Aging Effects on Neuromuscular Activity in Karate Practitioners

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Abstract: Aging leads to a general decline in body functions that affects quality of life. Sports practice is recommended as a means to attenuate the impact of the aging process. The aim of this study was to identify and analyze the neuromuscular activity and its patterns on active karate practitioners and assess the effects of the aging process. Two groups of black belt male karate practitioners, one with nine practitioners over 50 years old and the other with 21 practitioners aged between 20-30 years old performed the frontal kick *mae-geri*. Kinematic and electromyographic data of five muscles were collected from the right leg. Results showed two distinct periods of muscular activation in the *mae-geri* performance, with similar muscles activity patterns between groups. Nevertheless, some differences were found in the muscles' activity onset and offset, in root mean square and in inter-muscle delay and co-contraction periods. Those differences indicated that aging affects the neuromuscular activity in the *mae-geri* performance of the oldest karate practitioners. Nevertheless, the results showed that lifelong practice of karate can preserve the quality of the neuromuscular activity in older practitioners when they perform a kick, and this could be associated with benefits to balance control.

Key words: Aging, motor control, neuromuscular activity, karate, combat sports, martial arts.

1. Introduction

After the third decade of life, humans start to experience an aging-related decline in biological functions that affect the locomotors' performance [1], compromising their ability to do normal activities and to maintain the practice of sport. Those declines happen at the level of muscular strength production [2, 3], with a decrease of maximal strength associated with loss of muscle mass, and atrophy, with a decrease in cross-sectional area of muscle fibers and a decrease in the number of muscle fibers [4-6]. Age-related

reduction of strength also depends on the decrease in mitochondria and mitochondrial DNA [7], with a reduction of synthesis of muscle proteins [8].

The neurological activity declines with aging, too [9, 10]. At this level, changes occur in the detection of visual, vestibular and somatosensory stimuli [11-13], in processing the information [14] and in the response through muscle contraction [15]. These changes are related to the loss of neurons and a decrease in the functional capacity of the remaining neurons, leading to a decrease in the velocity of conduction in the nerve [16-19]. Proprioceptive receptors related with the control and determination of the limbs' position and movements continue to deteriorate with age, leading to a decrease in neuromuscular control and increasing

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the risk of falls in the elderly [9, 20].

In association with neuromuscular control and strength production, other factors, such as longer co-activation and co-contraction [21], or the reduction of specific tension in muscles may contribute to the age-related loss of force [22]. The co-activation and co-contraction between agonist and antagonist muscles are higher in the earlier ages, decreasing progressively with maturation, and learning and practice of skills [23]. There is a stabilization period [24], but the co-activation and co-contraction increases with aging, fundamentally after the fifth decade of life [25-27].

Neuromuscular control patterns of the movements and the changes related with aging lead to changes in the performance of both simple and complex skills. Several studies concluded that the changes in movement time increase with aging [10, 14, 28, 29], but the older people can perform motor skill activities using similar control strategies to young adults [28]. Rand and Stelmach [14] showed that several movement components were differently affected by aging, and this affected in different ways the decrease of the overall performance. Those authors suggest the existence of an age-related deficit in processing of sensory information, reducing the capability to plan and organize sequential actions.

The decline in neuromuscular function related to age [30, 31] can be slowed or delayed with regular physical activity [6]. Studies about training in older people confirm improvements in muscle strength [3, 32, 33], muscle power [34], explosive strength, walking speed and in balance. Improvements in the maximum oxygen consumption [1], as in the mitochondria functions [7] were found, which is important for the contractile activity of muscles.

Martial arts allow practitioners to maintain a regular and continuous practice throughout life, and some studies related these practices with benefits in the aging process. Gatts and Woollacott [35] showed that

Tai Chi practice improves neuromuscular control, which improves the balance and reduces the risk of falls. Similar conclusions about balance control were found in the Korean martial art Taekwondo [36], and also improvements in muscular strength and flexibility were noted [37].

In karate, the performance of specific skills is dependent on a high level of control and coordination of the limbs movements and balance, which is dependent on effective neuromuscular control. Consequently, aging can bring some problems to karate practitioners during the performance of their skills.

The latest research in karate has mainly focused on the kinesiological aspects of skills performance in both regular and elite practitioners aged below 50 years old. Some researchers analyzed the neuromuscular patterns, kinematic and kinetic activity of the punches [38-40], and others the kicks [41-45]. However, research about the relationship between aging and karate practice has to be done. Thus, considering the karate with a practice possible for life, we must know and understand how the aging process affects it, particularly in terms of neuromuscular activity, and the potential benefits to the quality of life of its practitioners.

The purpose of this study was to identify and compare the neuromuscular patterns of activity in veteran and younger black belt karate practitioners during the performance of the frontal kick *mae-geri* to verify the existence of differences related to aging. To fulfill this aim, the activity of the muscles of the hip flexion, knee extension and foot plantar flexion were compared between the younger and veteran groups during the performance of the *mae-geri* kick. We hypothesized that continuous and regular karate practice will reduce the effects of aging process on neuromuscular activity in older karate practitioners, preventing and attenuating the decrease in neuromuscular activity.

Table 1 Physical characterization of VetK and YgK practitioners.

