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The Effect of Eight Weeks of Training on Head and Neck Stability in Tsuki Punch after Neck Muscle Fatigue

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Original Article

Abstract

Introduction: Muscular fatigue can interfere with the proper functioning of postural stability strategies, hence decreasing stability and increasing the risk of injuries in athletes. The aim of this study is to examine the effect of training on head and neck stability against Tsuki punch during the neck muscle fatigue in male athletes.

Materials and Methods: 24 professional male karate athletes were selected and randomly divided into the experimental [n = 12, age: 20.92 ± 2.62 (y), weight: 71.00 ± 11.68 (kg), height: 1.77 ± 0.05 (m)] and control [n = 12, age: 22.08 ± 2.21 (y), weight: 72.15 ± 13.24 (kg), height: 1.78 ± 0.06 (m)] groups. The experimental group performed a training program for eight weeks, three times per week. Moreover, the angular displacement and acceleration of head and neck in Tsuki punch during muscular fatigue were measured by motion analysis system before and after the training protocol. Data were analyzed by paired t-test, independent t-test, and analysis of covariance (ANCOVA) at the significance level of 0.05.

Results: There was a significant difference in angular displacement (Experimental: 2.95 ± 1.85, Control: 4.15 ± 2.15) and acceleration before (Experimental: 16.29 ± 9.62, Control: 70.17 ± 12.23) and after (Experimental: 24.69 ± 15.98, Control: 70.86 ± 14.92) hitting the punching bag.

Conclusion: The outcome of this study showed that proprioception training can improve head and neck postural stability during muscular fatigue against external perturbation in Karate athletes. Therefore, these exercises can be used to reduce the effect of external perturbation on the head and neck of these athletes.

Keywords: Professional athletes; Proprioception; Karate; Perturbation

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Introduction

Stability is defined as the ability to maintain and control joint movements by the coordinated activity of the surrounding tissues and the nervous system. The human body is repeatedly exposed to two types of perturbation: internal perturbation produced by the individual's own body, including movement of the limbs, fatigue, musculoskeletal damage, and muscle stiffness, and external perturbations due to external forces acting on the body, such as impacts on the body, pushing, or walking (1). Perturbations affect the stability of the body. The nervous system uses two strategies, anticipatory postural adjustments (feedforward) and compensatory postural adjustments (feedback), to minimize the effect of the perturbations on the body (2).

The anticipatory strategy activates or restrains the muscles in order to generate force and torque to minimize perturbation before it is applied to the body, and has the potential to create a short-term adaptation in response to environmental changes and be launched with actual and perceived levels of the body stability (3). The compensatory strategy cannot make predictions and is activated by sensory feedback signals, and is the mechanism for repositioning of the body center of mass after the introduction of the perturbation. The presence of the anticipatory strategy does not preclude the compensatory strategy. The use of appropriate postural strategies and postural response by the nervous system is highly correlated with the visual and proprioceptive input to the nervous system (4).

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Proprioception is defined as conscious and unconscious perception of the sense of position (joint position), sense of motion (Kinaesthesia) and force, effort and heaviness (sense of force). Although these senses are divided into three distinct groups, in each movement, information related to all of them is transmitted to the nervous system by mechanoreceptors (5). In addition to receiving information from the mechanoreceptors, proprioception integrates sensory information received from them to determine the movements and position of body parts in space. Muscle fatigue impairs proprioceptive information; so that even visual input information cannot compensate for this perturbation in the proprioceptive information (6). In their study, Roberts and Vasavada concluded that neck flexor muscle fatigue increases static head oscillations (7). Moreover, the results of the study by Allison and Henry showed that in the presence of fatigue, the central nervous system (CNS) changes the body's postural regulation strategies. In their view, in the presence of fatigue and changes in control strategies, the perturbations created can have detrimental effects on the body (8).

