieri, Eusebi, et al. (2009) found that explosive strength was not different between men and women, but attributed this to low statistical power in their study. In another study (Sforza, Turci, Grassi, Fragnito, Pizzini, & Ferrario, 2000), women performed two punching techniques in a shorter time than did men. However, studies using experienced male karate athletes indicated better neuromuscular activation during complex motor skills (Cesari & Bertucco, 2008; Sbriccoli, Camomilla, Di Mario, Quinzi, Figura, & Felici, 2010), as well as superior anticipatory skills (Mori, Ohtani, & Imanaka, 2002). According to Blazević, Katić, and Popović, (2006), explosive strength and coordination seem to be extremely important to achieve top results in karate.

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Electromechanical delay is defined as the difference between the onset of the EMG and the beginning of movement (Cavanagh & Komi, 1979; Norman & Komi, 1979), and represents the motor units’ activation and shortening of the series elastic component of the musculoskeletal system (Grabiner, 1986). Studies analyzing the electromechanical delay in the upper limb muscles showed values between about 25 msec. and 85 msec. (Cavanagh & Komi, 1979; Norman & Komi, 1979; Gabriel & Boucher, 1998; Vint, McLean, & Harron, 2001; Howatson, Glaister, Brouner, & van Someren, 2009), although none of these studies examined female participants.

Few researchers have studied the effects of training on electromechanical delay. After a 16-week strength training period, Hakkinen and Komi (1983) found no significant differences in electromechanical delay under a reflex contraction, and seven weeks of sprint training did not change the electromechanical delay of the knee extensor muscle (Zhou, McKenna, Lawson, Morrison, & Fairweather, 1996). On the other hand, Kubo, Kanehisa, Ito, and Fukunaga (2001) found that a 12-week isometric training increased the stiffness and Young’s modulus of tendon structures, as well as muscle strength and volume. The authors concluded that the changes in the tendon structures could be an advantage for shortening the electromechanical delay and increasing the rate of torque development. Grosset, Piscione, Lambertz, and Pérot (2009) found that endurance training leads to a decrease in electromechanical delay while plyometric training increased the electromechanical delay. These authors also reported an inverse relationship between the electromechanical delay and musculotendinous stiffness.

Sex differences on electromechanical delay have only been studied by a few researchers. Bell and Jacobs (1986), studying the electromechanical response times and rate of force development in men and women during a maximal voluntary isometric contraction of the elbow flexors, found a significantly shorter electromechanical delay in men. Winter and Brookes (1991) also found smaller electromechanical delay in men ($M = 39.6$ msec., $SD = 1.2$) than in women ($M = 44.9$ msec., $SD = 2.0$), and they suggested differences in musculotendinous stiffness. In addition, Zhou, Lawson, Morrison, and Fairweather (1995) found a shorter electromechanical delay in men but only in the 18–24 yr. age group. Recent studies found no statistically significant differences in electromechanical delay between men and women in hamstrings (Blackburn, Bell, Norcross, Hudson, & Engstrom, 2009) and triceps surae (Yavuz, Sendemir-Ürkmez, & Türker, 2010). However, it has also been reported (Moore, Drouin, Gansneder, & Shultz, 2002), that pre-fatigue electromechanical delay was shorter in women ($M = 22.1$ msec., $SD = 5.8$) than in men ($M = 28.4$ msec., $SD = 7.9$) in the vastus lateralis muscle during an isokinetic contraction.
Thus, differences in the electromechanical delay between men and women are somewhat inconclusive due to the different methods used in measurements. In addition, the comparison of the electromechanical delay between the sexes in a sport-specific motor skill has not yet been investigated. Electromechanical delay may be an indicator of the efficiency of muscle activation and transmission of the contractile force to the bone lever, revealing the efficiency and effectiveness of the punch. Therefore, the aim of the study was to verify if there were differences between the sexes on the electromechanical delay, identifying a greater success in the punch performance. It is also an objective of the study to verify the differences in the motor control and coordination between the sexes, due to differences between the activation of the agonist and antagonist muscles. Despite contradictory results concerning sex differences in the electromechanical delay, the differences in the properties of the contractile muscle tendons mechanism between men and women (Kubo, Kanehisa, & Fukunaga, 2003; Burgess, Graham-Smith, & Pearson, 2009) may suggest a lower electromechanical delay in male karate athletes.