	Age (years)	Height (cm)	Weight (kg)	Leg length (cm)	Body fat (%)	Weekly training hours (h)	Black belt level (Dan)	Years of practice
VetK	54 ±4 [a]	176 ±5	76 ±9	91 ±3	19 ±2 [a]	5 ±1	5 ±1 [a]	35 ±10 [a]
YgK	23 ±5	172 ±7	72 ±14	89 ±5	13 ±7	7 ±4	1 ±1	13 ±4

VetK = Veteran karate practitioners. YgK = Young karate practitioners. Values are means ±SD.
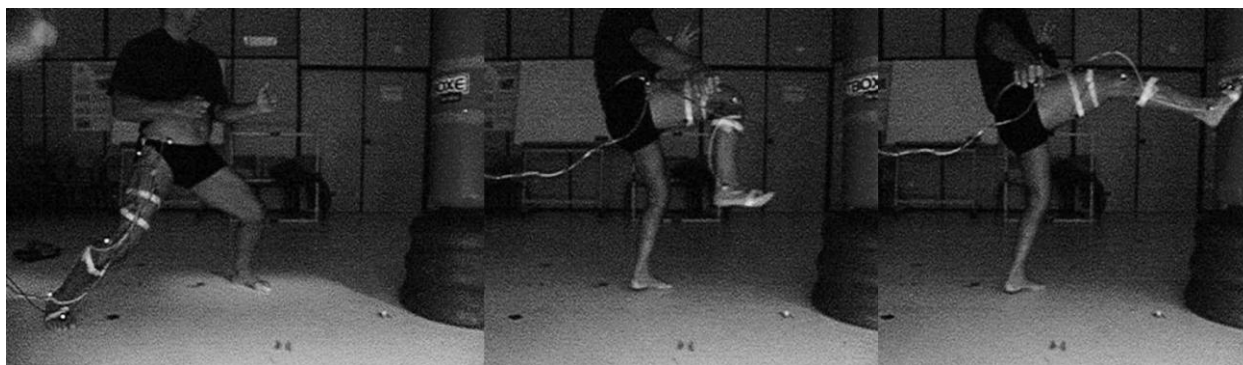[a] Specifies statistically significant differences between groups ($\alpha \leq 0.05$).

Fig. 1 Illustration of the experimental setup showing a veteran karateka facing the bag at the starting position of *zenkutsu-dachi*, with the right leg in backward extension, and the left leg flexed on the thigh and bent at the knee, with both feet on the floor, and the *mae-geri* kick movement until the final position of the foot in contact with the target.

2. Methods

2.1 Participants

Thirty male black belt karate practitioners with more than 10 years of continuous practice volunteered to participate in the study. Two groups were formed; one with nine veteran karate practitioners aged more than 50 years old (VetK), and the other with 21 karate practitioners aged between 20 and 30 years old (YgK). All participants were in perfect health and without history of neuromuscular or cardiovascular disease. All participants signed an informed consent document.

The demographics of the two groups are shown in Table 1.

This study was conducted according to the Helsinki Declaration and was approved by the scientific committee of the Sport Sciences School of Rio Maior, Polytechnic Institute of Santarém, Portugal.

2.2 Experimental Design

Each karate practitioner (karateka) participated in a single measurement session where the surface electromyographic (SEMG) activity of five muscles and the kinematic of the right leg (dominant) during the performance of the *mae-geri* kick were recorded simultaneously. The kick was performed into a vertical floor training bag. The target area was at a height of 90 cm from the ground and at a distance of each participant's lower limb length. Participants started from the typical karate static stance of *zenkutsu-dachi* (Fig. 1). They kicked in response to a sound stimulus activated by a trigger linked and synchronized between the SEMG and the video recording device. Each participant performed three fast and strong repetitions of the *mae-geri* kick with impact of the metatarsals, *koshi,* on the bag. There was a rest period of 30 seconds between repetitions. The median value of the three trials was used for analysis.

2.3 Apparatus

After skin preparation, electrodes were placed on the muscles according to the recommendation by SENIAM [46], with the ground electrode placed on the fifth lumbar vertebra. The SEMG was recorded through the MP100 Data Acquisition System with a sampling rate of 1050 Hz, and 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.

The kick movement was filmed with a high-speed camera (Casio EX-FH20), with a sampling frequency of 210 Hz, and positioned perpendicular to the plane of movement at a distance of two meters. Five reflective markers were placed along the lower extremity, specifically on 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.

The records were cut and analyzed with the software Ariel Performance Analysis System (APAS, Ariel Dynamics-2003). The criterion for cutting the raw data of SEMG and video records for analysis was to carry out the initial cut 200 ms before the trigger input signal and the final cut 200 ms after the moment the *koshi* made contact with the bag. The first frame where *koshi* contacts in the bag was considered as the instant time 0 for all measurements.

On the final files the determination of the onset/offset on muscle activation and the onset of segmental movements were done visually by a single expert researcher on the Matlab outputs. The remaining data were automatically processed through the Matlab software.

2.4 Data Reduction

2.4.1 SEMG

The SEMG was recorded from *Quadriceps Femoris* in the portions of the *Rectus Femoris* (RF) and *Vastus Lateralis* (VL), the long head of the *Biceps Femoris* (BF) muscle, the *Tibialis Anterior* (TA) muscle and the lateral portion of the *Gastrocnemius* (GA) muscle.

The SEMG 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 [47, 48], in each studied muscle (Fig. 2).

