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ARTICLE

Levels of Gnostic Functions in Top Karate Athletes—A Pilot Study

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High-quality sensory perception and body scheme (somatognosis) are important aspects for sport performance. This study compares stereognosis, body scheme, and kinesthesia in a group of 36 competitive karate athletes against a control group of 32 general population participants. The stereognosis Petrie test, two body scheme tests, and three kinesthesia tests served as outcome measurement tools. No significant difference was found in the stereognosis Petrie test, for the dominant ($p = .389$) or the nondominant ($p = .791$) hand, nor in the kinesthesia test (dominant, $p = .661$ and nondominant, $p = .051$). Karate athletes performed significantly better in the body scheme tests, that is, fist width estimation ($p = .024$) and shoulder width estimation ($p = .019$), as well as in karate-specific kinesthesia tests, that is, single punch ($p = .010$) and triple punch ($p = .001$). This study confirms competitive karate athletes have significantly better somatognosis, and better accuracy when performing quick dynamic movements compared with the general population.

***Keywords*:** proprioception, body scheme, kinesthesia, stereognosis

Karate is a very physically demanding sport that requires specific skills, such as prompt reaction, speed, agility, strength, balance, precision, and coordination (Chang et al., 2018; Imamura et al., 2002; Thomas & Ornstein, 2018). Reaction skills are especially important in Kumite (Lisowska et al., 2021; Petri et al., 2019). When performing Kumite, two karate athletes compete in sparring using techniques that vary in styles that can include striking, kicking, and counter attacks (Padulo et al., 2014; Wen et al., 2020). Rapid sensory perception and motor responses determine the athletes' ability to defeat their opponent (Martínez de Quel et al., 2020). Optimal quick reaction requires intact sensory perception and processing, prompt decision making, and precise motor response. The rapid

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movement between two athletes within a short distance (Quinzi et al., 2016) is dependent on the athletes' ability to read the gestures and movements of their opponent in order to process them and initiate an appropriate response (Hadad et al., 2020). Therefore, a quick reaction time is a crucial element in Kumite (Chaabène et al., 2012). Among other contributors, these quick reaction abilities may be related to the perception of one's own body in space. Motor control is hierarchically arranged incorporating multiple parts of the central nervous system that constantly process multisensory stimuli and control the movement accordingly (Buchholz et al., 2012; Kobesova & Kolar, 2014; Toutounji et al., 2011). Synthesis of sensory information collected from various receptors is processed in numerous central nervous system regions and results in complex gnostic functions which serve to recognize previously learned information relating to such things as objects, persons, places, and movements. Inputs from sensory and cognitive processes determine an individual's ability to acquire, master, adjust, and improve motor skills and abilities (Voelcker-Rehage, 2008). Movement planning is dependent on multisensory integration (Sober & Sabes, 2003). An individual must have a good understanding of his or her body in order to plan all movements well. The sensory input from one's body must be organized into an unambiguous "image." Information from the visual, tactile, proprioceptive, and vestibular systems are important components of forming this image (Ondra et al., 2017). Since all movements are directly associated to sensations, we can assume that the better the quality of multisensory perception and integration (Gadhvi & Waseem, 2021), the better the quality of movement (Kobesova & Kolar, 2014). Impaired motor control is related to increased risk of musculoskeletal injury (Chmielewski et al., 2021). There are numerous factors associated with the quality of sport performance, including physical, cognitive, emotional, and motivational factors (Smith, 2003). Sensory integration, motor planning, and coordination determine situational awareness (Kakavas et al., 2020). Acquisition of motor skills is dependent on neuronal plasticity both at the cortical and subcortical levels in the central nervous system (Kakavas et al., 2020). Therefore, we can speculate, that a high quality of gnostic function and ideomotor functions, and perfect body scheme is one prerequisite for athletic skill (Chmielewski et al., 2021).