Repetitive movements of the upper limbs in front area of the body are the main components of karate techniques (9). The perturbations due to functional activities and movements of the limbs enter the higher segment in the opposite direction to the movement of the limbs. Therefore, the force of the upper limb movements enters the cervical spine and through it to the head area (10). Thus, the head and neck area of karateka athletes are frequently exposed to internal (high-speed, strong, free movement of the upper limbs) and external perturbations (repeated punches to the opponent or the punching bag with the hands) (11). Failure to properly neutralize these perturbations will increase the oscillation and sudden acceleration in the head and neck area, which in addition to the possibility of sudden acute injuries (12), will lead to gradual changes in the discs and vertebrae of the neck and the onset of osteoarthritic symtoms, and due to affecting nerve roots, it may lead to neurological disorders in athletes (13). Therefore, reducing the impact of perturbations by improving head and neck stability is very important in preventing injuries to these areas in sports.

In some studies, (external) perturbation anticipation has been proposed as an injury prevention mechanism in athletes. Mihalik et al. found in a study that when ice hockey athletes predict a blow to the head, less angular acceleration occurs in their head area (14). Additionally, the results of a study on motorcyclists showed that perturbation anticipation reduces head and neck injuries in these athletes (15). So far, few studies have proposed an exercise program to influence the postural strategies of the nervous system and reduce body fluctuations in the face of perturbations. Regarding the effect of exercise on fluctuations in fatigue, we can only refer to the study by Hassanlouei et al. (1). In their study, they investigated the reducing effect of endurance training on muscle activity and postural fluctuations against perturbations during muscle fatigue, and concluded that following fatigue of the flexor and extensor muscles of the knee, decreased muscle activity and increased postural fluctuations were initially observed. However, after six weeks of endurance training, the subjects showed a high ability to maintain their posture in the face of perturbation during fatigue (1).

Despite the lack of studies on the effect of training on head and neck fluctuations in athletes during fatigue and since the positive effect of training can be a positive step to prevent gradual head and neck injuries in karate athletes, the present study aims to investigate this important issue. Given the positive results of studies on the effect of neck proprioceptive exercises on improving head and neck posture, joint position sense, sense of movement, balance and pain relief due to the high density of neck mechanoreceptors compared to other parts of the body and the important role of their input information in launching and level of activity of the postural stability strategies (16), the present study is conducted with the objective of investigating the effect of an eight-week neck proprioception training program on reducing head and neck fluctuations during muscle fatigue in elite male karate athletes.

Materials and Methods

This was a quasi-experimental study with the statistical population including athletes of Karate Premier League of Sirjan, Iran. After identifying the volunteer athletes, the inclusion and exclusion criteria were examined using a general evaluation form and 24 athletes were selected using purposive and convenience sampling method and randomly assigned to the control and experimental groups. The inclusion criteria were the age range of 18 to 25 years, having at least 5 years of karate experience, participation in the National Karate Premier League teams, and signing a written consent form for informed participation in the study. History of muscular, skeletal, and nerve pain in the head, neck, whole spine, and upper limbs, history of surgery in the head, neck, and whole spine, shoulder girdle and lower limbs, temporomandibular disorders, vision problems not corrected with glasses, hearing problems, long-term medication needs, pulmonary vascular diseases (PVDs) during the last five years, inner ear infection, and congenital disorders and abnormalities (17) were considered as the exclusion criteria. All subjects practiced karate for three 90-minute sessions per week and bodybuilding for three 60-minute sessions. The present study was approved with the ethics code IR.SIRUMS.REC.1398.002 in the research ethics committee of Sirjan University of Medical Sciences and registered on the Iranian Registry of Clinical Trials (IRCT) with code IRCT20190505043474N1.

First, the evaluation process was fully explained to the subjects. The assessment was performed individually by a tester according to the schedule provided to the subjects. The general procedure of the study was that first, the height and weight of the subjects were measured using a gauge and a scale, and with a specific program, general warming up was performed under the supervision of the examiner. The value of the one repetition maximum (1RM) of the subjects in the shoulder shrug was determined and 30% of it was calculated and then the markers of the motion analyzer were installed on the desired anatomical points. The muscle fatigue protocol was performed on the muscles and head and neck fluctuations test was performed against internal and external perturbations. Tsuki movement, which is the most widely used upper limb movement in karate, was used to produce internal and external perturbations. The internal perturbation was defined as a free Tsuki punch to the target, and the external perturbation was defined as a Tsuki punch to the punching bag. To ensure the homogeneity of the data in the two groups and evaluate the force produced by the upper limb in Tsuki punch, 30% of the 1RM and the time to reach fatigue were examined. The study process in pre-test and post-test was quite similar.