In the isolated SEMG bursts of each trial, the dependent variables of onset and offset of muscle activation, muscle activity duration, root mean square (RMS), the delay time between the beginning of inter-muscles activity and the co-contraction time between muscles were processed and studied.

To process the inter-muscles delay (IMD) and the co-contraction time, the muscles were organized in pairs with respect to their action as agonists (RF, VL, GA) and antagonists (BF, TA) on the joint movements (hip, knee and ankle).

2.4.2 Kinematic

The beginning of the forward movement (onset) in hip, knee, ankle and foot were the variables considered
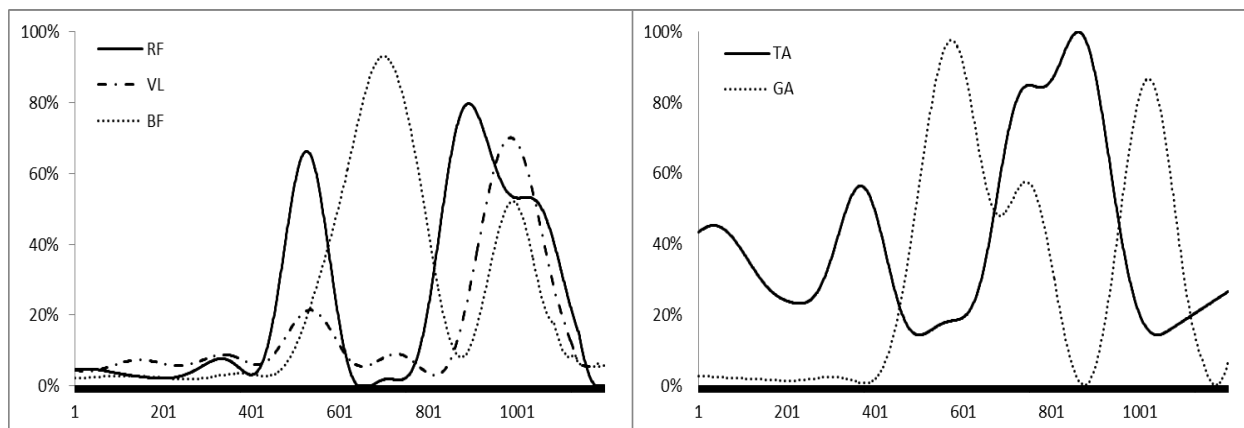

Fig. 2   Illustration of the SEMG of the *Rectus Femoris* (RF) and *Vastus Lateralis* (VL), the long head of the *Biceps Femoris* (BF), *Tibialis Anterior* (TA), and the lateral portion of the *Gastrocnemius* (GA) muscles activity during the *mae-geri* performance.

in this study. They were computed through the APAS system and the Matlab.

The virtual lab space was calibrated using eight control points, identified by a number and respective coordinates (x, y), in order to identify in all frames the coordinates of the reflective markers fixed on the participants. Then the reconstruction of the movement trajectory was made. The initial data were smoothed by the APAS software with a low pass digital filter of 5 Hz cut off [49].

2.5 Statistics

Descriptive data are presented as means and standard deviations. Normality of the data distribution (Kolmogorov-Smirnov) and homogeneity of variances (Levene's test) was evaluated for all variables. One Way ANOVA was performed to examine the differences between the two groups on the SEMG dependent variables and kinematic. Level of statistical significance was set at $\alpha \leq 0.05$.

Statistical analysis was performed with Statistical Package for the Social Sciences (SPSS 20.0 for Windows ®, SPSS Inc, Chicago, USA).

3. Results

3.1 Demographic Parameters

There were significant differences between VetK and YgK in age, body fat, black belt level and years of practice, achieving VetK higher values (Table 1).

3.2 Segmental Movement Time

Table 2 shows the onset time of the segmental movements as well as the significant differences between the VetK and the YgK.

The onset time of the segmental movements showed a kinematic sequence similar in both groups during the performance of the *mae-geri.* As is shown in the Fig 1, the kick began with a hip flexion movement followed by a proximal to distal and back forward direction until the *koshi* (metatarsals) contacted the training bag.

In VetK, all the mechanic segmental movement of *mae-geri* kicking began about 432 ms before the contact of the *koshi* with the bag. The last segment to initiate the movement was the metatarsal, 259 ms before the contact. All the segmental movements began significantly earlier in YgK ($\alpha < 0.05$).

3.3 Muscle Activity

As is shown in the Fig 2, two different activations occurred after the trigger signal, separated by an electrical silence were identified in the SEMG files, in all studied muscles and in both groups. For each muscle these activations were referenced as first (e.g. RF1 or (1)) and second (e.g. RF2 or (2)) activation period. Other studies have also showed a double muscular activation in karate [39, 50] and elite mixed martial arts fighters [51].

Table 3 shows the SEMG dependent variables to the muscle activity in the VetK and Ygk and the significant differences between groups.

The onset of muscle activation defines a sequential time pattern of muscle recruitment. In VetK, the TA and the RF were the earliest muscles to be activated during the first period of activity (TA1 and RF1 at 616 ms before contact in the bag). Next, the VL and BF activated, and finally the GA activated. The second period of activation had a similar sequence, except that the GA was activated before the BF.

Table 2   Kinematic time variables between VetK and YgK practitioners.

