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Research Article

The Effects of Aging on Electromechanical Delay: A Comparison between Karate Athletes and Non-Athletes -

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ABSTRACT

Normal aging in humans is associated with a progressive decline in biological functions that affect motor performance. This study intended to analyze the effects of aging on electromechanical delay during the mae-geri kick performance. Forty-six males were divided into three groups according to age and sports practice: 9 veteran karate practitioners aged between 50 and 63 years (VetK), 21 young karate practitioners (YgK) and 16 non-karate practitioners aged between 18 and 35 years old. Electromechanical delay was defined as the time interval between the onset of the electric activity of a muscle and the beginning of joint movement. The statistical analysis was performed with One-Way Analysis of Variance and Turkey HSD Post-Hoc (SPSS, version 17.0). Rectus femoris EMD was found to be significantly longer in VetK, suggesting that aging has a negative impact on the neuromuscular activity and contractile capacity of this muscle.

Keywords: Electromyography; Karate; Combat sports

INTRODUCTION

It is a fact that older adults are increasing in the human population with life expectancy increase, wherein sports practice is associated with health maintenance and a better quality of life in older people. However, human aging leads to a progressive decline in biological functions that affect the body and so the locomotor system [1] and the sportive performance. With increasing of age also, the nervous system is affected by the continuous loss of neurons and the decrease of functional capacity of the remaining neurons [2], leading to a decrease in axons potential action conduction velocity due to demyelization [3-7]. Sensory-motor and cognitive abilities weaken with aging [8], affecting the capacity to receive the sensory information [9-12], to centrally process information [13] and to execute the response through muscle contraction [14]. In addition, the proprioceptive receptors related to limb position and movement deteriorate with aging and are associated with a decrease in the neuromuscular control and an increase in the risk of falls in older adults [15], which could be related to a slower reaction time in older adults [16-18] compared to young adults. Skeletal muscle aging is characterized by a decrease in muscle mass due to the loss of muscle fibers [19,20], which is the main reason for a decrease in strength observed with increasing age [21,22]. The decrease of the neuromuscular junction surface area causes an increase in the time that a muscle takes to contract in response to nervous stimuli [2]. Other effects of aging are associated with a reduced aerobic capacity [23] and with an increased recovery time due to a decrease in the oxidative capacity and a decrease in the density of capillaries in skeletal muscle [2,24]. At the skeletal system, people lose bone mass as they age because there is a decline in the number of osteoblasts [25], which decreases the rate of matrix formation compared with the rate of matrix breakdown by osteoclasts [2]. Joints lose articular cartilage and cartilage matrix, becoming stiffer and less flexible [26]. In addition, connective tissues with abundant collagen, such as tendons and ligaments, become less flexible and more brittle [2]. Despite the fact that age-related changes are inevitable, the rate of development is largely determined by genetic characteristics and individual lifestyle [8], but training is considered a way of slowing these effects of aging [27-31]. Accordingly, Holviala, et al. [28] found significant improvements in maximal and explosive strength, peak VO_2, walking speed and balance, in healthy men with average 56 years old, after 21-week twice weekly in the endurance training and combined strength and endurance training groups. It has also been reported that training altered the angle-torque relation, associated with the increase in agonist activation and changes in muscle-tendon properties [29]. Thus, regular strength, endurance or combined strength and endurance training with adequate intensity may decrease some of the physiological effects of aging seen in skeletal muscle [31]. The study of neuromuscular activity in sports athletes generally uses electromyography systems to collect several data from muscle activity. In the present study, the Surface Electromyography (SEMG) analysis was used to identify the time interval between the onset of the electric activity of a muscle and the beginning of the joint movement. This time is considered the Electromechanical Delay (EMD) [32,33] and represents the motor units' activation and shortening of the elastic series component of the musculoskeletal system [34]. Studies that analyse the effects of aging on EMD are scarce. Grosset, et al. [35], in their research on children between 7 and 11 years old, found that EMD decreases with age, in plantar flexor muscles using supramaximal electrical stimulations. However, it has been reported that EMD increases with aging in subjects aged between 18 and 60 years old, using supramaximal stimulation [36]. Nevertheless, there are no studies that analyse the effects of aging on EMD during the performance of sport-specific motor skills. Therefore, the aim of this study was to analyse the effects of aging on EMD in karate practitioners when they perform the frontal kick, the *mae-geri*. Supporting the actual knowledge about the effects of aging on the neuromuscular system, we hypothesized that EMD increases with the aging process in veteran karate practitioners even though they remain physically active.

