The Effect of Muscular Fatigue on Neck Proprioception Performance between Elite Athletes and Non-Athletes

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Abstract

Introduction: The poor performance of neck proprioception is a risky factor for athlete's head and neck injury. Muscle fatigue as an inevitable factor of any physical activity can cause disorder in proprioception performance. This study intends to investigate the effect of cervical muscular fatigue on neck proprioception performance in elite karate athletes in comparison to non-athletes. **Materials and Methods:** Sixteen professional karate athletes and sixteen non-athletes participated in this study. Cervicocephalic relocation test measuring angle repositioning error during active cervical extension and rotation movements was used to assess neck proprioception ability, before and after isotonic muscular fatigue. Data were analyzed by independent T-test and paired T-test with SPSS (version 20) and alpha level set at 0/05. **Results:** There is no significant difference in neck sense status before and after neck muscular fatigue in both groups. Also, there is significant difference in neck proprioception performance between karate athletes and non-athletes following extension ($P<0.05$). In addition, athletes had greater joint position errors than non-athletes. **Discussion:** Although muscular fatigue did not affect proprioceptive neck performance, probably the effects of degenerative changes in neck proprioception and the acceleration repeated movements in karate athletes weaken their neck proprioception function in some direction in comparison to non-athletes. Therefore, it is important to improve the performance of neck proprioception in karate athlete's trough special neck proprioception training.

Key words: Martial Arts, Proprioception, Muscle Fatigue

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Introduction

Proprioception is a combination of intentional and unintentional awareness of joint position (sense of joint position), movement (sense of movement), force, heaviness and effort (sense of force) (1). Sensory information of proprioception is provided by Mechanoreceptors in muscles, Tendons, joints, Fascia and skin among which, joint is considered to be the main source of sensor information because of Muscle spindle (2). The neck muscles are among the muscles which have high Muscle spindle density (3). As a matter of fact, neck proprioception plays an important role not only in stability of head and neck, but also in control and harmony of the head and eyes movements (4).

What so ever factor which causes disturbance to transferring of the proprioception information sensory is known as an important factor provoking incorrect patterns of movement and frequent syndromes with chronic pain (5). There are several factors leading to these types of disorders including, age, damages, pain, diseases and fatigue (6). It is worth mentioning that the injury which can deeply affect the performance of proprioception is Whiplash injury which might occur while driving accidents, doing sports or working (7). It has different levels of damage, from slight to severe (8). The factor causing Whiplash injury is neck sudden acceleration due to cervical extension, frontal or lateral bending of head (8-11). Since Whiplash injury is common during driving or in driving races, the majority of studies have been conducted in this context,

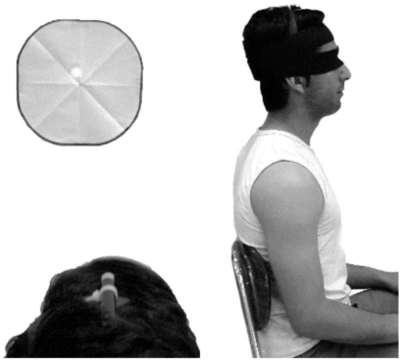

Figure 1. A: the subject position during the Cervicocephalic Relocation Test, B: effect of laser marker on the sheet

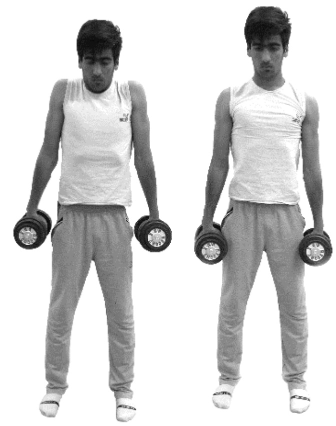

Figure 2. Position of the subjects during fatigue protocol

in other words no study has been carried out to examine this type of injury among athletes. According to the research findings relating to the neck proprioception status among people suffering from Whiplash injury, neck proprioception performance becomes poor even due to the minor injury in neck. Pinsault *et al.* reported that fatigue in neck muscles can get the neck status to fall among healthy adults (12). On the other hand, there are some other studies showing that fatigue in the neck muscles does not affect the neck proprioception. The study conducted Sajjadi *et al.* can be referred to as a striking illustration of this, in this study the potential effect of fatigue in neck muscles on neck proprioception was examined among a group of young men and women. Based on its findings fatigue did not have a significant effect on the neck proprioception ability among the subjects (6). Hassanlouei *et al.* studied the knee proprioception among the individuals who performed Resistance and endurance training and concluded that these exercises lessoned the effect of the fatigue (13). Considering this conclusion, it might probably be conclude mentioned that, fatigue might have less significant effect on proprioception performance among athletes.