		Hip	Knee	Ankle	Foot
Onset movement time (ms)	VetK	432 ±43 [a]	334 ±46 [a]	296 ±18 [a]	259 ±11 [a]
	YgK	495 ±71	406 ±48	353 ±38	309 ±31

VetK = Veteran karate practitioners. YgK = Young karate practitioners. Values are means ±SD. Time—millisecond.

[a] Specifies statistically significant differences between groups ($\alpha \leq 0.05$).

Table 3   The variables of muscle SEMG in the *mae-geri* performance by VetK and YgK practitioners.

		RF1	VL1	BF1	TA1	GA1	RF2	VL2	BF2	TA2	GA2
Onset muscles activation time (ms)	VetK	616 ±62 [a]	558 ±56 [a]	499 ±61 [a]	616 ±61 [a]	479 ±43	255 ±53	135 ±26	93 ±35 [a]	325 ±44	114 ±38
	YgK	513 ±69	500 ±70	411 ±61	573 ±101	465 ±42	241 ±59	155 ±24	87 ±46	293 ±70	110 ±32
Offset muscles activation time (ms)	VetK	395 ±65 [a]	367 ±55 [a]	219 ±69 [a]	414 ±70 [a]	187 ±48	-22 ±28	-45 ±18	-44 ±15	62 ±18 [a]	-56 ±12
	YgK	322 ±64	318 ±60	110 ±64	302 ±85	167 ±42	-31 ±28	-47 ±18	-36 ±23	31 ±39	-60 ±12
Muscle activity duration (ms)	VetK	217 ±57	196 ±48	273 ±98	193 ±43	304 ±72	278 ±59	178 ±23	127 ±44 [a]	265 ±39	154 ±21
	YgK	183 ±43	179 ±34	292 ±79	256 ±95	299 ±54	271 ±47	201 ±22	134 ±51	262 ±53	167 ±23
SEMG root mean square (% RMS)	VetK	15 ±2 [a]	24 ±8	51 ±5 [a]	28 ±13	43 ±7	57 ±7 [a]	59 ±5	29 ±9	59 ±7	47 ±9
	YgK	28 ±13	32 ±14	41 ±10	29 ±12	46 ±9	49 ±9	56 ±7	35 ±13	54 ±11	47 ±10

VetK = Veteran karate practitioners. YgK = Young karate practitioners. Values are means ± SD. Time—millisecond; RMS—% of the normalized SEMG; RF—*Rectus Femoris*; VL—*Vastus Lateralis*; BF—*Biceps Femoris*; TA—*Tibialis Anterior*; GE—*Gastrocnemius*. First (1) and second (2) activation periods in the studied muscles.
[a] Specifies statistically significant differences between groups ($\alpha \leq 0.05$).

Table 4   Inter-muscles delay and co-contraction in the execution of *mae-geri* by VetK and YgK practitioners.

		RF1-VL1	RF1-BF1	VL1-BF1	TA1-GA1	RF2-VL2	RF2-BF2	VL2-BF2	TA2-GA2
IMD (ms)	VetK	64 ±58 [a]	123 ±108	89 ±64	146 ±53	113 ±41	152 ±45	33 ±50 [a]	218 ±59
	YgK	29 ±27	123 ±74	96 ±76	121 ±71	84 ±54	146 ±67	75 ±44	183 ±69
Co-contraction (ms)	VetK	153 ±63	89 ±115	111 ±81	40 ±44 [a]	157 ±27 [a]	118 ±56	140 ±46	45 ±23
	YgK	179 ±49	88 ±116	99 ±100	153 ±122	188 ±37	105 ±51	128 ±44	76 ±50

VetK = Veteran karate practitioners. YgK = Young karate practitioners. Values are means ± SD. IMD and co-contraction—millisecond; RF—*Rectus Femoris*; VL—*Vastus Lateralis*; BF—*Biceps Femoris*; TA—*Tibialis Anterior*; GA—*Gastrocnemius*. First (1) and second (2) activation periods in the studied muscles.
[a] Specifies statistically significant differences between groups ($\alpha \leq 0.05$).

The YgK presented a similar sequence time of muscles activation, however, during the first period the VL and BF muscles were activated significantly later than in the VetK and in the second period the VL was activated significantly before than the VetK (Table 3).

The offset time in the VetK presented a similar sequence to the onset but in the second period the muscles activity finished after the contact of the *koshi* with the bag, with exception of the TA (Table 3). In the VetK, the BF was deactivated before the VL. The YgK differed significantly because their muscles deactivate closer to contact of the *koshi* with the bag, specifically the RF, VL, BF and TA in the first activity and the TA in the second activity.

The duration time of musculars activity in the VetK varies between 304 ms (GA1) and 193 ms (TA1) in the first activation period and between 278 ms (RF2) and 127 ms (BF2) in the second activation period.

Nevertheless, the veterans' GA, BF and VL muscles had a larger time of activity in the first period than in the second (between 304 and 196 ms), unlike the RF and TA which presented a larger time of activity in the second period (278 and 265 ms, respectively). YgK showed a significantly larger duration time of activation in VL muscle during the second period.

The muscle activation intensity in the VetK had a minimum value of RMS of 15% on the RF and a maximum value of 51% on the BF in the first period of activity. In the second period of activity, the muscles increased the RMS about 30%, except for the BF where the intensity was reduced about 20% (Table 3). YgK had significantly higher RMS in RF muscle and lower in BF muscle during the first activity. In the second activity, the RMS of the RF muscle was lower in the YgK.