METHODS

Participants

Forty-six male subjects volunteered to participate in the study and signed an informed consent document. Three groups were formed according to sport, years and level of practice, and age of the participants: 9 veteran karate practitioners aged between 50 and 63 years (VetK); 21 young karate athletes aged between 18 and 35 years (YgK); and 16 non-karate athletes aged between 18 and 35 years (NK) but physically active in other sports. All participants were in perfect health and without a history of neuromuscular or cardiovascular disease. The demographics of the three groups are shown in table 1.

Experimental Procedures

All experimental procedures were approved by the scientific committee of the Sports Sciences School of Rio Maior, Polytechnic Institute of Santarém, and performed in agreement with the ethical standards of the Helsinki Declaration [37]. Each subject participated in a single measurement session where the SEMG activity of five muscles and the kinematic of the right lower limb (dominant) were recorded simultaneously. The studied motor skill was the karate kick *mae-geri*, which started from the karate stance of *zenkutsu-dachi* and ended when the metatarsals (*koshi*) hit the vertical training bag, with target area set at a height of 90 cm from the ground and at a distance of

Table 1: Demographic characterization of participants in the study.

Variable	VetK	YgK	NK	F	*P*
Age (years)	54.2 ± 3.9	22.9 ± 5.4	23.1 ± 5.8		
Height (cm)	176.3 ± 4.7	172.7 ± 7.0[a]	178.8 ± 6.2[a]	4.388	0.018
Weight (kg)	76.3 ± 9.2	71.8 ± 15.0	73.3 ± 10.2	.424	NS
Fat mass (%)	19.0 ± 2.2[a]	13.3 ± 6.8[a]	14.5 ± 4.3	3.579	0.036
Inferior limb length (cm)	91.2 ± 3.4	88.9 ± 5.0	90.4 ± 4.6	1.001	NS
Weekly training (h)	5.3 ± 1.7	7.4 ± 4.5[a]	3.5 ± 1.8[a]	5.000	0.012
Black belt level (Dan)	4 ± 1.7[a]	1 ± 0.6[a]	-	53.071	< 0.001
Training practice (years)	34.8 ± 9.9[a,b]	13.4 ± 4.4[a]	9.9 ± 4.3[b]	71.287	< 0.001

Values are mean ± SD. ANOVA *P* values are shown. VetK: Veteran Karate Practitioners; YgK: Young Karate Athletes; NK: Non-Karate Athletes; cm: Centimeter; kg: Kilogram; %: Percentage; h: Hour.
[a,b]Significant ($p < 0.05$) difference between groups, respectively. NS: Not Significant.

Table 2: Beginning of joint movements before contact time during mae-geri kick performance.

Joint movements	VetK	YgK	NK	F	*P*
Pelvic girdle (ms)	535.4 ± 68.2	499.2 ± 55.7	503.9 ± 54.7	.572	NS
Hip flexion (ms)	488.3 ± 77.0	479.0 ± 70.5	460.7 ± 57.2	2.857	NS
Knee extension (ms)	410.9 ± 41.4	374.9 ± 59.0	365.6 ± 25.6	1.923	NS
Ankle plantar flexion (ms)	354.2 ± 43.3	325.9 ± 38.5	338.6 ± 30.4	1.277	NS

Values Are Mean ± SD. ANOVA *P* Values Are Shown Vetk: Veteran Karate Practitioners; Ygk: Young Karate Athletes; NK: Non-Karate Athletes; Ms: Millisecond. NS: Not Significant.

each participant's lower limb length. Figure 1 shows the experimental setup of a veteran karateka performing the *mae-geri* kick movement from the starting stance of *zenkutsu-dachi* until the final position with the foot contacting the target.