However, it has not yet been clearly defined as to what the body scheme or perception of one's own body involves, how to evaluate it clinically, or how to address this aspect of possible impairment therapeutically. Even the terminology is inconsistent with the terms "body image," "body awareness," and "body scheme" being used interchangeably. The term "body image" is mostly defined as an individual's subjective picture of their body, irrespective of how their body actually looks and in medical literature this is mostly investigated in relation to psychological disorders, such as eating disorders (Hosseini & Padhy, 2021; Mento et al., 2021; O'Loghlen et al., 2021) or psychological consequences of conditions causing body dysmorphia (Bowie et al., 2021; Vani et al., 2021). The term "body awareness" is usually considered as an interpretation of proprioception and interoception in relation to mental processes (Mehling et al., 2011), cognitive, behavioral, emotional, and body–mind theories and concepts (Zeine, 2014). Body awareness training is frequently presented as mindfulness training or mind–body awareness training to increase the sense of well-being (Mehling et al., 2011). Yoga, tai chi, meditation, and other awareness-based practice training can be applied to improve the interaction with the environment (Mehling et al., 2011), to reduce anxiety, improve cognition (Sathyanarayanan et al., 2019), to provide psychological and pain-related benefits for patients suffering from a variety of conditions (Mehling et al., 2011). While interoception, a term not commonly used in correlation to these processes, relates to how the brain integrates the signals received from the body in such a way that allow a person to continuously adapt the physiological representation one holds of their own body, as is needed for things, such as homeostasis. And finally, the term "body scheme" can be understood as awareness of the relationship of body parts to one another. Body scheme, however, has also been referred to as somatognosis (Tichý, 2003). Both terms represent a more complex phenomena, where the recognition of the body scheme in humans is a dynamic image, enabling continuous awareness of our body, its parts, their functions, position, shape, and/or movements (Tichý, 2003). With this in mind, proprioception's role is understood to be a critical component of somatognosis, while interoception, and perception through other senses, such as tactile, vestibular, and visual feedback also play a role. The terms body scheme or somatognosis best represent the concepts explored in our study.

Kolar (2013) proposes that somatognosis analysis is important to correctly select a treatment program for movement dysfunctions and suggests that somatognosis tests need to become a consistent part of the clinical assessment. It was shown that body awareness integration within sport training helped to reduce musculoskeletal painful syndromes in a population of cross-country skiers (Kobesova et al., 2018). Good somatognostic function in an athletic population was previously reported by Kovac et al. (2020) who identified a significantly better performance in tests focusing on lower limb gnostic function in competitive racewalkers when comparing them with a nonathletic population. Therefore, the objective of this study was to compare the quality of gnostic functions in elite karate athletes with a control group of regular population not performing any type of sport on a competitive level. Somatognosis tests introduced by Kolar were used in this study (Kolar, 2013). We expected the karate athletes to have better quality of gnostic functions.

Material and Methods

Participants

Competitive karate athletes (males, $n = 14$ and females, $n = 22$) from the national team who have been practicing karate for at least 6 years were included in the study. The exclusion criteria were musculoskeletal pain, injury, infectious, or any other type of disease. The karate athletes were tested at a national club camp in 2020. Tests were performed at least 2 hr after their last training session to minimize the effect of training fatigue. The participants in the control group were people not actively engaged in any type of sport (males, $n = 14$ and females, $n = 19$). Each participant was tested for approximately 10 min in a private room to eliminate any auditory, visual, or other stimuli, which would cause distraction. Personal data were collected from each participant. The width of their dominant fist from the second to the fifth metacarpophalangeal joint and the width of their shoulders, that is, the distance between the acromion's was measured before the testing. Table 1 shows demographic data of the sample. A written informed consent was obtained from all participants. The study conforms with The Code of Ethics of the World Medical Association and was the study was approved by the ethics committee of the Slovak Medical University, Faculty of HealthCare, Banská Bystrica, number 2/2021.

