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12 authors, including:

Annamaria Petito
Università degli studi di Foggia

Antonio Ivano Triggiani
Università degli studi di Foggia

Laura Capranica
Italian University of Sport and Movement "Fo…

Marcellino Monda
Second University of Naples

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ORIGINAL ARTICLE

Differences in corticospinal system activity and reaction response between karate athletes and non-athletes

Fiorenzo Moscatelli[1,2] · Giovanni Messina[1,3] · Anna Valenzano[1] · Annamaria Petito[1] · Antonio Ivano Triggiani[1] · Antonietta Messina[3] · Vincenzo Monda[3] · Andrea Viggiano[4] · Vincenzo De Luca[5] · Laura Capranica[2] · Marcellino Monda[3] · Giuseppe Cibelli[1]

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Abstract The aim of this study was to verify the hypothesis that transcranial magnetic stimulation (TMS) parameters over the hand region of the motor cortex, such as resting motor threshold (rMT) and motor evoked potential (MEP) latency, predict the behavioural performance of karate athletes in the response time (RT) test. Twenty-five male karate athletes (24.9 ± 4.9 years) and 25 matched non-athletes (26.2 ± 4.5 years) were recruited. Using TMS, we investigated cortico-spinal system excitability. Compared with controls, the athletes showed faster RT ($p < 0.001$), lower rMT ($p < 0.01$), shorter MEP latency ($p < 0.01$), and higher MEP amplitude ($p < 0.01$); moreover, there was a significant positive linear correlation between RT and rMT ($p < 0.001$), between RT and MEP latency ($p < 0.0001$), and a negative correlation between RT and MEP amplitude ($p < 0.001$). The practice of competitive sports affects both the central and peripheral nervous system. Subjects that showed higher cortical excitability showed also higher velocity, at which the neural signal is propagated from the motor cortex to the muscle and consequently better RT. The lower rMT and the shorter MEP latency observed in athletes support the effects of training in determining specific brain organizations to meet specific sport challenges.

Keywords Cortical excitability · Reaction time · Transcranial magnetic stimulation · Karate

Introduction

Karate is a discipline of martial art requiring high technical skills, such as a fine control of movement both in static and dynamic conditions along with a great ability to perform the main technical actions (strikes and kicks) as fast as possible [1]. During a karate match, the athletes perform very complex actions which must be fast and accurate, thus this discipline is a good example of a competitive sport with high levels of temporal and spatial constraints which require fast reactions. In fact, in sparring (''kumite'') and matches of karate, two athletes face each other within a 2-m distance, making offensive attacks against each other [2]. Roberts et al. showed that even when the task (i.e., karate punch) does not involve anticipation or decision making, expert–novice differences are evident in motor control (e.g., peak hand velocity) and have been attributed to the microstructure of white matter in the cerebellum (i.e., superior cerebellar peduncles) and motor cortex [3]. The primary motor cortex (M1) is a complex network of interconnected localized groups of neurons with similar inputs and outputs, aimed to control movements [4]. The role of the M1 is to generate neural impulses that control the execution of movement [2]. Heavily involved in voluntary contraction of skeletal muscles, the M1 shows a high degree of plasticity and adaptation due to motor

✉ Giovanni Messina
gianni.messina@unina2.it

[1] Department of Clinical and Experimental Medicine, University of Foggia, Foggia, Italy

[2] Department of Motor, Human and Health Science, University of Rome, "Foro Italico", Rome, Italy

[3] Department of Experimental Medicine, Section of Human Physiology and Unit of Dietetics and Sports Medicine, Second University of Naples, Naples, Italy

[4] Department of Medicine and Surgery, University of Salerno, via Allende snc, Baronissi, SA, Italy

[5] Department of Psychiatry, University of Toronto, Toronto, Canada

learning and practice [5, 6], which produces modifications in the number of synapses, synaptic strength, and topography of stimulus-evoked movement representations [7]. In particular, training induces persistent-encoded behaviors within the adult nervous system [8, 9] to allow the precise execution of difficult motor tasks [10]. By requiring a high level of coordination for the precise execution of technical skills in static and dynamic conditions, karate could represent a valuable model to investigate the effects of chronic training on the corticospinal system excitability of athletes.