**Method**

**Participants**

Ten male and eight female karate athletes of the Portuguese Karate National Team, with similar average training experience ($M = 15.0$ yr., $SD = 2.0$ vs $M = 16.0$ yr., $SD = 2.0$), respectively, participated in this study. All participants were black belts and had competed in kumite (combat against an adversary) at national and international levels, with a minimum of 10 yr. of practice. The physical characteristics of the male and female karate athletes are shown in Table 1. The study was approved by the ethical committee of the Sport Sciences School of Rio Maior, Polytechnic Institute of Santarém, and written informed consent was obtained from all the participants.

**Motor Skill**

Each participant, with the right upper limb (dominant upper extremity), performed 10 choku-zuki (straight punch), alternated with a series of five repetitions, as fast and powerfully as possible, with impact on the makiwara (karate training instrument). In this karate technique, there is a proximal-to-distal kinematic chain that may permit the transference of energy from the shoulder flexion to the elbow extension (VencesBrito, Rodrigues Ferreira, Cortes, Fernandes, & Pezarat-Correia, 2011). Some other authors refer to the existence of a proximal-to-distal transference in other sport skills (Joris, van Muyen, van Ingen Schenau, & Kemper, 1985; Elliott, Marsch, & Blanksby, 1986; Herring & Chapman, 1992; Putnam, 1993; Hirashima, Kadota, Sakurai, Kudo, & Ohtsuki, 2002). Furthermore, the el-
bow performs a pronation movement until the moment of contact of the fist hitting the target. In addition, trunk rotation follows the shoulder flexion and stops after the impact of the fist on the target. In the present study, only the movements of the shoulder flexion and elbow extension were analyzed because these two movements are extremely important in the punch execution by moving the segments, in the sagittal plane, toward the target. The participants started their performance in the heiko-dachi stance, i.e., their feet were parallel to the shoulder width and the right hand retracted to the hip, in a fist, with the palm facing up. The instruments of data collection caused no limitation to the trunk or upper limb movement.

**Procedures**

The participants were informed about all the procedures before data collection, and performed three repetitions of the motor skill in a preparatory period. The procedures used, specifically the time between repetitions, did not allow the appearance of fatigue during the punch performance.

The makiwara was vertically fixed to the ground and the target edge was not fixed, allowing deformation on impact. The participants were positioned in relation to the target, at the distance of the upper limb length. This procedure is frequently used in karate training, i.e., in measuring the contact distance.

Surface EMG activity of the muscles deltoïd, anterior and posterior portions, pectoralis major (clavicular head), latissimus dorsi, triceps brachii, and biceps brachii were recorded using surface active bipolar electrodes (1992–2002 National Instruments, Frankfurt, Germany), with an input impedance of 10 GΩ, noise of 1 μV, common mode rejection ratio (CMRR) of 120 db, and gain of 2,500. The electrodes were fixed to the self-adhesive detection surfaces (Medicoelectronics, Copenhagen, Denmark) of Ag/AgCl electrodes, with detection surfaces of 10 mm, in which the respective centers had 20 mm of distance. After the skin preparation, the electrodes were placed in the middle of the muscular belly with a longitudinal orientation, according to recommendations of several authors (Basmajian & De Luca, 1985; Weiss, Silver, & Weiss, 2004; Konrad, 2005).