Table 4 shows the IMD and co-contraction time between muscles in the VetK and YgK as well as the

significant differences between groups.

The VetK presented higher IMD period in VL-BF muscles, respectively agonist and antagonist of the knee extension, during the first activity than in the second. The RF-VL, agonists of hip flexion and knee extension, the RF-BF, respectively agonist and antagonist of knee extension, and the TA-GA, respectively antagonist and agonist of foot plantar flexion, had a lower IMD period during the first activity, but in the TA-GA the IMD was higher than in the RF-VL and RF-BF in the two activation periods. YgK showed significantly smaller IMD in RF-VL and higher in VL2-BF2 than did the VetK (Table 4).

The co-contraction time in the VetK was higher for all the muscle pairs in the second period of activation, particularly on RF-BF ((1) = 89 ms; (2) = 118 ms) and VL-BF ((1) = 111 ms; (2) = 140 ms), with an increase about 30 ms on this period. TA-GA first period of co-contraction and RF-BF second period of co-contraction were significantly higher in YgK than in VetK (Table 4).

4. Discussion

In the present study, the results showed the existence of a specific neuromuscular phasic pattern of control and coordination of the *mae-geri* kick performance, on both groups, which seems to be adapted to the age of the karate practitioners.

The complexity of the kick performance generated two distinct contractile activities on the muscles in all karate practitioners, much as was found in other studies [45, 51]. The first activation was related with the initial hip flexion movement and the stabilization of the knee and ankle, while the second activation was related with the knee extension and foot plantar flexion at the ankle level to finalize the kick. In these muscles, there was found to be a temporal and reciprocal sequential order of agonists and antagonists recruitment. This order was similar between the two groups, and is typical of ballistic movements, corresponding to a proximal-to-distal mechanic

segmental sequence of movements [39, 45, 50]. The physical action was similar between groups, but the movements began earlier in the YgK. Nevertheless, the muscle activation on YgK, especially in the RF1, VL1, BF1 and VL2, began closer to the moment of contact of the *koshi* with the bag, reflective of less time being required to transfer the contractile muscle energy to the segments, to move and control them during the kick. This shows that in VetK, there could exist a loss of conduction velocity by the nervous system, as evidenced by some authors [16-19], and a loss of motoneurons and muscle fibers as a consequence of the natural aging process [19, 30]. However, these results could as well be related to the veterans' significantly higher body fat and less muscular mass, resulting in a smaller number of fibers being available [2-6] in the VetK, probably with a reduction in the synthesis rates of muscle proteins and mitochondrial functions [8].

The neuromuscular conduction velocity and the characteristics of muscles seems to be two primary factors involved in the differences between VetK and YgK. The study shows that during the muscles' activity duration, the agonist muscles VL and GA, and the antagonist muscle BF, tend to be activated for more time in the first period than in second period, in the VetK. This shows the importance of the initial control of the acceleration and balance when the karateka begins to perform the kick from a static stance [45]. In the second period, there is an increase in the duration of the RF activation. This is associated with the continuity of hip flexion and the beginning of knee extension, and with the TA activation, to stabilize the foot position. YgK tend to have a higher second period of activity in the agonist (RF and VL) and antagonist (TA) muscles, which might reflect that the second activation increases the acceleration and velocity of knee flexion and the foot stabilization, in anticipation of contact with the bag. In any event, the activity duration of the VL muscle during the second period was significantly higher in the YgK.

The RMS shows that the muscle activation intensity was, in general, lower than 60%. Consequently, there was not necessarily a great intensity of muscular activity needed to perform the *mae-geri* kick. In this context, the activation intensity of the agonist (RF, VL and GA) and antagonist (TA) muscles was lower in the first period than in the second period, in both groups, except in the BF muscle. This reflects that the main purpose of the first muscles' activity was to begin the segmental movements, with the hip and knee well controlled by the action of the BF muscle, without great levels of strength to accelerate the segments, as was referred by other study [45]. Despite this common behavior in both groups, significant difference was found between VetK and YgK in the activation intensity of both RF and BF muscles, during both periods of activity. This could reflect a greater intervention of the antagonist action (BF) in the hip and knee during the initial movement of the kick to increase the control, stability and body balance in the VetK.

The IMD shows if the muscles were simultaneously activated. The IMD in the *mae-geri* performance tends to be lower in the first period of muscles activity than in the second period, in both groups, except in VL2-BF2. This lower IMD shows that the antagonist activity in the first period is needed to control the initial segmental movements and transfer the body weight from a bipedal stance into a unipedal stance. This action needs joints to stabilize and requires balance control. In the second period, the antagonists were activated later, facilitating the initial acceleration and velocity in the joint movements, and preparing the segments for the impact of the *koshi* on the bag.

VetK tended to have a higher IMD during both periods of muscles activity than YgK, especially in RF1-VL1. The RF1-VL1 differences in the IMD between the groups could be related with the anticipation in the transfer of contractile energy to the knee extension in the YgK. In the VetK it must be initially more centered in the joint stabilizations and balance control, and this is something associated with the aging effects [21, 25-27, 35, 36]. This requirement was reflected in a lower IMD of the RF2-BF2 in the VetK, who, because they needed the antagonist muscle BF2 activity to increase the knee extension control, slowed down the movement but increased the control of the impact and body balance.