Excellence in sport performance requires not only physical and motor capabilities, but also sensory-cognitive skills. The majority of sports is performed under conditions of stress, because of the physical demands, psychological demands, environmental demands, expectations, and pressure to perform high-level performances [11]. Under such conditions, the athlete's ability to quickly and accurately pick up relevant information will reduce the time of making a decision [12]. In sport, acyclic rapidity is the ability to perform a single movement in the shortest time and it is a crucial skill in sports like karate: the analysis of contact times is an effective means to evaluate athletes' acyclic rapidity and it was recently used to quantify the performance of athletes [13]. The reaction time (RT) and anticipatory skill are critical aspects of perceptual abilities that have been considered advantageous to the player's successful performance [14]. In fact, authors consider RT as a key strategy in competitive sports which require fast reactions, such as karate and sprint events of athletics [15]. As non-invasive techniques, transcranial magnetic stimulation (TMS) and neuroimaging techniques have been largely used to investigate adaptive changes in human motor cortex [16, 17], contributing to understand how networks in the brain build and to optimize the motor programs responsible for coordination of muscle activity involved in complex motor learning [8]. Due to the measurable characteristics of the MEP from peripheral muscles, motor cortex excitability has become the most common topic in TMS studies [18]. Evidence of adaptations within motor cortex that shares characteristics with motor learning (e.g., the retention of a newly acquired skill) has been found in response to repetitive practice of simple movements, such as ballistic movements of the digits, and the improvement in task performance was accompanied by an immediate increase in MEP response [19]. Another study examined whether a single session of strength training induces similar corticospinal system activity changes to those found in the early phase of ballistic motor learning [20]. These authors conclude that a single session of strength training shares similar neural changes to ballistic motor learning by providing evidence of a shift in TMS-induced twitch force direction toward the training direction. The potential for reorganization of functional representation in the sensorimotor cortex is well described and is supported by a number of experimental studies [20, 21]. Evidence for the effects of motor training and skill acquisition on the functional representation of the hand has come from studies on the monkeys and in subjects learning a one-handed five-finger exercise on the piano [22]. With the method of TMS, corticospinal excitability has been tested during the phases of a motor training, where the training-induced changes are reflected in an increase of MEP over trained muscles. It has been shown that even a short training period (some minutes) induces changes in cortical excitability, lasting several minutes after the training session [23]; however, no study investigated the effect of long-term training effect. The aim of this study was to examine the differences between karate athletes and non-athletes in resting motor threshold (rMT) and MEP responses, and to analyze the relationships between neural activity in M1 and reaction response performance. Therefore, we hypothesized that athletes might show different cortical excitability in resting condition compared with non-athletes, and that such a difference might be correlated to reaction response performances, thereby proving that better performances would reflect higher cortical excitability.

Materials and methods

Subjects

Twenty-five right-handed male karate athletes (24.9 ± 4.9 years) and 25 matched non-athletes (26.2 ± 4.5 years) were recruited (Table 1). All procedures conformed to the directives of the Declaration of Helsinki. The karate athletes were members of the Foggia karate team (Italy), all black belts, regularly competing at national and international levels and undergoing a training regimen of at least five 2-h sessions week^{-1} for the previous 5 years. The controls declared to be not engaged in any competitive or amateur sports. Subjects were asked not to perform any physical activity in the 2 days before the recordings. The Institutional Ethics Committee of the University of Foggia approved the study. Participants were provided with comprehensive information regarding the

Table 1 Anthropometric characteristics

Parameter	Karate athletes	Non-athletes	p value
Age (year)	24.9 ± 4.9	26.2 ± 4.5	>0.05
Height (cm)	176.1 ± 3.9	176.3 ± 7.2	>0.05
Body mass (kg)	78.1 ± 11.4	80.7 ± 10.4	>0.05

Values are expressed in mean ± standard deviation possible risks and discomforts due to TMS, and were ensured that they were free to withdraw from the study at any time. Furthermore, a medical examination ascertained the absence of psychoactive or vasoactive medication assumption, and risk factors or other contraindication to TMS [24]. All subjects gave their written informed consent before participation.