To perform the fatigue protocol, the 1RM of the subject in shoulder shrug was first calculated; to do this, the subject was standing and holding two 30 kg dumbbells. In this position, the arms hung at the sides of the body and the elbows were fully open. The metronome was set to 40 beats per minute. The subject performed the shoulder shrug movement completely without bending the elbow and keeping the torso and head in line until he could not continue anymore or start performing the movement incorrectly. The number of his performances was recorded and then using Equation 1, the 1RM value and at the end, its 30% were calculated (17).

Relation 1 Displaced weight (kg) ÷ (1.0278 × number of repetitions to fatigue × 0.0278)

To perform the fatigue protocol, the subject was asked to perform the shoulder shrug with 30% of the 1RM totally similar to the way stated so that he could no longer perform it, and declare the Borg scale (10-point scale) as very severe (Above 8) (9). The time to fatigue was also recorded with a chronometer (Quartz, Japan) with an accuracy of 0.01 seconds.

The motion analysis device (Raptor-H Digital Real TimeSystem, USA) was utilized to record three-dimensional head and neck oscillations in the laboratory of Shahid Bahonar University of Kerman, Iran. All six cameras of the device were used and the camera layout was adjusted so that each marker could be seen by at least two cameras. The frequency of the cameras was considered to be 120 Hz (18). On the evaluation day, the device was calibrated initially. Marking was performed on the C7 spinous process, Glabella, Tragus, the posterior outer part of the acromion process, the olecranon process, and the ulnar styloid process. The subject was first placed in a standing position with parallel legs (shoulder width) with a distance slightly longer than the length of the upper limb in front of the punching bag. He was then asked to put the same leg as his punching hand back as the size of the sole of his foot while keeping his shoulder width, place the elbow of his punching hand in a 90-degree position, rotate his fist and forearm into the supination state, and hold his fist on the iliac crest. For uniformly of the Tsuki punch in the subjects, an area with a white label was specified on the punching bag and based on the height of each subject, the height of the punching bag (its retaining ring was moved on a chain hanging from the ceiling) was changed so that the upper part of the white label was at the same level as the subject’s shoulders (Figure 1, a).

In order to evaluate the oscillations of the head and neck against internal perturbations, the subject was asked to perform the Tsuki free punch in the described position without using the body (rotational movement in the back, torso, or shoulders) in the fastest and strongest possible manner towards the target without hitting it (Figure 1, b). The subject performed one exercise attempt and three main attempts and rested for 5 seconds between each repetition (19). Kinematic assessments of the head, neck, and punching hand were recorded using the motion analyzer throughout the performances.

To assess the oscillations of the head and neck in the face of external perturbations, all steps were similar to those in the assessment of the internal perturbations, except that the subject distanced himself from the bag as the length of the upper limb so that the elbow could fully open when punching and the fist could hit the bag. In this case, the subject’s shoulder or torso did not be pulled forward and he could maintained the original position (Figure 1, c).