However, new approaches discuss that the importance of proprioception is not limited to receiving enough ad timely information from mechanoreceptors in contrast, central processing, motor output have more significant importance. Perception cannot be simply defined as receiving information, but it is a process of memory and learning which is totally dependent on the ability of the person to integrate and use the information gathered by proprioception. In accordance with this approach, since athletes are involved in learning more complex skills, they are more engaged in the central processing of proprioception process compared normal individuals who do their routines activities automatically (14). There are few studies supporting this hypothesis. Some have already surveyed the ability of knee and ankle proprioception among athletes playing football, tennis and gymnastics (15-17). Besides, some other have studied the knee and ankle ability of proprioception among the athletes active in different levels of some fields including, football, gymnastics, Aerobic, badminton and dance (18, 19).

Karate is a field in which a person is to perform some acceleration movments in the head and neck (20). It is also dependent on action and perception demands, and it requires the athletes to learn some special skills to prevent the attacks which are frequently imposed on the performers (21). Martial arts enjoy great popularity around the world; however, due to the several injuries caused in head and neck, they have raised the concern among people active in sport community (22, 23). The most common mechanisms causing injuries in head and neck are reported to be; the rival's hand hit, long training sessions and fatigue among athletes (24). Injuries in the neck as well as fatigue can result in developing disorders in proprioception and aggravating these injuries. As proprioception plays an important role in optimizing the sport performance and preventing the injuries, recognizing its disorders and adopting an effective method to promote the performance of proprioception highly significant (25). As mentioned previously, there was no study carried out to examine the performance of neck proprioception among elite karate athletes in comparison with non-athletes and to study the effect of fatigue on the performance of neck proprioception, the current study was carried out to have these factors investigated.

Materials and Methods

The present smi-experimental and interventional study was conducted on 16 male professional karate athletes performing in the premier karate league and 16 non-athletes men volunteering

Table 1. Descriptive data of the participants

Variable	Athletes (n=16)		Non-athletes (n=16)		*P*-value
	Mean±SD	Domain	Mean±SD	Domain	
Age (year)	21.00±2.73	18-25	20.81±1.87	18-24	0.82
Weight (kg)	71.38±11.32	55-100	70.00±12.24	50-98	0.74
height(cm)	1.87±0.05	1.67-1.89	1.75±0.04	1.67-1.83	0.14
BMI (kg/m2)	22.47±3.45	17.79-30.86	22.64±3.21	17.10-29.26	0.88
Physical activity record (year)	12.31±2.49	9-17	-	-	-

Table 2. Independent T-test results to compare sense status between athlete and non-athlete groups

Group (Degree)	Sense status	Athletes	Non-athletes	*P*-value
		Mean±SD	Mean±SD	
Before fatigue exposure	Sagittal	4.10±0.83	2.38±1.01	0.00
	Horizontal	4.79±1.69	4.10±0.83	0.16
After fatigue exposure	Sagittal	3.17±1.46	2.78±0.87	0.36
	Horizontal	4.82±1.86	4.35±0.94	0.37

to take part in the study. They were asked to fill out the form containing their personal information and medical records, as well as the consent. The inclusion criteria included; being in the 18 to 25 age range, having balk belt necessary for karate athletes. on the other hand, there were some exclusion criteria mainly known as suffering from headache, having pain in neck, experiencing injury or surgery in head, spinal cord and shoulder, having temple and jaw disorder, suffering sight disorders not treated by glasses as well as audition disorders requiring aids, taking medicines for a long time, having systematic Neurological problems and experiencing the inner ear infections (6, 12). The participants first were individually present at the laboratory to have their repetition maximum was determined, the angle repositioning error test and the fatigue protocol were imposed. The angle repositioning error test was re-performed 20 seconds after the completion of fatigue protocol.