Methodology

To minimize possible circadian influences, measurements were performed at the time between 14 and 16 h. Participants seated in comfortable armchair, in a quiet room, with their right hand stabilized and supported during the exam with the elbow positioned at 90° flexion, to have the same muscle length during electromyography (EMG) recording. The motor cortex excitability was evaluated using a 70-mm figure-of-eight coil connected to a Magstim Rapid^2 (maximum output 2.2 T) Transcranial Magnetic Stimulator (The Magstim Company Ltd, UK), placed over the left motor cortex. A mechanical arm maintained the handle of the coil tangential to the scalp with the handle pointing backward at 45° away from the midline while delivering the stimulus. The location of the stimulation was identified on each subject's scalp using the SofTaxic navigator system (E.M.S. Italy, http://www.emsmedical.net). Individual rMT was determined from the left motor cortex, according to a standardized procedure [18]. Evoked muscle responses at rMT condition were acquired by surface EMG, and were recorded using the BioPack MP150 (BIOPAC Systems, Inc., CA, USA) and the raw EMG signal processed and analyzed by the Acknowledge software, version 4.1 (BIOPAC Systems, Inc., CA, USA) with a high-pass filter (frequency cutoff: 10 Hz). Surface electrodes (diameter: 1 cm) were placed over the first dorsal interosseus FDI muscle (active electrode) and over the associated joint or tendon (reference electrode) in a classical belly tendon montage, whereas the ground electrode was placed over the dorsal part of the forearm. In this study, we consider three neurophysiological parameters: rMT, MEP latency, and MEP amplitude. MEP is an electrical potential that can be recorded from a muscle following direct stimulation of the motor cortex using TMS. TMS-induced MEPs can be elicited in a target muscle only above a given stimulation intensity, termed resting motor threshold. This threshold is defined as the minimum stimulation intensity needed to elicit an MEP of at least 50 μV with 50 % probability in a fully relaxed muscle and is different between individuals and different muscle groups. The rMT was measured at complete rest and was expressed as a percentage of the maximal stimulator output. The MEP latency is a measure of central motor conduction time and the velocity at which the neural signal is propagated from the motor cortex to the muscle. The MEP amplitude provides a measure of the magnitude of corticospinal excitability.

The Cambridge Neuropsychological Test Automated Battery (CANTAB) is a computer administered battery of tasks [25]. After a brief practice exercise using the Motor Control Task (MOT) test, simple reaction time test (RTI) was administered. MOT is considered a user-friendly way to introduce the CANTAB touch screen to the participants. Participants touch a series of flashing crosses displayed sequentially on the screen. This brief exercise is designed to familiarize participants with the touch screen interface and to reveal any problem in vision, movement, or comprehension that could affect the performance.

RTI is a measure of response time, movement time, and vigilance during the test. Using their dominant hand, the participants must respond to a yellow spot appearing on the screen by letting go of the press pad button and touching the location, in which the spot appeared. The subjects were instructed to respond as quickly as possible to a visual stimulus. The analyzed output variable is mean reaction response time.

Statistical analysis

Statistical analyses were performed by the R Project for Statistical Computing (version 3.1.0). Descriptive and outcome statistics are presented as mean (M) ± standard deviation (SD), and statistical significance was set at $p < 0.05$. The Shapiro–Wilk test was used to check the normal distribution of variables. Cohen's effect sizes (ES) were also calculated. An ES ≤ 0.2 was considered trivial, from 0.3 to 0.6 small, <1.2 moderate, and >1.2 large. The t test was used to investigate the differences between two groups. Linear regression analysis was performed to investigate the relationship between rMT and RT, between MEP Latency and RT, and between MEP amplitude and RT.