The typical phasic pattern of reciprocal enervation in the agonist and antagonist muscles recruitment was associated with well-trained and learned ballistic skills. In the performance of those skills, the co-contraction periods tended to be shorter. Nevertheless, the aging process affected the neuromuscular control patterns, namely, increasing the agonist and antagonist muscles co-contraction in older people [21, 25-27]. In the present study, the times of muscular co-contraction was similar between the two groups, and tended to be greater during the second period of activity. This reflected an increase of control over the joint movements to prepare the contact of the *koshi* with the bag. However, the VetK presented significantly smaller co-contraction times in the TA1-GA1 and RF2-VL2. Thus, the co-contraction and IMD data suggest that the effects of the aging process could be seen in the middle-aged VetK, in patterns typical to co-contraction found in elderly people. The longevity of the karate practice could be the reason to the maintenance of this similar pattern between VetK and YgK.

In general, it is assumed that aging alters the neuromuscular activity, and possibly, the motor control strategies, leading to performance deficits, and it was our expectation to find significantly different SEMG parameters, allowing the identification of the aging process in the neuromuscular patterns on VetK. Nonetheless, we found a specific neuromuscular pattern to control and coordinate the *mae-geri* kick performance that was similar between VetK and YgK. The few differences found in temporal muscular activity of the VetK showed the effects of aging, but the continued practice over the years, presumably

increased efficiency for this group, and that could explain the similar neuromuscular control activity with the YgK.

This study was limited to a sample of high rank karate practitioners, all male, all black belts, and all with many years of practice. This evidence leads to the question whether the middle aged practitioner and youths, women, or lower level practitioners would show the same characteristics of neuromuscular pattern in the kicking control. Nonetheless, the results of this study provide useful information to karate practitioners and coaches, and also to researchers who study the neuromuscular control in sportive skills performance related with aging.

5. Conclusions

In conclusion, the VetK showed that continuous practice throughout life can preserve the quality of the neuromuscular activity in the control of kicking performance. In fact, the Vetk and YgK show a similar pattern for controlling and coordinating their muscles when they perform the *mae-geri* kick. However, the older practitioners show a few adaptations in the onset time to the recruitment of hip muscles. This could be related to a loss of transmission velocity in the nervous system and a loss in the excitation capacity and contractile capacity of the muscles due to aging.

The similar intensity of muscular activity, with the exception of the *Rectus Femoris* and *Biceps Femoris*, and the similar times of intermuscular delay and co-contraction periods in almost all of the pairs of analyzed muscles in the two groups, can also confirm the conclusion that Karate practice by elderly people mitigates the aging effects and can contribute to a better quality of life.

The presented and discussed findings confirm the formulated hypothesis that continuous and regular karate practice will reduce the effects of aging process on neuromuscular activity in older karate practitioners, preventing and attenuating the decrease in neuromuscular activity. So it is reasonable to assume that the improvement of body balance and the prevention of falls are important benefits of karate practice by middle-aged and elderly people, and that continuous Karate practice might be beneficial for the functionality of neuromuscular activity.

Acknowledgments

References

[1] Holviala, J., Kraemer, W. J., Sillanpää, E., Karppinen, H., Avela, J., Kauhanen, A., Häkkinen, A., and Häkkinen, K. 2012. "Effects of Strength, Endurance and Combined Training on Muscle Strength, Walking Speed and Dynamic Balance in Aging Men." *European Journal of Applied Physiology* 112 (4): 1335-47.

[2] Häkkinen, K. 1994. "Neuromuscular Adaptation during Strength Training, Aging, Detraining and Immobilization: A Review." *Critical Reviews in Physical and Rehabilitation Medicine* 6: 161-98.

[3] Jozsi, A. C., Campbell, W. W., Joseph, L., Davey, S. L., and Evans, W. J. 1999. "Changes in Power with Resistance Training in Older and Younger Men and Women." *The Journals of Gerontology: Series A, Biological Sciences and Medical Sciences* 54 (11): M591-6.

[4] Brooks, S. V., and Faulkner, J. A. 1994. "Skeletal Muscle Weakness in Old Age: Underlying Mechanisms." *Medicine and Science in Sports and Exercise* 26 (4): 432-9.

[5] Doherty, T. J., Vandervoort, A. A., Taylor, A. W., and Brown, W. F. 1993. "Effects of Motor Unit Losses on Strength in Older Men and Women." *Journal of Applied Physiology* 74 (2): 868-74.

[6] Faulkner, J. A., Larkin, L. M., Claflin, D. R., and Brooks, S. V. 2007. "Age-Related Changes in the Structure and Function of Skeletal Muscles." *Clinical and Experimental Pharmacology and Physiology* 34 (11): 1091-6.

[7] Eluamai, A., and Brooks, K. 2013. "Effect of Aerobic Exercise on Mitochondrial DNA and Aging." *Journal of Exercise Science and Fitness* 11 (1): 1-5.

[8] Barazzoni, R, Short, K. R., and Nair, K. S. 2000. "Effects of Aging on Mitochondrial DNA Copy Number and Cytochrome C Oxidase Gene Expression in Rat Skeletal Muscle, Liver, and Heart." *The Journal of Biological Chemistry* 275 (5): 3343-7.

[9] Horak, F. B. 2006. "Postural Orientation and Equilibrium: What Do We Need to Know about Neural Control of Balance to Prevent Falls?" *Age and Ageing* 35 (S2): ii7-11.