Testing

Assessment of Hand Stereognosis (Petrie Test)

Two wooden blocks were used to assess hand stereognosis (Figure 1). This test is also called the Petrie test (Kolar, 2013). One wooden block is a square-based

Table 1 Descriptive Characteristics of Both Groups

	Karate group ($n = 36$)				General population control group ($n = 32$)					
Variable	Mean	*SD*	Min	Max	Mean	*SD*	Min	Max	*U*	*p* value
Age (years)	18.97	4.04	17	38	20.16	2.28	17	27	856	<.001
Height (cm)	171.43	9.16	158	190	173.81	11.17	154	98	649	.338
Weight (kg)	64.27	9.57	41	81	68.69	14.45	47	100	653	.341
Body mass index (kg/m^2)	21.79	2.05	17.87	28.02	22.59	3.66	18.2	39.1	639.5	.435
Fist width (cm)	8	0.74	7	9	8.03	0.74	7	10	634.5	.45
Shoulders width (cm)	36.08	3.21	30 41	36.08	36.48	3.38	30	42	614.5	.31

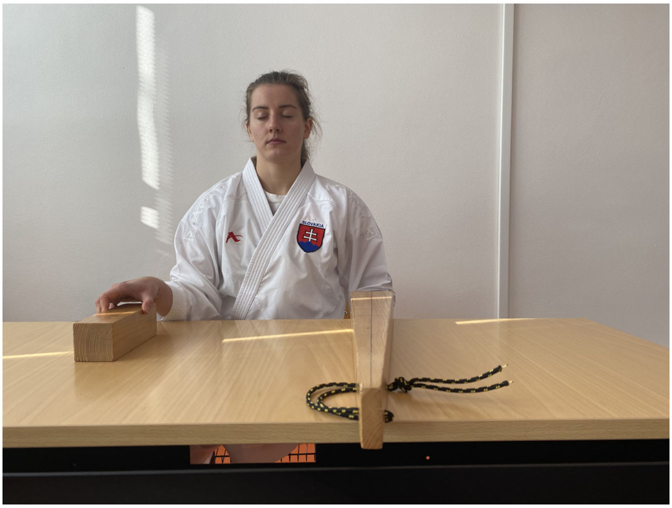

Figure 1 — Petrie hand stereognosis test.

cuboid shape with 20 cm × 6.8 cm × 6.8 cm dimensions. The other wooden block is 70 cm long, rectangular-based pyramid with a 10 cm × 6.8 cm base. The width is gradually slanted from 10 to 2 cm. The participant first palpated the cuboid block without any visual feedback, eyes closed, for 30 seconds to haptically remember the width of 6.8 cm, while trying to memorize the distance as accurately as possible using only their sense of touch. Afterwards, the participant palpated the tapering wooden block, trying to localize the width of the first wooden block (6.8 cm) as accurately as possible. Participants estimation (positive, negative, or zero) was measured and recorded (in millimeters). The positive deviation was indicated on the widening part and the negative deviation on the narrowing part of the wooden block. First, the test was performed by the dominant hand, followed immediately by the nondominant hand. There was one trial for each hand.

Body Scheme Assessments

The participant was asked to adopt the Heiko-dachi stance. Instructions were to close their eyes and keep them closed until instructed to open them again. Subsequently, the participant was instructed to raise both upper limbs to shoulder height with slight flexion at the elbow joints. With the upper limbs in this position, the participant delineated the width of his/her fist (from the second to the fifth metacarpophalangeal joint) using both index fingers (Figure 2). This test was performed one time and the distance between the index fingers was measured with a measuring tape (in centimeters). The observed deviation from the real width of the fist was recorded and used for statistical analysis.

Next, the assessment for shoulder width estimation was explored. The participant performed the test with their eyes closed. Adopting the Heiko-dachi stance, the participant demonstrated the width of his or her shoulders using their palms facing each other on a vertical axis (Figure 3). The distance shown between the palms was measured with a measuring tape comparing it with their true shoulder width, previously measured by the researcher as the distance between their two acromions. This test was performed once and the difference between real distance measured by the clinician and width estimated by the subject was used.