Results

No discomfort or adverse effects during TMS were noticed or reported.

Compared with controls, karate athletes showed lower rMT (57.1 ± 4.2 vs 64.9 ± 4.6 % of max stimulator output; $p < 0.01$; ES = 1.8), shorter MEP latency (22.2 ± 1.5 vs 24.8 ± 1.0 ms; $p < 0.01$; ES = 2.0), and higher MEP amplitude (0.90 ± 0.25 vs 0.51 ± 0.12 mv; $p < 0.01$; ES = 1.9) (Fig. 1).

The reaction time response was shorter in karate athletes compared with non-athletes (371.5 ± 21.6 vs 431.1 ± 20.0 ms; ES = 2.8; $p < 0.001$) (Fig. 2).

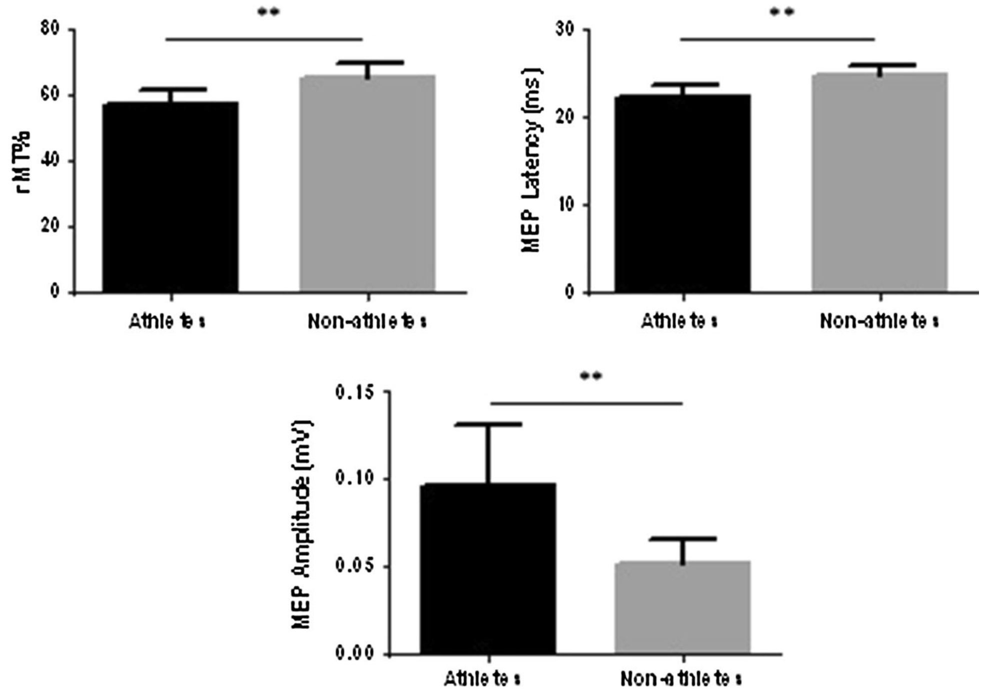

Fig. 1 Resting motor threshold (rMT %), evoked potential (MEP) latency (ms) and motor evoked potential amplitude (mV) in karate athletes and in non-athletes. Values are expressed in mean ± standard deviation. *$p < 0.01$

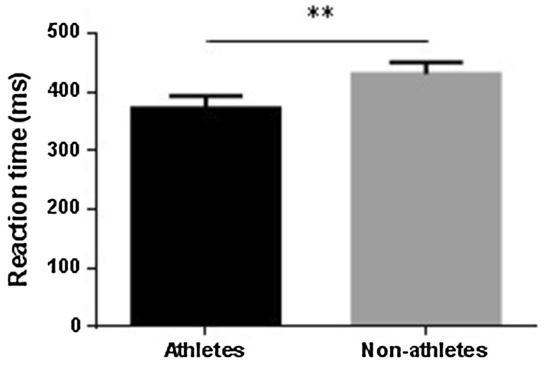

Fig. 2 Visual reaction time (ms) in karate athletes and in non-athletes. Values are expressed in mean ± standard deviation. *$p < 0.01$