[10] Jiménez-Jiménez, F. J., Calleja, M., Alonso-Navarro, H., Rubio, L., Navacerrada, F., Pilo-de-la-Fuente, B., Plaza-Nieto, J. F., Arroyo-Solera, M., García-Ruiz, P. J., García-Martín, E., and Agúndez, J. A. 2011. "Influence of Age and Gender in Motor Performance in Healthy Subjects." *Journal of the Neurological Sciences* 302 (1-2): 72-80.

[11] Lord, S. R. 2006. "Visual Risk Factors for Falls in Older People." *Age and Ageing* 35 (S2): ii42-5.

[12] Matheson, A. J., Darlington, C. L., and Smith, P. F. 1999. "Dizziness in the Elderly and Age-Related Degeneration of the Vestibular System." *New Zealand Journal of Psychology* 28 (1): 10-6.

[13] Whipple, R., Wolfson, L., Derby, C., Singh, D., and Tobin, J. 1993. "Altered Sensory Function and Balance in Older Persons." *Journal of Gerontology* 48 (Sep): 71-6.

[14] Rand, M. K., and Stelmach, G. E. 2012. "Effect of Aging on Coordinated Eye and Hand Movements with Two-Segment Sequence." *Motor Control* 16 (4): 447-65.

[15] Kenney, W. L., Wilmore, J., and Costill, D. 2012. *Physiology of Sport and Exercise* (5th ed.). Champaign: Human Kinetics.

[16] Jagga, M., Lehri, A., and Verma, S. K. 2011. "Effect of Aging and Anthropometric Measurements on Nerve Conduction Properties—A Review." *Journal of Exercise Science and Physiotherapy* 7 (1): 1-10.

[17] Sato, A., Sato, Y., and Suzuki, H. 1985. "Aging Effects on Conduction Velocities of Myelinated and Unmyelinated Fibers of Peripheral Nerves." *Neuroscience Letters* 53 (1): 15-20.

[18] Stetson, D. S., Albers, J. W., Silverstein, B. A., and Wolfe, R. A. 1992. "Effects of Age, Sex, and Anthropometric Factors on Nerve Conduction Measures." *Muscle and Nerve* 15 (10): 1095-104.

[19] VanPutte, C. L., Regan, J. L., Russo, A. F., Seeley, R. R., Stephens, T. D., and Tate, P. 2014. *Seeley's Anatomy and Physiology* (10th ed.). London: McGraw-Hill.

[20] Proske, U., and Gandevia, S. C. 2012. "The Proprioceptive Senses: Their Roles in Signaling Body Shape, Body Position and Movement, and Muscle Force." *Physiological Reviews* 92 (4): 1651-97.

[21] Kellis, E., Arabatzi, F., and Papadopoulos, C. 2003. "Muscle Co-activation around the Knee in Drop Jumping Using the Co-contraction Index." *Journal of Electromyography and Kinesiology* 13 (3): 229-38.

[22] Klein, C. S., Rice, C. L., and Marsh, G. D. 2001. "Normalized Force, Activation, and Coactivation in the Arm Muscles of Young and Old Men." *Journal of Applied Physiology* 91 (3): 1341-9.

[23] Basmajian, J. V. 1997. "Motor Learning and Control: A Working Hypothesis." *Archives of Physical Medicine and Rehabilitation* 58 (1): 38-41.

[24] Vandervoort, A. A. 2002. "Aging of the Human Neuromuscular System." *Muscle and Nerve* 25 (1): 17-25.

[25] Bautmans, I., Vantieghem, S., Gorus, E., Grazzini, Y. R., Fierens, Y., Pool- Goudzwaard, A., and Mets, T. 2011. "Age-related Differences in Premovement Antagonist Muscle Co-activation and Reaction-time Performance." *Experimental Gerontology* 46 (8): 637-42.

[26] Franz, J. R., and Kram, R. 2012. "How Does Age Affect Leg Muscle Activity/Coactivity during Uphill and Downhill Walking?" *Gait and Posture*, 37, 378–384. doi: 10.1016/j.gaitpost.2012.08.004.

[27] Peterson, D. S., and Martin, P. E. 2010. "Effects of Age and Walking Speed on Coactivation and Cost of Walking in Healthy Adults." *Gait and Posture* 31 (3): 355-9.

[28] Buchman, A. S., Leurgans, S., Gottlieb, G. L., Chen, C. H., Almeida, G. L., and Corcos, D. M. 2000. "Effect of Age and Gender in the Control of Elbow Flexion Movements." *Journal of Motor Behavior* 32 (4): 391-9.

[29] Seidler, R. D., Alberts, J. L., and Stelmach, G. E. 2002. "Changes in Multi-joint Performance with Age." *Motor Control* 6 (1): 19-31.

[30] Kallio, J., Søgaard, K., Avela, J., Komi, P., Selänne, H., and Linnamo, V. 2012. "Age-related Decreases in Motor Unit Discharge Rate and Force Control during Isometric Plantar Flexion." *Journal of Electromyography and Kinesiology* 22 (6): 983-9.

[31] Mau-Moeller, A., Behrens, M., Lindner, T., Bader, B., and Bruhn, S. 2013. "Age-related Changes in Neuromuscular Function of the Quadriceps Muscle in Physically Active Adults." *Journal of Electromyography and Kinesiology* 23 (3): 640-8.