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**TABLE 1**

**PHYSICAL CHARACTERISTICS OF THE MALE (n = 10) AND FEMALE (n = 8) KARATE ATHLETES**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Male Karate Athletes</th>
<th>Female Karate Athletes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Age, yr.</td>
<td>25.00</td>
<td>3.02</td>
</tr>
<tr>
<td>Height, cm</td>
<td>174.90</td>
<td>6.30</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>71.13</td>
<td>9.35</td>
</tr>
<tr>
<td>Fat mass, %</td>
<td>14.07</td>
<td>3.64</td>
</tr>
</tbody>
</table>
Raw EMG signals were digitally filtered (10–400 Hz), full wave rectified, and smoothed with a low pass filter of 50 Hz (Butterworth, 4th order). EMG signals were normalized using EMG signals from an isometric maximal voluntary contraction (IMVC) as a reference. Three different trials for IMVC were performed for each isolated muscle, with 1-min. rest between trials. The trials were collected with the segments positioned in that each muscle has an intervention as preferential agonist developing its maximal intensity of activation (Basmajian & De Luca, 1985; Weiss, et al., 2004; Konrad, 2005). The onset of the EMG was specified from the identification of an average value of activity, calculated on a time interval of 250 msec. at the beginning of muscle activity record. The average activity calculated over three times the standard deviation was considered as a threshold intensity that once attained and maintained for 25 msec. identified the time of onset of the EMG (Hodges & Bui, 1996; Giakas & Baltzopoulos, 1997; Micera, Sabatini, & Dario, 1998; Roetenberg, Buurke, Veltink, Forner Cordero, & Hermens, 2003). The EMG was digitized, together with the kinematic signals, by means of a 12-bit A/D converter (DaqCard™-700, Multifunction I/O, National Instruments) with a sample rate of 1,600 Hz. The acquisition was carried out using the DasyLab 6.0 (Biovision).

The movement times were recorded using an electromagnetic scanner system, FOB (“Flock of Birds2” System Ascension Technology, Software—Motion Monitor v.6.05), comprising an extended range transmitter and four electromagnetic sensors placed on the chest, arm, forearm, and makiwara. The system had a record fidelity on the order of 0.3 mm for the position of 0.15° for the orientation, with a sampling frequency of 100 Hz. The identification of the onset/offset of movement was visually performed on the MatLab output, by a single investigator trained for this purpose, and registered automatically, continuing with further data processing. The EMG and kinematic data were synchronized by a simultaneous trigger input signal in the kinematic and EMG files.

The electromechanical delay of the agonist and antagonist muscles was defined as the time interval from the onset of the EMG until the beginning of the shoulder flexion and elbow extension movements, while the electromechanical delay of the agonist-antagonist relationships was the time interval between the activation of the agonist muscles until the activation of the antagonist muscles.

Analysis

Statistical analysis was performed with the SPSS Version 17.0, with statistical significance set at $p < .05$. Normality (Shapiro-Wilks test) was satisfied at a significance level of .05, while Levene’s test revealed inequality of variances in the electromechanical delay of the anterior portion of deltoid muscle. A two-tailed independent samples Student’s $t$ test was
used to analyze differences between the sexes on the average of movement times and electromechanical delay variables. Effect size was calculated as Hedges’s $g$ (1981),\(^2\) except for the anterior portion of deltoid muscle that was used the Glass’s $\Delta$ (1976)\(^3\) because the sexes had unequal variances. Thereafter, was applied an unbiased estimator of the effect size (Hedges, 1981; Glass, McGaw, & Smith, 1981; Hedges & Olkin, 1985), by multiplying the Hedges’s $g$ and Glass’s $\Delta$ by a factor of $1–3/(4N–9)$, with $N$ being the total sample size. According to Cohen (1988), the effect size is considered small at 0.20 to 0.49, medium at 0.50 to 0.79, and large at 0.8 to 2.0. The positive or negative effect size shows the direction of the differences between the sexes, so if the effect size is negative, men had an electromechanical delay smaller than women.

**RESULTS**

**Movement Times**

The female karate athletes presented a significantly slower shoulder flexion movement ($p = .04$; effect size = 1.01; Table 2) than the male karate athletes; there were no significant differences between the sexes in the elbow extension.

**Electromechanical Delays**

Table 3 shows the electromechanical delay and the statistical differences between male and female karate athletes. Antagonist muscles showed a negative electromechanical delay because they were activated after the beginning of the movement, being responsible for the limb deceleration.

In the agonist muscles of shoulder flexion, men had a significantly smaller electromechanical delay for the anterior portion of deltoid muscle ($p = .03$; effect size = −1.16; Table 3). There was no significant difference in the pectoralis major muscle. Men showed a lower electromechanical delay for the antagonist muscles of the shoulder flexion (posterior portion of deltoid and latissimus dorsi), although the differences were not statistically significant.