Later on, Cervicocephalic Relocation Test by measuring the angle repositioning error was employed to have the head status sense evaluated (6). To have this evaluated, the participants were asked to sit on the chair located in 90 cm distance from the wall, with no arm and backrest, with their legs touching the ground and their hand placed on their legs. Laser marker placed on a plastic head band was located on the highest part of the subjects' head. A blindfold was also used to prevent the participants' sight. Next, they were asked to keep their head naturally and comfortably and the examiner pointed the laser light on the white sheet attached on the wall in front of the subjects. This stage is clearly presented in the figure 1.

While focusing on the point of reference, the subjects performed a complete active cervical extension on the sagittal axis, then they performed rotation movement to the right side gently and slowly on the horizontal axis and then they turn their head to the initial position (5, 26, 27). Angle repositioning error was evaluated through the formula by measuring the distance between the location of the laser marker on the sheet and the point of reference in Cm (28). On experimental test was attempted, after that the main test was repeated for three times. It should be mentioned based on the studies this method enjoys high validity and reliability measured to (r=0.87) and (r=0.95) respectively by ultrasound technique, so it is a suitable technique to be used in order to measure the sense of head status (29).

To have the repetition maximum evaluated a simple test was employed in which the subjects were asked to shrug their shoulders with their hands stretched on both sides of their body, while carrying 30 kilogram Dumbbells. The following formula was used (30):

Repetition maximum:

Active isotonic in form of Shoulder shrug with dumbbells comprising 30% of the repetition maximum was used to impose the protocol of fatigue. To be more specific, the participants were required to hold the dumbbells in their totally stretched hands and to shrug their shoulders in harmony with the metronome hit (40 hits a minute). The details of the method are illustrated in the figure 2 (12). The participants felt fatigue when they could not continue the movement, so based on the Borg CR-10 Scale referred to the movement as 1 Extremely Strong. Performing this movement

Table 3. The results of the dependent T- test to compare the Angle repositioning error before and after fatigue exposure

Sense status	Group (Degree)	Before fatigue exposure	After fatigue exposure	*P*-value
		Mean±SD	Mean±SD	
Athlete	Extension	2.92±1.54	3.17±1.46	0.18
	Rotation	4.79±1.69	4.82±1.86	0.42
Non-Athlete	Extension	2.38±1.01	2.78±0.87	0.09
	Rotation	4.10±0.83	4.35±0.94	0.95

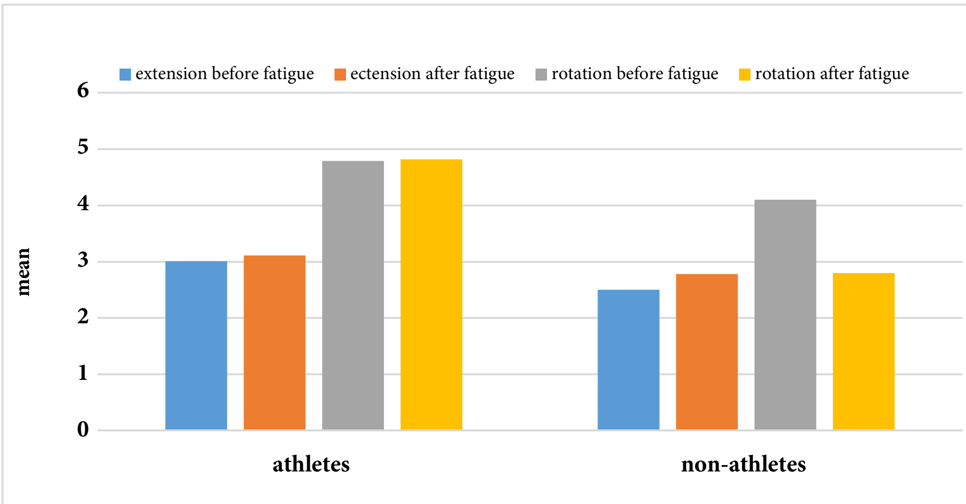

Figure 3. Mean changes of angle repositioning error among athletes and non-athletes in different sense status evaluation

on both sides of the body provokes the highest amount of involvement of shoulder, Trapezius shoulder, and central stabilizer of the spinal cord. Pinsault and Vuillerme have previously employed this method for the same purpose (12, 31).