[32] Baker, M. K., Atlantis, E., and Fiatarone Singh, M. A. 2007. "Multi-modal Exercise Programs for Older Adults." *Age and Ageing* 36 (4): 375-81.

[33] Barry, B. K., and Carson, R. G. 2004. "Transfer of Resistance Training to Enhance Rapid Coordinated Force Production by Older Adults." *Experimental Brain Research* 159 (2): 225-38.

[34] Caserotti, P. 2010. "Strength Training in Older Adults: Changes in Mechanical Musclefunction and Functional Performance." *The Open Sports Sciences Journal* 3: 62-6.

[35] Gatts, S. K., and Woollacott, M. H. 2006. "Neural

Mechanisms Underlying Balance Improvement with Short Term Tai Chi Training." *Aging Clinical and Experimental Research*, 18 (1): 7-19.

[36] Pons van Dijk, G., Lenssen, A. F., Leffers, P., Kingma, H., and Lodder, J. 2013. "Taekwondo Training Improves Balance in Volunteers over 40." *Frontiers in Aging Neuroscience* 5: 1-6.

[37] Brudnak, M. A., Dundero, D., and Van Hecke, F. M. 2002. "Are the "Hard" Martial Arts, such as the Korean Martial Art, Taekwon-do, of Benefit to Senior Citizens?" *Medical Hypotheses* 59 (4): 485-91.

[38] Gulledge, J. K., and Dapena, J. 2008. "A Comparison of the Reverse and Power Punches in Oriental Martial Arts." *Journal of Sports Sciences* 26 (2): 189-96.

[39] VencesBrito, A. M., Rodrigues Ferreira, M. A., Cortes, N., Fernandes, O., and Pezarat-Correia, P. 2011. "Kinematic and Electromyographic Analyses of a Karate Punch." *Journal of Electromyography and Kinesiology* 21 (6): 1023-9.

[40] Witte, K., Emmermacher, P., Hofmann, M., Schwab, K., and Witte, H. 2005. "Electromyographic Researches of Gyaku-zuki in Karate Kumite." In *Proceedings of XXIII International Symposium on Biomechanics in Sports,* edited by Wang, Q. Beijing, China: The People Sport Press, 861-5.

[41] Balsalobre-Fernández, C., Martínez-Majolero, V., Villacieros-Rodríguez, J., and Tejero-González, C. M. 2013. "Differences in the Vertical Jump and the Speed of Kick maegeri between International and National Karatekas." *Revista de Artes Marciales Asiáticas*, 8:13–20. doi: 10.18002/rama.v8i1.835. (in Spanish)

[42] Quinzi, F., Camomilla, V., Felici, F., Di Mario, A., and Sbriccoli, P. 2013. "Differences in Neuromuscular Control between Impact and no Impact Roundhouse Kick in Athletes of Different Skill Levels." *Journal of Electromyography and Kinesiology* 23 (1): 140-50.

[43] Quinzi, F., Sbriccoli, P., Alderson, J., Di Mario, A., and Camomilla, V. 2014. "Intra-limb Coordination in Karate Kicking: Effect of Impacting or not Impacting a Target." *Human Movement Science* 33: 108-19.

[44] Quinzi, F., Camomilla, V., Felici, F., Di Mario, A., and Sbriccoli, P. 2015. "Agonist and Antagonist Muscle Activation in Elite Athletes: Influence of Age." *European Journal of Applied Physiology* 115 (1): 47-56.

[45] VencesBrito, A. M., Branco, M. A. C., Fernandes, R. M. C., Rodrigues Ferreira, M. A., Fernandes, O. J. S. M., Figueiredo, A. A. A., and Cynarski, W. J. 2014. "Electromyography and Cinematic Evaluation of the Kick Mae-geri in Competitive Elite Karate and Karate not Competitors Black belt." *Revista UIIPS* 2: 84-103. (in Portuguese)

[46] Hermens, H. J., Freriks, B., Merletti, R., Stegeman, D., Blok, J., Rau, G., Disselhorst-Klug, C., and Hagg, G. 1999. *European Recommendations for Surface Electromyography: Results of the SENIAM Project.* Enschede, Netherlands: Roessingh Research and Development.

[47] Ball, N., and Scurr, J. C. 2011. "Efficacy of Current and Novel Electromyographic Normalization Methods for Lower Limb High-speed Muscle Actions." *European Journal of Sport Science* 11 (6): 447-56.

[48] Konrad, P. 2005. *The ABC of EMG. A Practical Introduction to Kinesiological Electromyography.* Scottsdale, Arizona: Noraxon U.S.A. Inc.

[49] Winter, D. A. 2009. *Biomechanics and Motor Control of Human Movement* (4th ed.). Hoboken, NJ: Wiley.

[50] VencesBrito, A. 2012. "Kinesiological Characterization of Choku-tsuki Executed with Impact and Compared to the Execution without Impact." *Revista de Artes Marciales Asiáticas* 7 (1): 12-25. (in Portuguese)

[51] McGill, S. M., Chaimberg, J. D., Frost, D. M., and Fenwick, C. M. 2010. "Evidence of a Double Peak in Muscle Activation to Enhance Strike Speed and Force: An Example with Elite Mixed Martial Arts Fighters." *Journal of Strength and Conditioning Research* 24 (2): 348-57.