Surface Electromyography: Before beginning the data collection, the participants were instructed and the skin prepared according to the European Recommendation for Surface Electromyography (SENIAM - Surface Electromyography for the Non-Invasive Assessment of Muscles) [38]. The SEMG was recorded through the MP100 Data Acquisition System with a sampling rate of 1050 Hz, with active bipolar surface electrodes (centres separated by 20 mm), TSD Model 150TM (BIOPAC Systems, Santa Barbara, CA, USA), with an input impedance of 10 GΩ, noise of 1 μV, common mode rejection ratio (CMRR) of 95 db and gain of 1000. SEMG was recorded from Rectus Femoris (RF) and Vastus Lateralis (VL) portions of the Quadriceps Femoris, long head of the Biceps Femoris (BF), Tibialis Anterior (TA) and Lateralis Gastrocnemius (GA). The signals were digitally filtered (10 to 400 Hz), full wave rectified, smoothed with a low pass filter of 12 Hz (Butterworth, 4th order), and normalized using the average value of the maximum peak of electromyographic activity of the three runs [39,40] in each studied muscle. The participants kicked in response to a sound stimulus activated by a trigger linked and synchronized with the SEMG and the video recording device. Each participant performed three kicks in the fastest and strongest way they could, with a rest period of 30 seconds between repetitions. The median value of the three trials was used for analysis.

Kinematics: The *mae-geri* kick was filmed with a high-speed camera (Casio EX-FH20), with a 210 Hz sampling frequency, positioned perpendicular to the plane of movement at a distance of two meters. Five reflective markers placed in the lower limb, identified the location of the right anterior superior iliac spine, the prominence of the greater trochanter, the lateral condyle of the femur, the fibular malleolus and the dorsal facet of the second metatarsal head. To identify the coordinates in all frames of the participant's reflective markers, the virtual lab space was calibrated. The initial data were smoothed by the Ariel Performance Analysis System (APAS, Ariel Dynamics-2003) with a low pass digital filter of 5 Hz cut-off [41] then cut and analysed. The criterion for cutting the raw data of SEMG and video records was to carry out the initial cut 200 ms before the trigger input signal and the final cut 200 ms after the first frame where *koshi* contacts with the bag. The first frame was considered the instant time 0 for all measurements. On the final files the onset/offset determination of muscle activation and the onset of segmental movements were performed visually by an expert researcher on the Matlab outputs. The remaining data were automatically processed through the Matlab software. For this study muscle EMD was defined as the time interval from the onset of the SEMG until the beginning of the joint movements [32,33,42,43] of the lower limb.

Statistical Analysis

Descriptive data are presented as means and standard deviations. Normality of the data distribution (Shapiro-Wilks test) and homogeneity of variances (Levene's test) were evaluated for all variables. One-Way Analysis of Variance (ANOVA) was performed to examine the differences between the three groups on the dependent variables. When a significant difference was found, Tukey HSD post-hoc test was used for the specific comparisons. Statistical analysis was performed with Statistical Package for the Social Sciences (SPSS 17.0 for Windows ®, SPSS Inc, Chicago, USA) and the level of statistical significance was set at $p \leq 0.05$.

RESULTS

Demographic characteristics

Body fat percentage ($p = 0.029$), black belt level ($p < 0.001$) and years of karate training practice ($p < 0.001$) were significantly higher in VetK compared with YgK. VetK had significantly higher training

Figure 1: Illustration of the experimental setup showing a veteran karateka performing the mae-geri kick movement from the starting stance of zenkutsu-dachi until the final position with the foot contacting the target.

practice than NK ($p < 0.001$; Table 1). YgK presented a significantly smaller height ($p = 0.015$) and a significantly higher weekly training hours ($p = 0.009$) compared with NK (Table 1).

Joint movement time

Table 2 shows the joint movements onset time as well as significant differences between groups.

The onset time of the joint movements showed a similar kinematic sequence between groups when they perform the *mae-geri* kick. VetK first moves the pelvic girdle, about 535 ms before the contact with the bag, following by the hip flexion, knee extension and ankle plantar flexion, about 488 ms, 411 ms and 354 ms, respectively. The joint movement times tend to be longer in VetK; nevertheless, no significant differences were found between groups (Table 2).