Upper-Extremity Kinesthesia Tests

The subject stood perpendicular to the wall. The distance from the wall was approximately the same as the length of their extended upper extremity. The subject adopted a Heiko-dachi stance (hip- to shoulder-width stance, knees in slight flexion, feet pointing straight ahead, and upper limbs relaxed). First, with their eyes open, participants touched an arbitrary point on the wall with the index finger (Figure 4). Then, with eyes closed, he/she aimed to touch the same point on the wall. The indicated point was marked and the distance between the two points was measured. The whole test was repeated twice for each side, first with their dominant hand and then with their nondominant hand, that is, four times in total. A mean value from the two trials for each hand was used for further statistical analysis.

Figure 2 — One's own fist width estimation test.

Karate-Specific Upper-Extremity Kinesthesia Tests

Strike Accuracy Test—Single Punch Test. During the test, the participants focused on one point on the wall at the height of their chin. The test was performed in a Heiko-dachi stance, with hands clenched into fists (Figure 5). The striking dominant upper limb was level with the point the subject was aiming at, the shoulder was kept in neutral position, the elbow in slight flexion, and the wrist in the neutral position. The impact surface of the Seiken strike was formed by the second and third metacarpophalangeal joints. The other hand was in the Hiki-te position. Only a strike that hit a point with the Seiken striking surface at a given level was considered a valid one. The test was composed of two phases: the preparation and the actual test phase. During the preparation phase, the participant memorized the arm position while touching the target and focusing on the position and height of the shoulder, elbow, and the striking knuckles. At this stage, the participant had their eyes open while

Figure 3 — One's own shoulder width estimation test.

punching the target 10 times with alternating hands. Then the test was performed with their eyes closed. The participant hit the target alternating hands (i.e., alternating right and left hand) attempting to hit the same point as in the preparatory phase, punching the target 10 times. The number of valid attempts was recorded.

Strike Accuracy Test—Triple Punch Test. The triple punch test increases the level of challenge by adding a component of accuracy. In this test, participants were required to punch three targets that were placed at various heights (Figure 6). The heights of the targets were set for each participant individually, to match them to appropriate heights. One target was set at the height of the participants chin, this target was called—Jodan, the second target was placed at torso height of the subject and called, Chudan. Finally, the third target was placed slightly below the waist level of the participant, and this target was called, Gedan. The test was composed of two phases: the preparation phase and the actual test phase. During

Figure 4 — Upper-extremity kinesthesia test.

the preparation phase, the participant rehearsed hitting the three targets with their eyes open, striking with alternating upper limbs with slight flexion at the elbow. The participant maintained the Heiko-dachi stance (see Figure 6) and hit each target five times adding up to 15 strikes executed at an arbitrary speed and frequency. During the testing phase, the participant, after given a verbal cue of "Jodan/up, Chudan/centre or Gedan/down" in random order executed the strikes aiming at the corresponding targets. The points on the wall remained in the same position and the participant stood in the same place adopting the same posture as in the preparation phase of the test, but this time performed the strikes with their eyes closed. The participant performed upper limb strikes alternating to 10 vocal commands, striking 10 blows at the points (Jodan, Chudan, and Gedan) randomly ordered by the examiner. Only a strike that hit a point with the Seiken striking surface was considered a valid one (Figure 7). The number of valid strikes out of 10 attempts was recorded and used for analysis.

Figure 5 — Strike accuracy test—single punch test.

Statistical Analysis

Descriptive statistics were used for statistical data processing. Statistical evaluation was performed using SPSS software (Version 20; IBM Corp., Armonk, NY). Shapiro–Wilk's test was used to test the normality of distribution. All measures showed a nonnormal distribution. The sample did not have a normal distribution, so the nonparametric Mann–Whitney *U* test test was used. Statistical significance was determined at a significance level of $\alpha = .05$.