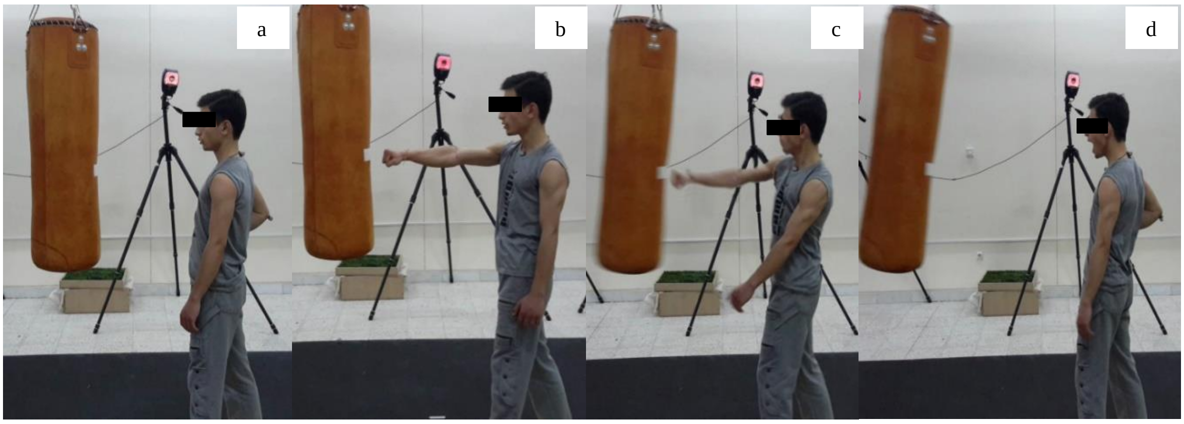


Figure 1. (a) Initial position, (b) Tsuki free punch, (c) Tsuki punch and its impact on the punching bag, (d) final position

Initially, the data of the motion analyzer were analyzed in CORTEX2.5 software. To eliminate the noise caused by the movement of markers, a 6 Hz Butterworth low-pass filter (LPF) was applied. Then the desired indicators including time, distance, and position of the markers were extracted.

The displacement of the angles of the head and neck in the sagittal plane was defined as the displacement of the angle of the distance between the two Glabella-Tragus and Tragus-C7 spinous process lines on the sagittal plane (20) and extracted in terms of degree using MATLABR2012a software.

The difference between the starting angle and the target angle was calculated as the amount of displacement changes in the head and neck angles. By evaluating the angular displacement changes (in radians) per unit time, the angular velocity was calculated and then the angular acceleration was extracted by calculating the velocity changes of the head and neck angles per unit time in radians per second squared. The coordinate axis method was used to calculate the force of the upper limb in Tsuki punch. The method of extraction of the force and relationships are given below (21).

Equation 2 is related to angular velocity (ω) and Equation 3 is related to angular velocity (α) in which dφ, dt, and dω denote the changes in angle, changes in time, and the changes in velocity, respectively.

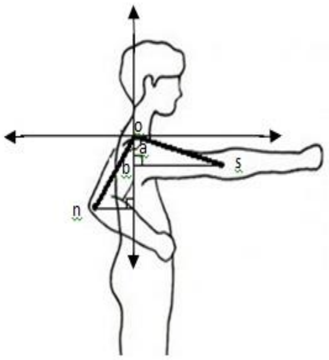
Relation 2	$\omega = d\phi / dt$
Relation 3	$\alpha = d\omega / dt$

Besides, ϕ is the angle between the two lines on and os, ω is the angular velocity, α is the angular acceleration, t is the time in which the point n reaches s, I is the inertia, and F is the force.

$$b = \tan^{-1} (y_n-y_o)/(x_n-x_o),\ a = \tan^{-1} (y_s-y_o)/(x_s-x_o)$$

$$\phi = a+b,\ \omega = \phi/t,\ \alpha = \omega/t$$

$$m_{arm} = (2.6)\ m_{whole\ body},\ I = m(on)^2,\ F = I\alpha$$



In the present study, a training program was used to increase neck proprioceptive function. Accordingly, and with regard to specific and non-specific factors of proprioception and effective training programs mentioned in previous studies as well as performance of karateka athletes, a combined training program was designed under the supervision of experts in the field.