Electromechanical delays

In the pelvic girdle movement, VetK presented a significantly longer RF EMD than YgK ($p = 0.046$) and the YgK showed a significantly shorter BF EMD than NK ($p = 0.001$). In the hip flexion movement, a significantly longer RF EMD was found in VetK compared with the YgK ($p = 0.015$) and a significantly shorter RF EMD in YgK compared with the NK ($p = 0.036$). A significantly shorter BF EMD was found in YgK compared with the NK ($p = 0.001$). The knee extension movement shows a significantly longer RF EMD in VetK compared with YgK ($p = 0.029$) and a significantly shorter EMD between YgK and NK ($p = 0.019$), as well as in the BF ($p = 0.001$). No significant differences were found between groups in the TA and GA muscles EMD in the ankle plantar flexion (Table 3).

DISCUSSION

Aging is a natural process that carries on biological and physiological modifications on the human body and brings constraints to the individual quality of life. Some of those constraints are related to the degeneracy of the nervous and musculoskeletal systems that, consequently, might create constraints on mobility and balance in the older people. Regular sports practice is recommended as a prevention factor to keep a healthy body, trying to delay the effects of aging [30]. This idea is corroborated by the present study's findings. It seems that age doesn't affect the performance of the *mae-geri* kick in what concerns the proximal to distal sequence [44-47] of segmental kinematic pattern, which is similar between the three groups. This pattern is related to the transition from a bipedal stance to a one-foot stance, with the energy transference from the hip flexion to the knee extension and consequently to the foot (metatarsals) hitting the training bag with the highest velocity as possible. However, an adjustment in the onset of the joint movements exists, which tends to be anticipated in VetK but without statistically significant differences between groups (Table 2). Despite the similar results of kinematic pattern, the VetK in the muscle activity to perform the hip flexion movement showed a significantly longer EMD in the RF than YgK, and the same tendency exists in relation to the NK, which could be associated with aging factors [36] as the decrease in tendon stiffness [48], the deterioration of tendon material [2,49], loss of muscle mass [19,20], and the decrease in the velocity of muscle stimulation by the nervous system [8], conducts to an anticipation of the muscle recruitment and contraction. On the other hand, the YgK showed a significantly shorter RF EMD than NK and in its antagonist, the

Table 3: Shows the EMD and the statistical differences between the groups. Muscles EMD during mae-geri kick performance.

Movement	EMD	VetK	YgK	NK	F	*P*
Pelvic girdle	RF (ms)	80.3 ± 45.5[a]	9.8 ± 58.0[a]	63.1 ± 91.0	3.942	0.028
	BF (ms)	-26.5 ± 71.9	-86.7 ± 118.9[a]	45.8 ± 65.5[a]	7.769	0.001
Hip flexion	RF (ms)	127.4 ± 59.1[a]	32.3 ± 70.1[a,b]	103.7 ± 97.3[b]	5.546	0.008
	BF (ms)	6.3 ± 91.0	-64.6 ± 130.6[a]	85.1 ± 79.9[a]	7.673	0.002
Knee extension	RF (ms)	204.9 ± 42.5[a]	133.7 ± 59.4[a,b]	198.3 ± 80.6[b]	5.477	0.008
	VL (ms)	146.9 ± 51.3	125.8 ± 65.4	174.1 ± 71.1	2.340	NS
	BF (ms)	92.6 ± 56.0	38.5 ± 129.2[a]	179.8 ± 72.5[a]	7.836	0.001
Ankle plantar flexion	TA (ms)	262.2 ± 45.9	246.8 ± 85.4	240.1 ± 86.6	.222	NS
	GE (ms)	124.6 ± 56.4	138.6 ± 46.3	110.8 ± 51.1	1.416	NS

Values Are Mean ± SD. ANOVA P Values Are Shown. EMD: Electromechanical Delay; RF: Rectus Femoris Portion Of The Quadriceps Femoris; BF: Long Head Portion Of The Biceps Femoris; VL: Vastus Lateralis Portion Of The Quadriceps Femoris; TA: Tibialis Anterior; GE: Lateralis Gastrocnemius; Vetk: Veteran Karate Practitioners; Ygk: Young Karate Athletes; NK: Non-Karate Athletes; Ms: Millisecond.
[A,B] Significant *(p* < 0.05*)* Difference Between Groups, Respectively. NS: Not Significant.