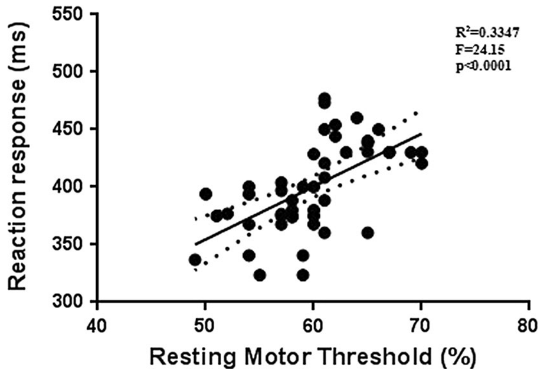

Fig. 3 Correlation between reaction time (ms) and rMT % in all participants

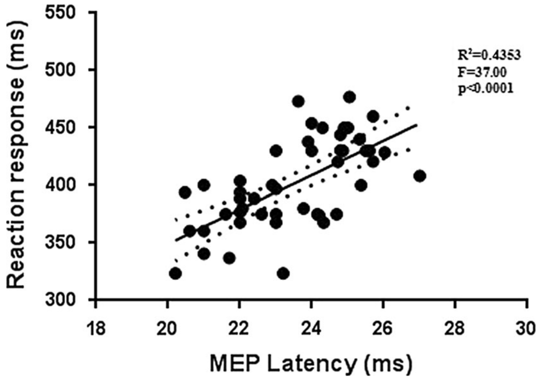

Fig. 4 Correlation between reaction time (ms) and MEP latency (ms) in all participants

The data from all subjects of both groups showed a significant correlation between RT and rMT ($p < 0.001$) (Fig. 3), between RT and MEP latency ($p < 0.0001$) (Fig. 4), and between RT and MEP amplitude (Fig. 5); these correlations did not differ between the two groups (data not shown).

Discussion

The results of this study demonstrated that a chronic training results in a faster RT, a lower rMT, a shorter MEP latency, and a higher MEP amplitude. These results are in agreement with other literature data. In fact, the athletes, especially those engaged in combat sports, execute motor movements under pressure, because they have to respond

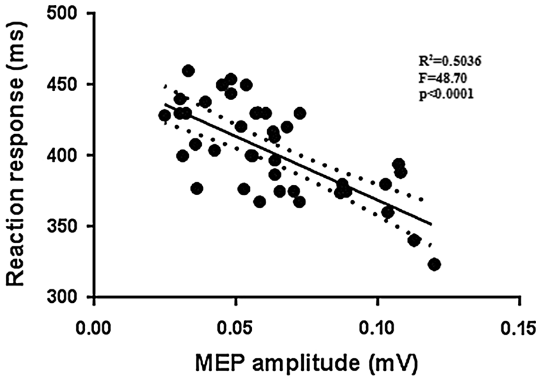

Fig. 5 Correlation between reaction time (ms) and MEP amplitude (mV) in all participants