The specific factors included joint position sense exercises with and without visual feedback, kinesthesia exercises, and force exercises, and the non-specific factors included coordination exercises, muscle function exercises, and exercises on unstable surfaces. The training program was performed for 25 to 30 minutes per session, three days a week for 8 weeks as part of the bodybuilding program of the experimental group; while the subjects in the control group performed their usual bodybuilding program. The training program was held in the subjects' bodybuilding club and under the supervision of a tester in groups and stationery. The time of each session was divided as 5 minutes for warm-up, 18 to 24 minutes for 3 stationary repetitions, and finally, 1 to 2 minutes for cooling down. For all training sessions, the number of stations was 5, the total number of repetitions of the stationary program was 3, and the rest time between each station was 30 seconds. The progress of the exercises was defined as increasing the time in each training session and increasing the difficulty level of the exercises at the beginning of each week. Thus, 3 levels of time progress and 8 levels of difficulty progress were considered for the exercises.

The Shapiro-Wilk test was used to ensure the normality of the data distribution in the groups. Then, Paired t and Independent t tests were exploited for the intragroup and intergroup comparisons, respectively. The analysis of covariance (ANCOVA) test was used to compare the mean data between the control and experimental groups in the post-test and to eliminate the confounding factor of the pre-test. Finally, the data were analyzed in SPSS software (version 20, IBM Corporation, Armonk, NY, USA). $P < 0.05$ was considered as the significant level.

Results

In the present study, 24 male professional karatekas ranging in age from 18 to 25 years were examined. The mean age of the participants in the experimental and control groups was 20.92 ± 2.62 and 22.08 ± 2.21 years, respectively, and their mean weight was 71.00 ± 11.68 and 72.15 ± 13.24 kg, respectively.

The height of the experimental group and the control group was respectively 1.77 ± 0.05 m and 1.78 ± 0.06 m. The experimental group had a body mass index (BMI) of 22.53 ± 3.44 kg/m^2 and the control group had a BMI of 22.77 ± 4.02 kg/m^2. The sports experience of the experimental and control groups was 13.00 ± 2.67 and 11.15 ± 1.40 years, respectively. The results of the independent t test showed that there was no significant difference in the demographic variables between the two groups ($P < 0.05$).

The description of the characteristics of the subjects by groups and the pre-test and post-test stages is presented in table 1. Additionally, the independent t-test and paired t test were utilized to evaluate the homogeneity of data between the groups and between the stages, respectively.

The results of the paired t-test to compare the mean of the data related to the time to fatigue indicated a significant difference between the pre-test and post-test stages in the experimental group ($P < 0.05$). Based on the results of the independent t-test to compare the mean of the data related to fatigue time, there was a significant difference between the experimental and control groups in the post-test stage ($P < 0.05$), but no significant difference was observed in other cases ($P < 0.05$).

Pattern of changes in the mean head and neck angle (head and neck oscillations) in each frame by groups, testing steps in the Tsuki free punch, and Tsuki punch to the punching box as a total of 120 frames (one second) is shown in figure 2. The pattern of Tsuki punch movement is also shown in the figure as the average of the x-axis data and the styloid process marker at the wrist. Frame 60 is associated with the end of the Tsuki punch in all subjects.

Figure 3 shows the start time of the head movement and the movement of the upper limb in the free tsuki punch and the tsuki punch to the boxing bag, which is indicated by an arrow on the figure. Each frame is equal to 0.008 seconds, which in total, the beginning of head movement in both groups, both test stages, and both Tsuki punch patterns took place approximately 0.056 seconds earlier than the beginning of hand movement.

Table 1. Description of the characteristics of the subjects

Variable	Stage	Control (n = 12) Mean ± (SD)	Experimental (n = 12) Mean ± (SD)	P
The force produced in the upper limb in the free Tsuki punch (force)	Pretest	568.18 ± 98.84	528.18± 129.69	0.23
	Posttest	561.57 ± 93.31	548.53 ± 112.85	0.25
	P value	0.68	0.53	
The force produced in the upper limb in the Tsuki punch to the punching bag (force)	Pretest	570.80 ± 95.93	556.87 ± 91.46	0.62
	Posttest	580.35 ± 90.13	554.31 ± 109.24	0.34
	P value	0.71	0.93	
30% of 1RM (kg)	Pretest	11.53 ± 0.94	12.03 ± 1.19	0.24
	Posttest	11.76 ± 0.90	12.23 ± 0.88	0.20
	P value	0.08	0.35	
Time to reach fatigue	Pretest	75.23 ±23.25	73.00 ± 27.65	0.82
	Posttest	76.19 ± 22.93	110.08 ±51.42	0.02*
	P value	0.91	0.002*	