Several statistical procedures were used to analyze the data collected. Kolmogorov-Smirnov test was employed for data normalization, then the independent T-test was applied to compare age mean, height, weight, BMI and to compare the amount of Angle repositioning error among athletes and non-athletes participants. Additionally, the dependent T-test was applied to compare the amount of angle repositioning error before and after the fatigue exposure. Significance level of all the test was $P<0.05$, all data analysis was done by SPSS software version 20.

Results

The descriptive data of the participants are presented in the table 1. As can be seen, there is no significant difference between two groups of athletes and non-athletes regarding the age, height, weight and BMI. All participants in the athletes group had Karate Black belt and they had 12.31 years of experience in doing this type of sport.

To have the data related to angle repositioning error in both groups of athletes and non-athletes analyzed, independent T-test was applied whose results are illustrated in the table 2. According to the results of the current study, regarding the sense status, only in extension movement on sagittal axis, and before the fatigue exposure, the significant difference between two groups was observed ($P<0.05$). In addition, there was no significant difference between two groups as regard to sense status.

The results of dependent T-test are displayed in table 3 which clearly shows that there is no significant difference between two groups regarding the amount of the Angle repositioning error before and after fatigue exposure.

According to the figure 3, there was an increase observed in the amount of angle repositioning error after fatigue exposure in both athletes and non-athletes groups, but higher amount was recorded for the participants in the athletes group. Angle repositioning error was measured to be higher in both groups during the rotation movement on horizontal. Generally, higher mean of angle repositioning error was observed among the athletes compared with non-athletes.

Discussion

The findings of the current study showed that muscular fatigue brought about an increase in the angle repositioning error in both groups of athletes and non-athletes, but it should be considered that the findings were not significantly meaningful. According to the studies in the literature, not only can fatigue affect upper nervous junction of muscles which will gradually result in a decrease in unintentional activity of the muscles, it also can affect muscles and their contraction mechanisms. Additionally, fatigue can increase the muscular discharge duke threshold and is an effective factor in simultaneous activity of Alfa-Mega. Due to the effect of fatigue, sense messengers to Alfa movement neurons change make the joint unable to have suitable protective function with the help of muscle (32).

To explain why the results of the current study were not significantly meaningful, firstly the important role of proprioception receivers should be taken into account. Sense status of the joint is resulted from different sources such as; mechanical receivers of the joint, skin afferent and muscular receivers; consequently, although muscular fatigue can cause some disorders in muscular proprioception receivers, the role of other receivers cannot be neglected (24). The second important factor regarding the results of the present study is the protocol of fatigue. Despite the fact that some muscles and even stabilizers of spinal cord are also affected by the fatigue protocol, the main purpose of this protocol is to involve muscles of shoulders and the upper trapezius, its main reason can be the other muscles' activity to make up the effects of fatigue (12, 31). Amonoo-Kuofi *et al.* reported that the aggregation of muscular dukes of the neck is in the middle part of it and in Cervico-thoracis in the middle layer of the muscles which is toward the lower parts of the neck (33). In addition to what was mentioned above, the activity of the Vestibular system should not be neglected. This system provides very important pieces of information about the status of head and neck and about the head in relation with the body which are integrated with other pieces of information. All of these systems create independent frames of information which are converted into the meaningful data by CNS. It should be also considered that the gentle and constant movement of the participants during the test made the amount and the accuracy of the data from Vestibular system decrease, it never disappears completely, though (34, 35).

There are several studies corresponding to the results of the present study among which the one conducted by Sajjadi *et al.* can be mentioned (6). They rejected the theory of the effect of fatigue on the head angle repositioning error in their study. Moreover, Sterner *et al.* studied the effects of fatigue on shoulder proprioception and approved that fatigue could not affect the sense status of shoulder (36). Besides, Miura *et al.* stated that general fatigue could result in the deficiency in central processing of proprioception, but regarding the local fatigue it might not be true (37). In contrast, there are some studies with opposite results. According to the study conducted by Pinsault *et al.* on a group of healthy males, fatigue produced a significant effect on angle repositioning error (12). The main reasons to be considered in regard to the inconsistency between the findings of these two studies are fewer number of participants and (9 individuals) and different age range (28.1±6.3). Based on many researches, aging can bring about change in proprioception status and in different muscular functions of neck and other parts of the body (38, 39). According to the present study, there was no significant difference between the group of athletes and non-athletes except for one case; head movement on sagittal axis before fatigue, but it should be mentioned that review of literature did not demonstrate any study conducted to compare the proprioception status between athletes and non-athletes. On the other hand, the study done by Han *et al.* examined the ankle proprioception status among athletes in different levels of various fields such as; gymnastics, badminton, football, aerobic and dance, according to its findings, there was a significant difference between groups of athletes and non-athletes which was related to the ability of the ankle proprioception (P<0/05); however, in the same study there was no significant relation between the ability of the ankle proprioception and the years of training among athletes (18).