The electromechanical delay between the activation of the agonist muscles until the activation of the antagonist muscles of the shoulder flexion revealed statistically significant differences between the sexes in the pectoralis major / posterior portion of deltoid, where the male karate athletes had a higher electromechanical delay ($p = .005$; effect size = 1.95; Table 3), and in the anterior portion of deltoid / latissimus dorsi, where the female karate athletes presented a higher electromechanical delay ($p = .047$; Table 3). The electromechanical delay was calculated as:

$$g = (M_1 - M_2) / S_{pooled}$$

where $M_1$ and $M_2$ are the means of karate athletes and nonathletes, and $S_{pooled}$ is the pooled standard deviation, with $S_{pooled} = \sqrt{(n_1 - 1) S_1^2 + (n_2 - 1) S_2^2 / (n_1 + n_2 - 2)}$, where $n_1$ and $n_2$ are sample size, and $S_1$ and $S_2$ are the standard deviation for the male and female karate athlete, respectively.

$$\Delta = (M_1 - M_2) / S_2$$

\(^2g = (M_1 - M_2) / S_{pooled}\) where $M_1$ and $M_2$ are the means of karate athletes and nonathletes, and $S_{pooled}$ is the pooled standard deviation, with $S_{pooled} = \sqrt{(n_1 - 1) S_1^2 + (n_2 - 1) S_2^2 / (n_1 + n_2 - 2)}$, where $n_1$ and $n_2$ are sample size, and $S_1$ and $S_2$ are the standard deviation for the male and female karate athlete, respectively.

\(^3\Delta = (M_1 - M_2) / S_2\)
effect size = −1.21; Table 3). Concerning the other agonist-antagonist relationships of shoulder flexion, no statistically significant differences were found. No significant differences between the sexes were found in the electromechanical delay of the agonist (triceps brachii) and antagonist (biceps brachii) muscles of the elbow extension, neither in the agonist-antagonist relationship.

**Discussion**

It was only in the shoulder flexion that a sex difference was found. Male karate athletes had a significantly longer shoulder flexion, suggesting that this movement could allow longer segment acceleration in men (Gottlieb, 2001). Dynamic training is effective in reducing punch movement time (Dinn & Behm, 2007), though the differences between men and women have not yet been studied. The punch was characterized by a proximal-to-distal sequence, similar to other sport movements (Joris, et al., 1985; Elliott, et al., 1986; Herring & Chapman, 1992; Putnam, 1993; Hirashima, et al., 2002), before impact on the target.
It was also found that the anterior portion of the deltoïd muscle and the pectoralis major muscle were activated before the beginning of the movement, being responsible for starting shoulder flexion movement and for the initial limb acceleration. The antagonist activity, at the posterior portion of deltoïd and latissimus dorsi muscles, develops the force that halts the limb and protects the joint structures. Results of the elbow extension showed a similar trend by the activation of the triceps brachii and the biceps brachii, helping in both limb acceleration and deceleration, respectively, during the punch performance.

Concerning the electromechanical delay, men and women had a similar pectoralis major electromechanical delay, although there was a significantly smaller electromechanical delay in male karate athletes in the anterior portion of deltoïd muscle. A limitation to this analysis is that the coracobrachialis, which is also an agonist muscle of the shoulder flexion (Thompson & Floyd, 2001; Seeley, Stephens, & Tate, 2008), was not studied because it is only accessed by depth electromyography (Correia, Santos, & Veloso, 1993), with constraints for the karate punch movement performed in the real situation of practice or competition. However, electromechanical delays in the agonist muscle of the shoulder flexion were in agreement with the findings of other studies that showed a longer electromechanical delay in women (Bell & Jacobs, 1986; Winter & Brookes, 1991; Zhou, et al., 1996), and suggests that male karate athletes may need less time for motor unit activation and shortening of the musculoskeletal system (Grabiner, 1986) to perform this specified karate punch. Accordingly, male karate athletes had a better effectiveness in the transfer of the contractile force to the beginning of the movement. Differences in musculotendinous stiffness have been suggested by Winter and Brookes (1991) as possible causes for the difference in the electromechanical delay between the sexes, but that cannot be concluded from the present results. On the other hand, literature reports differences in tendon properties between men and women (Kubo, et al., 2003; Burgess, et al., 2009), which might explain some of the differences for the longer electromechanical delay in the female karate athletes.