SD: Standard deviation; 1RM: One-repetition maximum; * Significance at the level of $P < 0.05$

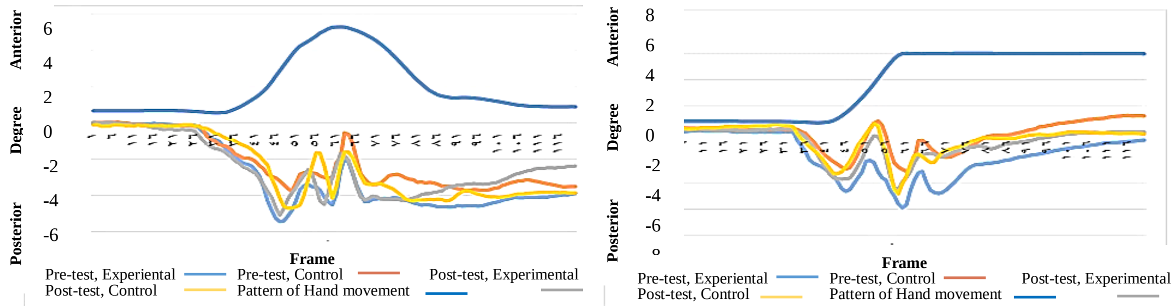


Figure 2. Pattern of changes in the mean head and neck angles (head and neck oscillations) in the experimental and control groups in the pre-test and post-test stages in the Tsuki free punch movement (top) and the Tsuki punch to the boxing bag (bottom).

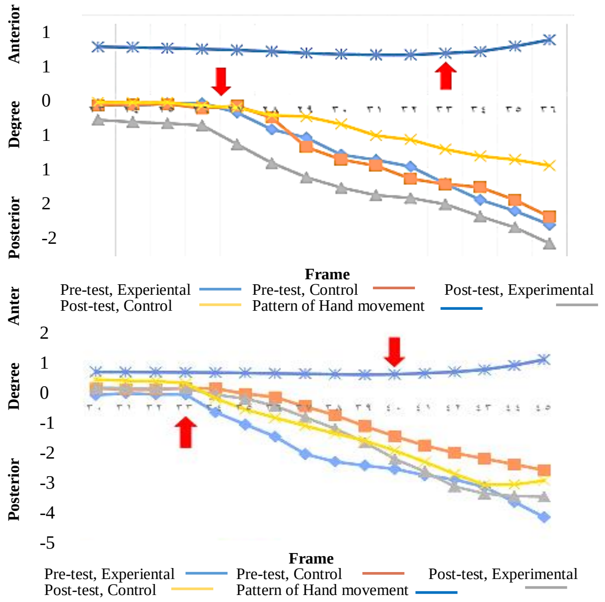


Figure 3. Starting points of head movement and upper limb movement in free Tsuki punch (top) and Tsuki punch to boxing bag (bottom)

The results of the paired t-test (P1) to compare the mean of data related to changes in the head displacement and angular acceleration in the free Tsuki punch in the pre-test and post-test stages in the control and experimental groups and also the results of ANCOVA test (P2) associated with these angles between the study groups is presented in table 2.

Based on the paired t-test results, a significant difference between the pre-test and post-test stages was observed in the experimental group at the angular acceleration of the head and neck at 0.24 seconds after the Tsuki punch (P1 < 0.050).

The time of entry of the external perturbation due to Tsuki punch to the punching bag was considered in frame 60 and the maximum displacement of the head and neck in the experimental and control groups was reported to be in frame 63 in the pre-test stage and in frames 62 and 63 in the post-test stage, respectively.

The results of the paired t-test (P1) to compare the mean of data related to changes in the head displacement and angular acceleration in the Tsuki punch to the punching bag in the pre-test and post-test stages in the control and experimental groups and also the results of ANCOVA test (P2) associated with these angles between the study groups is presented in table 3.