Results

No significant intergroup difference was identified for dominant or nondominant hand in the Petrie Stereognosis test nor the kinesthesia test. The karate athletes group, however, performed significantly better in both body schemes tests, that is,

Figure 6 — Strike accuracy test—triple punch test.

karate athletes estimated both their fists width and shoulder width more accurately as compared with the control group of the general population participants. Also, in the karate-specific tests, that is, single punch test and triple punch test, the karate athletes performed significantly better compared with the control group of the general population participants. The results are shown in Table 2.

Discussion

The results of this study identified significantly better body schema and better striking accuracy when performing quick dynamic movements in karate athletes as compared with the general population participants not performing any type of sport regularly.

Research shows, that a close relationship exists between body perception, sensory integration, and movement (Buchholz et al., 2012; Sober & Sabes, 2003).

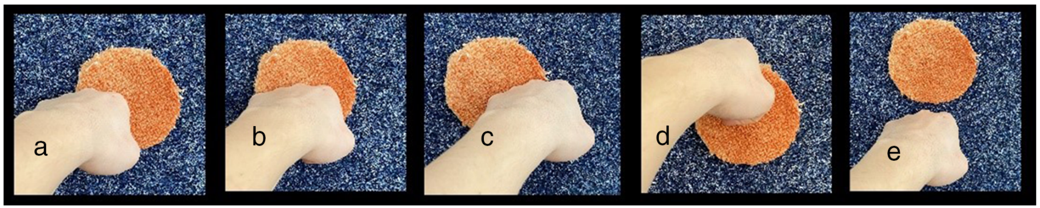

Figure 7 — Strike accuracy test—detail of the impact area of the Seiken surface consists of the second and third metacarpophalangeal joints. (a, b) A valid strike is recognized when the target represented by 9 cm diameter circle is hit with the Seiken strike surface. (c, d, e) Invalid strokes.

Table 2 Karate and General Population Control Groups Results

Test	Karate ($n = 36$)		General population ($n = 33$)		U	p value
	Dominant	Nondominant	Dominant	Nondominant		
Petrie (cm)	1.90 ± 3.48	1.85 ± 3.36	2.94 ± 6.19	1.34 ± 5.34	689	Dominant .389
					597.5	Nondominant .791
Kinesthesia (cm)	2.89 ± 1.77	2.64 ± 1.7	2.74 ± 1.26	3.04 ± 1.90	563	Dominant .695
					643	Nondominant .365
Fist width (cm)	0.83 ± 1.83		2.53 ± 3.84		758	.024*
Shoulder width (cm)	4.22 ± 6.32		8.68 ± 8.96		772.5	.019*
Single punch (points)	8.36 ± 1.62		7.03 ± 2.46		782.5	.010*
Triple punch (points)	5.81 ± 2.19		3.91 ± 2.15		304.5	.001*

Note. Values are provided as mean ± *SD*.
*Statistically significant difference observed $p < .05$.

This relationship is especially important when discussing proprioceptive senses and the role they play in providing one with continuous feedback about body shape, body position and movement, and muscle force (Proske & Gandevia, 2012). In the current study, elite karate athletes demonstrated better ability to proprioceptively estimate and show their body dimensions, that is, the width of their fists and shoulders, which means they could feel and "read" their body better than the general population.