Regarding the shoulder flexion agonist-antagonist relationship, the differences between the male and female karate athletes could represent a different pattern of controlling the neuromuscular coordination in those male and female karate athletes. This analysis identified differences in intermuscular coordination in the punch performance, although it revealed a similar coordination pattern between men and women, i.e., reciprocal activation, because the activation of the antagonist muscles was closer to the endpoint of the agonist burst, retarding the beginning of the agonist/antagonist co-contraction. This coordination pattern creates small periods of co-contraction and allows more time to segment acceleration (Basmajian, 1977). The activation of the antagonist muscles closer to the endpoint
of the agonist burst (Rodrigues Ferreira & VencesBrito, 2010) or a smaller duration of the muscle co-contraction or co-activation could indicate the achievement of a motor skill (Basmajian, 1977; Pousson, Amiridis, Cometti, & Van Hoecke, 1999).

Men and women had similar electromechanical delay in the triceps brachii muscle, showing the importance of stabilizing the elbow and the limb acceleration (Witte, Emmermacher, Hofmann, Schwab, & Witte, 2005; Neto & Magini, 2008) during the punch performance. A similar antagonist activation of the elbow extension (biceps brachii) and movement time showed the same tendency to halt the limb at the movement’s endpoint in male and female karate athletes. The low statistical power also confirms this similar activation between the sexes in the agonist-antagonist relationship of elbow extension movement.

Male and female karate athletes possessed a biphasic EMG pattern (Yamazaki, Suzuki, & Mano, 1993; Zehr, Sale, & Dowling, 1997; Pousson, et al., 1999), revealing the importance of the antagonist action in the control of the punch, produced in ballistic movements, for the protection of joint structures (Solomonow, Baratta, Zhou, Shoji, Bose, Beck, et al., 1987; Baratta, Solomonow, Zhou, Letson, Chuinard, & D’Ambrosia, 1988; Solomonow, Baratta, Zhou, & D’Ambrosia, 1988; Yamazaki, Itoh, & Ohkuwa, 1995; Pfann, Hoffman, Gottlieb, Strick, & Corcos, 1998; Gottlieb, 2001; Shapiro, Prodoehl, Corcos, & Gottlieb, 2005). The antagonist action is also important in karate athletes because of the need to halt the limb to reduce effective contact with the opponent in the competitive situation and training. Accordingly, the implementation of new competition rules, including excessive force at the contact when attacking permitted areas, has reduced injury in top level karate competition (Arriaza, Leyes, Zaeimkohan, & Arriaza, 2009). Sbriccoli, et al. (2010), studying the neuromuscular control adaptations in elite athletes, found lower antagonist activation during an isokinetic task and a higher activation during a front kick. Those results suggested that elite karatekas used a different neuromuscular pattern to better control the specified movement. Accordingly, Sørensen, Zacho, Simonsen, Dyhre-Poulsen, and Klausen (1996) also suggested an improved neuromuscular control during a complex motor task in taekwondo athletes.

It may be concluded that there was a greater efficiency in neuromuscular coordination in the punch performed by male karate athletes, as fundamental to the success of skill execution and performance of ballistic movements, which was due to the existence of a smaller electromechanical delay in the activation of the agonist muscle in relation to the movement’s starting time. In addition, there were sex differences in neuromuscular coordination in relation to the activation of the agonist until the activation of the antagonist muscles, evidenced by the electromechani-
Electromechanical delay, which identifies different muscle activation patterns, mainly in the shoulder flexion movement.

This study was conducted to analyze sex differences in electromechanical delay during a punch movement performed by elite athletes was limited in generalization to other levels of practice. In addition, the number of participants in the study was limited by the low number of athletes reaching this high competitive level. Coaches should take note of differences in performance between the sexes as this could be important in the creation and conduct of different training strategies between men and women and among groups with different levels of practice. Further investigation should analyze different levels of practice to better understand the relationship of the electromechanical delay with movement duration time.

REFERENCES


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