Additionally, in the study by Aydin *et al.* the ankle proprioception was compared between a group of gymnasts and a group of non-athletes, it was concluded that gymnasts had more ability of the ankle proprioception (40). It is worth mentioning that doing a lot of ankle related practices in gymnastics to demonstrate delicate control, balance and rotation movements can best describe the findings of that study. Muaidi *et al.* could also conclude that there was no significant relation between the ability of the ankle proprioception and the years of training among athletes (16). According to another study carried out by Ashton Miller *et al.*, proprioception was not affected by the training and maybe higher ability of the ankle proprioception among athletes could be related to rudimentary and intrinsic ability of these athletes (41).

According to the findings of different studies, the rotation movement can cause the increase in the head angle repositioning error among athletes and non-athletes (11). One of the probable reasons for that is more challenge in the status control system in the rotation movement. According to the present study, there was a significant difference between two groups regarding the head angle repositioning error in extension movement before the fatigue exposure (*P*<0/05). One of the most popular movement in Karate is head and neck extension in order to protect the head against the head hit. Actually, in many cases, lack of proper protective action provokes the possibility of the head to be hit resulting in extension in the head and neck (42). Posterior muscles are considered as the strongest group of muscles, also the head and neck bending on sagittal and frontal axes is limited to chin and era contact with the Sternum and shoulder, but there is no such a limitation for the extension movement. Therefore, the head extension movement potentially increases the risk of the injury among people. Although there is no study relating to the extension movement in karate, it can be considered to be similar to Whiplash injury in driving. Whiplash injury is in the range degree of 0 to 4. This injury does not have any physical injury or musculoskeletal symptoms in the head and neck when it is between the ranges of 0 to 2 degree. However, according to the study by Sterling *et al.*, people suffering from Whiplash injury with range degree of 1 and 2 might demonstrate head angle repositioning error in extension movement (3.6±0.4) in comparison with rotation movement (2.4±0.2) when compared with healthy people performing extension (2.9±0.6) and rotation (2.3±0.3) movements (11). Furthermore, Tre leaven *et al.* studied the people with Whiplash injury and reported that head angle repositioning error was more in the extension movement (3.5±0.4) in comparison with healthy individuals (2.4±0.3) (9). Increase in the superficial muscular activity of the neck, sensitivity of the muscular dukes and disorders in inputs proprioception are reported to be the more extension movement of the head (8-11).

Considering the group of the athletes, there are some studies referring to the Degenerative changes in the neck spinal cord, for example, according to the findings of the study by McIntosh *et al.*, football players emphasize the importance of neck proprioception practice in order to protect head and neck from injuries (43). Additionally, Armstrong *et al.* sated that evaluation of the neck and head sense status among athletes, can play an important role in recognition of the possible head and neck injuries; as a result, neck proprioception performance among athletes playing Karate is frequently affected by acceleration movements, and lack of attention paid to the importance of head and neck practice strengthen these possible dangers (44). Taking all the discussed points into consideration, it is suggested that athletes practicing karate have their joint sense status assessed at the beginning of the training season to prevent the possible dangers to head and neck, and do special exercise to increase the neck proprioception.

Conclusion

Although the neck fatigue did not have any effect on the neck proprioception performance, there is a possibility for the neck proprioception receivers to affect the neck proprioception performance due to the gradual effect of s frequent hit and acceleration movements on the head and neck among the athletes in karate. Regarding the importance of the proprioception in preventing the injuries and in improving the function of athletes, betterment in the neck proprioception among athletes in karate and conducting more researches in this field are of great importance.