Body scheme is used for controlling multisegment movements and the interaction with the surrounding space around us, in particular during human locomotion (Ivanenko et al., 2011). Karate consists of sets of very complex locomotion stereotypes. To act and move accurately, the nervous system must be able to read the shape and size of one's own body and its orientation in space. Long-term intensive training also affects skeletal anatomical parameters, especially with younger athletes (Song et al., 2018; Steinberg et al., 2017; Yang et al., 2014). Highly skilled female karate athletes with advanced technical efficiency, high basic, and specific motor efficiency were identified to have a wider wrist and fist diameter (Jukić et al., 2013). According to Jukić et al. (2012), dimensionality of the skeleton, particularly of the hand, significantly determines the fighting efficiency of a young female "karateka." It can therefore be said, that long-term high-intensity training causes adaptive changes both in function and in structure. High-level somatognostic function can be both the consequence of frequent intensive training but also a prerequisite to becoming an elite athlete, that is, it may be one component of sport skills which may also be genetically determined because elite sporting performance is a result of the interaction between several factors including genetic and training factors with deliberate practice playing a key role (Ericsson, 2004, 2008; Ericsson et al., 2009; Tucker & Collins, 2012). It should be clear, however, that when discussing somatognosis as body awareness, it is not merely interchangeable with proprioception. Somatognosis requires good tactile and vestibular information but also information from the body's internal organs (interoception) that provides the continuous input to know where a person is and the circumstances under which they exist in that space. In any case, it seems important to evaluate and train the body scheme, that is, somatognosis in competitive athletes. Kovac et al. (2020) confirmed that better lower limb gnostic function exists in competitive racewalkers when compared with a nonsporting population. However, it still needs to be determined if application of concepts targeting somatognosis, such as yoga, TaiChi, Feldenkrais, and the Alexander method or even meditation techniques focusing on perception, attention, and consciousness itself (Mehling et al., 2011), may possibly improve the quality of movement and sports performance. According to Naranjo and Schmidt (Naranjo & Schmidt, 2012), meditation practice improves the ability to monitor and optimize any necessary readjustment of a person's movement trajectory, leading to better motor performance (Naranjo & Schmidt, 2012).

In the Petrie test, which represents stereognosis, that is, the ability to identify the shape, size, and form of a three-dimensional object via tactile perception in the absence of visual stimuli (Schermann & Tadi, 2021), karate athletes scored better, but not significantly so, when performing the test with the dominant hand which may result from their preference to train and use primarily the dominant upper limb in sparring. The control group achieved better results when palpating the objects with the nondominant hand; however, the intergroup difference for both dominant and nondominant hand did not demonstrate statistical significance. To test manual stereognosis, the tactile object recognition test is mostly used (Schermann & Tadi, 2021). A subject is asked to recognize common objects, such as a pen, key, or comb placed in his or her hand while keeping their eyes closed. Such tests are suitable to diagnose patients with sensory dysfunction on any level of neural pathways or centers responsible for stereognostic function (receptors, peripheral nerves, spinal dorsal columns, or somatosensory cortex of the parietal lobe) but not sufficiently sensitive to appreciate the small differences in the quality of stereognosis. Here presented, although not a very well-known test, the Petrie test, is a test protocol that may serve such a purpose (Kolar & Lepsikova, 2013). It would be interesting to examine the quality of participants stereognosis using the Petrie test in sports that require perfect manual control such as juggling, rock climbing, or gymnastics and aerobics when positions with hand support are often applied. Similarly, it can be expected that individuals working in professions requiring perfect manual skills, such as watchmaking, needlework, or some art activities like painting will score better in the Petrie test than the general population. The relationship between stereognosis and specific sport skill acquisition and performance still needs to be determined. In karate, perfect manual control plays an important role. Hands can be used as a weapon. Various specific fist positions are used in Karate punching techniques, such as Seiken, Uraken, Kentusi, or Ippon-Ken. An open hand is formed to be used as "knife hand" (Shuto), the inner side of the hand is used to hit the target during a Haito strike, while the back of the hand is used in the Haishu strike. Finally, the heel of the palm is used to hit the target in a Teisho strike. Thus, karate specialists must be able to adjust, strengthen, and use their hands for the intended specific purpose, which requires an ability to change their hand position very quickly and dynamically. Therefore, we used the Petrie test to investigate the quality of manual stereognosis, which is necessary for this type of movement to occur in a karate population.