as quickly as possible to sequence of opponents attacks [26]. Furthermore, these rapid movements occur mainly automatically and are based on a long-learning process [26]. Moreover, Mori et al., found significant differences between karate athletes and non-athletes in basic motor visual task [14]. In this study, the author showed that the athletes responded faster than the novices in the video-stimulus RT, which simulated the real stimuli and task of karate, indicating a superior anticipation of the athletes regarding the opponent's attack [27]. Our results are in agreement with the results show from Mori et al. In fact, karate athletes showed a better RT compared with controls [28]. In fact, athletes showed also higher cortical excitability compared with non-athletes. It can be argued that this difference results from better skills due to training. Physical exercises as well as motor skill learning have been shown to induce changes in regional brain morphology, and this has been demonstrated for various activities and tasks, such as moderate aerobic exercise [29], or learning how to juggle and practicing golf [30]. Using voxel-based morphometry, Taubert et al., for example, showed that practicing a balancing task over a period of 6 weeks was associated with an increase of gray matter in the left supplementary motor area as well as the dorsolateral prefrontal cortex bilaterally [31]. Animal studies provide evidence for various mechanisms underlying neuroplasticity associated with exercise and motor learning, such as angiogenesis, synaptogenesis, and neurogenesis [32]. Brain plasticity refers to changes in the organization of the brain as a result of different environmental stimuli [19]. In motor plasticity paradigms, several behavioural factors (e.g., the initial level of proficiency, rate of improvement and the final level of attainment) have been identified as influencing the variability of individual response to the plasticity inducing protocols [33], the different functional outcomes after neurological injury [34, 35], and the effectiveness of rehabilitation or training [36]. The decrease in cortical motor threshold found in athletes suggests changes in the excitability of the corticospinal projection to the playing hand. A change in corticomotor threshold may arise from a shift in the balance between inhibitory and excitatory inputs to cortical or spinal motorneurones.

The results of our study suggest that, in the athletes group, there is a change in the level of cortical and/or spinal excitability. According to the literature, this mechanism can include the establishment of new connections and/or alterations in the effectiveness of previously existing connections. It seems that long-term potentiation, known to occur in the hippocampus, can also occur in the motor cortex with the learning and retention of motor skills. In fact, other authors using TMS investigated the corticomotor representation of a hand muscle in a group of highly skilled elite racquet players, and compared the findings with those in a group of social players and a group of non-playing control subjects [37]. These authors found an increase in corticomotor excitability of the playing hand and changes in the topography of the cortical motor map for the playing hand, which were not seen in a group of social players. These alterations point to the occurrence of long-term functional changes in the motor cortex or corticomotor pathway, which may be associated with the acquisition and retention of complex motor skills [2].

Considering the whole population, linear regression was significant between RT and rMT, between RT and MEP latency, and between RT and MEP amplitude. Moreover, as shown in Figs. 3, 4, and 5, athletes deal more the lower part of the linear regression line. Thus, these data suggest that sport practice can play a role to influence rMT and MEP latency, and that these parameters predict the sport performance. These results appear to be due to neural plasticity. The practice of competitive sports affects both the central and peripheral nervous system. Subjects that showed higher cortical excitability also showed higher velocity at which the neural signal is propagated from the motor cortex to the muscle and consequently better RT. In particular, the lower rMT, the shorter MEP latency, and the higher muscle response (MEP amplitude) observed in karate athletes supports the effects of training in determining specific brain organizations to meet specific sport challenges [2]. In fact our results, according to literature [38], demonstrate that the changes in motor performance that result from training are the result of changes in synaptic activity and/or cortical reorganization (i.e., neural plasticity) caused by the repeated activation of specific neural networks and the strength of the activations of those networks, then it follows that larger neural activations should lead to a greater reorganization than smaller activations when the number of activations is equivalent. Therefore, the acquisition and maintenance of specific motor skills can associated with plastic changes in the controlling neural system.

In conclusion, the present findings showed changes in the motor cortex excitability in the representation of the corticospinal projections to the hand in a group of karate athletes. Furthermore, the correlation found between RT and physiological parameters suggests that rMT, MEP latency, and MEP amplitude can influence the RT. Thus, the differences found between the two experimental groups suggest that long-term reinforcement and constructive practice of motor training can lead to functional plasticity of the corticomotor projections [2]. The differences found in our study could be caused by better cortical connectivity due to training. In fact, the adult brain has the ability to modify its organization (Brain plasticity) through physiological mechanisms, such as the repetitions of simple movements. However, in a changing environment, brain plasticity enables the nervous system to ensure that proper activation of muscles may be acquired and maintained to serve the behavioural goal, and recently, a genetic component has been observed for brain plasticity [19]. Therefore, further studies are needed to clarify the nature of the differences emerged in cortical excitability between trained and untrained subjects.

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Compliance with ethical standards

Conflict of interest None.

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