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All authors made substantial contributions to conception, design, acquisition, analysis and interpretation of data.

References

1. Riemann BL, Myers JB, Lephart SM. Sensorimotor system measurement techniques. Journal of athletic training. 2002;37(1):85.
2. J R. Control of human voluntary movement. London: Chapman and Hall; 1994.
3. Proske U, Gandevia SC. The proprioceptive senses: their roles in signaling body shape, body position and movement, and muscle force. Physiological reviews. 2012;92(4):1651-97.
4. Kuramochi R, Kimura T, Nakazawa K, Akai M, Torii S, Suzuki S. Anticipatory modulation of neck muscle reflex responses induced by mechanical perturbations of the human forehead. Neuroscience letters. 2004;366(2):206-10.
5. Arami J, Rezasoltani A, Khalkhali Zaavieh M, Rahnama L. The effect of two exercise therapy programs (proprioceptive and endurance training) to treat patients with chronic non-specific neck pain. Journal of Babol University of Medical Sciences. 2012;14(1):77-84.
6. Sajjadi E, Olyeai G, Talebian S, Hadian M, Jalaei S, Mahmoudi R, et al. The effect of muscular fatigue on cervical joint position sense in young and healthy men and women: a preliminary study. Journal of Modern Rehabilitation. 2014;8(1):43-51.
7. Otte A. Whiplash injury: new approaches of functional neuroimaging: Springer Science & Business Media; 2012.