BF, revealing an activation of those muscles closer to the beginning of the segmental movement in this group, but with the BF being activated after the hip flexion started. This activation strategy is associated with karate training, which increases the braking efficiency of the antagonist hip flexion muscles in YgK and increases the neuromuscular pattern of reciprocal innervation to control of *mae-geri* performance. In fact, BF muscle has a negative value in the VetK and YgK groups in pelvic girdle movement compared with NK, and in hip flexion between YgK and NK, suggesting that his antagonist action in karate athletes is lesser, beginning after the movements are initiated. Those differences were related to sports practice [50] and identify that Vetk and YgK remain with a similar BF control pattern. However, the breaking action of this antagonist muscle in the joint movement allows better control of the kick execution in the NK with intent to protect the joints structures [30,51] but shows that the movement was not learned or trained for [43].

In the knee extension movement during the *mae-geri* kick execution, the significantly longer RF EMD in VetK compared with YgK suggests that the older karatekas need more time to transfer the contractile muscle energy to extend the leg in the knee joint. The neuromuscular impairment could be the reason for this longer EMD, but another possibility is the double action of this muscle [30,52,53]. It acts in the hip as in the knee during the kick performance. However, the significantly shorter EMD in YgK compared with NK shows a better transference of contractile energy to the knee joint in YgK, which seems to be related to sports practice, namely by the fact that experienced karate athletes usually presented shorter EMD compared with NK [43]. In addition, Kubo et al. [54] found a significant decrease in EMD after a 12-week training program of isometric knee extensions in healthy men, suggesting that training might be effective for shortening the EMD, despite the fact that a 7-week sprint training did not significantly change the electromechanical delay of knee extensor muscles [55]. However, in the present study, YgK had 13 years of training practice and a shorter EMD was expected.

The VL, portion of *quadriceps femoris,* also responsible for the knee extension, does not show significant differences between groups. Nevertheless, a tendency of lower EMD exists in both karateka groups than in the NK group, reflecting a more efficient transference of contractile energy to begin the knee extension in karatekas than in NK due to the karate practice. But between the two karate groups, the VL EMD tends to be longer in VetK, reflecting the consequences of the aging process on the neuromuscular activity.

The training and age effects are presented too in the BF EMD in its antagonist action of the knee extension where the YgK showed a significantly shorter EMD than VetK and NK, but the VetK tends to have a shorter EMD than NK. So the shorter EMD in the karateka groups should be associated with an efficient breaking control of knee extension movement [53] to kick, anticipating the BF intervention, contrary to what the NK does. However, we must understand that this muscle begins to be stretched when the hip and knee start their movements in the kick performance.

The stabilization of the ankle joint, with the foot in plantar flexion, to hit the training bag with the *koshi* in the *mae-geri* performance is necessary to take advantage of the energy from the proximal joints to do a faster and stronger kick and to protect the ankle and foot joints. Nevertheless, there is inexistence of statistically significant differences between groups in TA and GE EMD during the kick performance; however, those muscles tend to have a longer EMD in the karateka groups than NK. This could be related to an anticipation of blocking the ankle joint and foot in the position to make the impact in the training bag in the NK, which is associated with inexperience, trying to decrease the injury risk. The practice seems to tend to avoid the early ankle blocking. Yet, the found tendency to a longer TA EMD and a lower GE EMD between the VetK and the YgK could be caused by the aging process and might be related to the foot plantar flexion anticipation done by the VetK.

CONCLUSION

As previously hypothesized, aging increases the RF EMD in the VetK in relation to the pelvic girdle, hip flexion and knee extension movements, suggesting that aging has a negative impact on the neuromuscular activity and contractile capacity of this muscle. It can also be concluded that training reduces the EMD in the YgK compared with NK practitioners, specifically in the RF and BF muscles when they act in the hip flexion and knee extension movements, improving the kick performance.

The study was limited by the inexistence of a group with veteran non-karate practitioners that might complete the analysis and comparisons with the VetK group. The impossibility of collecting data from the muscles acting on the pelvic girdle stabilization and from the *iliopsoas* and *gluteus maximus* muscles could be a limitation to the analysis of the EMD in the hip flexion movement. Furthermore, the non-use of a wireless SEMG system could be a constraint to the kick performance during the study. However, this study brings useful information about the effects of aging on the neuromuscular system activity in the control of lower limb movement, specifically in the *mae-geri* kick performance, which is important for karate coaches, allowing them to improve the methodologies of practice with older people.

Further studies should analyse the EMD in older adult non-karate practitioners and in female groups performing the *mae-geri* kick, considering a more extensive muscles analysis.

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