Finally, we tested kinesthesia. Interestingly, there was no significant intergroup difference in simple kinesthesia tests, where visual control was manipulated. In these tests, participants stood and first touched a point on the wall with their eyes open and then attempted to touch the exact same point on the wall with their eyes closed. Both groups yielded similar results for both dominant and nondominant hands. In karate-specific kinesthesia tests, represented by the single punch and the triple punch tests, the karate group was more accurate. This is not surprising since those are basic karate stereotypes the competitive athletes train on an everyday basis because "karatekas" predominantly use upper limb karate techniques (Chaabène et al., 2014). Improving movement accuracy is an important part of sport drills and various training strategies have been proposed to optimize spatial accuracy with movements where reaching a specific target is necessary (Gaspar et al., 2019; Milley & Ouellette, 2021; Sherwood & Rothman, 2011). The better results in the karate group indicate a better quality of neuromuscular control in well-trained karate athletes (Quinzi et al., 2018). The cortex is a superior structure of ideokinetic motor control executed by the locomotor system based on the movement idea formed in the mind. Kinesthesia and somatognosis are integrative parts of cortical ideokinetic motor control. Quite frequently, applied techniques in sport utilize ideokinetic imagery where athletes mentally rehearse sport stereotypes in order to promote motor learning, performance, and motivation. The technique is based on response-produced sensory information (Mulder, 2007). Motor imagery activates overlapping areas in the brain, especially the somatosensory cortex involved in movement preparation and execution. Repeated movements are effective in inducing cortical representational changes and facilitate the learning of movements in a manner similar to actual physical training. However, the somatosensory cortex decreases in size if a relevant body part becomes less active (Mulder, 2007). According to Holmes and Spence, body-centered reference frames representing the body surface topographically demonstrate significant plasticity in response to training (Holmes & Spence, 2004). Somatognosis, that is, the body schema and surrounding personal space perception result from the interaction of numerous central nervous system centers processing multisensory information that determines characteristics of motor responses (Holmes & Spence, 2004). The above described neurophysiological principles of motor control are critical in sport performance. Perfect kinesthesia and somatognosis in top-level karatekas confirmed in this study may result from intensive sport training but may also be a prerequisite for elite sport performance. While Tucker and Collins (2012) argue that individual performance thresholds are determined by genetic make-up, and training can be defined as the process by which genetic potential is realized, Ericsson (Ericsson, 2004, 2008; Ericsson et al., 2009) emphasizes the critical importance of deliberate practice. Therefore, it may be important to evaluate and train these modalities in the sport population to improve performance (Han et al., 2015; Li et al., 2009; Majcen Rosker et al., 2021) and to prevent injuries or achieve full motor restoration after sport injuries (Ergen & Ulkar, 2008; Ghaderi et al., 2020; Lephart et al., 1997; Safran et al., 2001). Training programs that move toward methodologies that place an emphasis on neural rather than just morphological and strength aspects of training may turn out to be beneficial.

The results of this study must be interpreted with caution and in light of several limitations. First, fatigue could have influenced the results of the karate athletes tested because participants were participating in an intensive training camp during the weeks of the experiment and testing took place 2 hours after their last training session. The tests were not physically but mentally challenging and required full attention. Any physical exhaustion or mental stress could have played a role both in the general population participants and karate athletes outcomes. Second, the karate group was younger (mean age = 18.97 years) than the control group (mean age = 20.16 years). Although this difference proved to be statistically significant, from a neurophysiological standpoint, both groups consisted of young participants and the little over 1-year difference in age probably did not play any role in how tests were performed or interpreted. Third, the results for males and females were evaluated together. The study samples were too small to analyze the results according to gender. And finally, only karate athletes were examined within this study; therefore, the results cannot be generalized to different sport disciplines.

Conclusion

This study confirms that karate athletes have significantly better somatognosis and better movement to target accuracy, when performing quick dynamic movements as compared with the general population not performing any type of sport on regular basis. Regular karate practice on a competitive level may have a positive influence on body scheme (somatognosis) and kinesthesia but at the same time, these modalities may be a prerequisite to becoming a highly skilled karate practitioner (athlete).

Acknowledgments

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