8. Heikkilä HV, Wenngren B-I. Cervicocephalic kinesthetic sensibility, active range of cervical motion, and oculomotor function in patients with whiplash injury. Archives of Physical Medicine and Rehabilitation. 1998;79(9):1089-94.
9. Treleaven J, Jull G, Sterling M. Dizziness and unsteadiness following whiplash injury: characteristic features and relationship with cervical joint position error. Journal of Rehabilitation Medicine. 2003;35(1):36-43.
10. Armstrong BS, McNair PJ, Williams M. Head and neck position sense in whiplash patients and healthy individuals and the effect of the cranio-cervical flexion action. Clinical Biomechanics. 2005;20(7):675-84.
11. Sterling M, Jull G, Vicenzino B, Kenardy J. Characterization of acute whiplash-associated disorders. Spine. 2004;29(2):182-8.
12. Pinsault N, Vuillerme N. Degradation of cervical joint position sense following muscular fatigue in humans. Spine. 2010;35(3):294-7.
13. Hassanlouei H, Falla D, Arendt-Nielsen L, Kersting UG. The effect of six weeks endurance training on dynamic muscular control of the knee following fatiguing exercise. Journal of Electromyography and Kinesiology. 2014;24(5):682-8.
14. Han J, Waddington G, Adams R, Anson J, Liu Y. Assessing proprioception: a critical review of methods. Journal of Sport and Health Science. 2016;5(1):80-90.
15. Lin C-H, Lien Y-H, Wang S-F, Tsauo J-Y. Hip and knee proprioception in elite, amateur, and novice tennis players. American journal of physical medicine & rehabilitation. 2006;85(3):216-21.
16. Muaidi Q, Nicholson L, Refshauge K. Do elite athletes exhibit enhanced proprioceptive acuity, range and strength of knee rotation compared with non-athletes? Scandinavian journal of medicine & science in sports. 2009;19(1):103-12.
17. Lephart SM, Myers JB, Bradley JP, Fu FH. Shoulder proprioception and function following thermal capsulorraphy. Arthroscopy: The Journal of Arthroscopic & Related Surgery. 2002;18(7):770-8.
18. Han J, Anson J, Waddington G, Adams R. Sport attainment and proprioception. International Journal of Sports Science & Coaching. 2014;9(1):159-70.
19. Han J, Waddington G, Anson J, Adams R. Level of competitive success achieved by elite athletes and multi-joint proprioceptive ability. Journal of Science and Medicine in Sport. 2015;18(1):77-81.
20. Muiños M, Ballesteros S. Peripheral vision and perceptual asymmetries in young and older martial arts athletes and nonathletes. Attention, Perception, & Psychophysics. 2014;76(8):2465-76.
21. Arriaza R, Leyes M. Injury profile in competitive karate: prospective analysis of three consecutive World Karate Championships. Knee Surgery, Sports Traumatology, Arthroscopy. 2005;13(7):603-7.
22. Pieter W. Competition injury rates in young karate athletes. Science & Sports. 2010;25(1):32-8.
23. Destombe C, Lejeune L, Guillodo Y, Roudaut A, Jousse S, Devauchelle V, et al. Incidence and nature of karate injuries. Joint Bone Spine. 2006;73(2):182-8.
24. Stapley PJ, Beretta MV, Dalla Toffola E, Schieppati M. Neck muscle fatigue and postural control in patients with whiplash injury. Clinical neurophysiology. 2006;117(3):610-22.
25. Guskiewicz KM, McCrea M, Marshall SW, Cantu RC, Randolph C, Barr W, et al. Cumulative effects associated with recurrent concussion in collegiate football players: the NCAA Concussion Study. Jama. 2003;290(19):2549-55.
26. Chen X, Treleaven J. The effect of neck torsion on joint position error in subjects with chronic neck pain. Manual therapy. 2013;18(6):562-7.
27. Treleaven J. Sensorimotor disturbances in neck disorders affecting postural stability, head and eye movement control. Manual therapy. 2008;13(1):2-11.
28. Artz NJ, Adams MA, Dolan P. Sensorimotor function of the cervical spine in healthy volunteers. Clinical Biomechanics. 2015;30(3):260-8.
29. Roren A, Mayoux-Benhamou M-A, Fayad F, Poiraudeau S, Lantz D, Revel M. Comparison of visual and ultrasound based techniques to measure head repositioning in healthy and neck-pain subjects. Manual therapy. 2009;14(3):270-7.
30. BAVLI O. Comparison the effect of water plyometrics and land plyometrics on body mass index and biomotorical variables of adolescent basketball players. 2011.
31. Vuillerme N, Pinsault N, Bouvier B. Cervical joint position sense is impaired in older adults. Aging clinical and experimental research. 2008;20(4):355.
32. Asmussen E. Muscle fatigue. Medicine and science in sports. 1978;11(4):313-21.
33. Amonoo-Kuofi H. The density of muscle spindles in the medial, intermediate and lateral columns of human intrinsic postvertebral muscles. Journal of anatomy. 1983;136(Pt 3):509.
34. G M-J. Posture. Principles of neural science. 4th ed. New York: Mc Graw-Hill; 2000.
35. Peterson BW, Goldberg J, Bilotto G, Fuller JH. Cervicocollic reflex: its dynamic properties and interaction with vestibular reflexes. Journal of Neurophysiology. 1985;54(1):90-109.
36. Sterner RL, Pincivero DM, Lephart SM. The effects of muscular fatigue on shoulder proprioception. Clinical Journal of Sport Medicine. 1998;8(2):96-101.
37. Miura K, Ishibashi Y, Tsuda E, Okamura Y, Otsuka H, Toh S. The effect of local and general fatigue on knee proprioception. Arthroscopy: The Journal of Arthroscopic & Related Surgery. 2004;20(4):414-8.
38. Rix GD, Bagust J. Cervicocephalic kinesthetic sensibility in patients with chronic, nontraumatic cervical spine pain. Archives of Physical Medicine and Rehabilitation. 2001;82(7):911-9.
39. Kaplan FS, Nixon JE, Reitz M, Rindfleish L, Tucker J. Age-related changes in proprioception and sensation of joint position. Acta Orthopaedica Scandinavica. 1985;56(1):72-4.
40. Aydin T, Yildiz Y, Yildiz C, Atesalp S, Kalyon TA. Proprioception of the ankle: a comparison between female teenaged gymnasts and controls. Foot & ankle international. 2002;23(2):123-9.
41. Ashton-Miller JA, Wojtys EM, Huston LJ, Fry-Welch D. Can proprioception really be improved by exercises? Knee Surgery, Sports Traumatology, Arthroscopy. 2001;9(3):128-36.
42. Proctor MR, Cantu RC. Head and neck injuries in young athletes. Clinics in sports medicine. 2000;19(4):693-715.
43. McIntosh AS, McCrory P. Preventing head and neck injury. British journal of sports medicine. 2005;39(6):314-8.
44. Armstrong B, McNair P, Taylor D. Head and neck position sense. Sports medicine. 2008;38(2):101-17.