Table 2. Results of paired t (P1) and analysis of covariance (ANCOVA) (P2) tests to compare the mean changes of head and neck angles in free Tsuki punch

Variable	Group	Pretest	Posttest	P1	P2
		Mean ± (SD)	Mean ± (SD)		
Maximum posterior angular displacement of the head and neck in the first oscillation (degree)	Experimental	4.62 ±1.72	3.69 ± 1.58	0.120	0.870
	Control	2.89 ± 1.12	3.26 ±1.59	0.390	
angular displacement of the head and neck at the moment of completion of the Tsuki punch (degree)	Experimental	5.87 ± 4.12	3.94 ±2.71	0.080	0.510
	Control	2.92 ±2.33	4.05 ± 3.11	0.230	
Angular acceleration of the head and neck in the first head oscillation after the onset of the Tsuki punch (radians per square second)	Experimental	7.51 ± 2.05	6.66 ± 1.54	0.530	0.090
	Control	4.40 ±2.93	7.93 ± 3.36	0.080	
Angular acceleration of the head and neck at 0.024 seconds before the end of the Tsuki punch (radians per square second)	Experimental	59.16 ± 33.75	50.19 ±37.31	0.350	0.110
	Control	71.34 ±42.40	69.68 ± 51.00	0.900	
Angular acceleration of the head and neck at 0.024 seconds after the end of the Tsuki punch (radians per square second)	Experimental	74.55 ± 23.63	57.18 ± 29.19	0.006*	0.710
	Control	61.56 ± 27.36	64.74 ±34.38	0.700	

SD: Standard deviation; * Significance at the level of P < 0.05

Table 3. Results of paired t (P1) and analysis of covariance (ANCOVA) (P2) tests related to displacement and angular acceleration of head and neck in Tsuki punch to boxing bag

Variable	Group	Pretest Mean ± (SD)	Posttest Mean ± (SD)	P1	P2
Maximum head and neck angular displacement at the moment of impact to the boxing bag (degree)	Experimental	4.52 ± 2.28	2.95 ± 1.85	0.010*	0.020*
	Control	3.04 ± 2.09	4.15 ± 2.15	0.880	
Angular acceleration of the head and neck in 0.024 seconds before the Tsuki punch to the punching bag (radians per square second)	Experimental	27.10 ± 0.64	16.29 ± 9.62	0.004*	< 0.001*
	Control	32.92± 15.40	70.17 ± 12.23	< 0.001*	
Angular acceleration of the head and neck at 0.024 after the impact of the Tsuki punch to the punching bag (radians per square second)	Experimental	65.89 ± 28.93	24.69 ± 15.98	< 0.001*	< 0.001*
	Control	67.73 ± 18.52	70.86 ± 14.92	0.710	

SD: Standard deviation; * Significance at the level of P < 0.05

The paired t test results showed that in terms of maximum displacement of head and neck angles at the moment of impact to the punching bag, there was a significant difference between the angular accelerations of head and neck at 0.024 seconds before and after the impact of Tsuki to the punching bag in the experimental group in the pre-test and post-test stages (P1 < 0.050). However, in terms of head and neck angular acceleration 0.024 seconds before Tsuki hit the punching bag, a significant difference was observed between the pre-test and post-test stages in the control group (P1 < 0.050). The results of the ANCOVA test indicated that in all three variables, there was a significant difference between the control and experimental groups in the post-test (P2 < 0.050).

Discussion

The findings of the present study suggested that when performing a free Tsuki punch and a Tsuki punch to the boxing bag, the head starts to move in the posterior directon (opening the head angle) before the Tsuki punch begins. The results of the study by Gurfinkel et al., which aimed to evaluate the electromyography of the neck muscles and the kinematics of the head area during rapid arm movement in different directions, showed that before the acceleration of the upper limb, posterior acceleration can be observed in the head area. They stated that the reason for this posterior acceleration in the head area was the activation of Splenius capitis and Upper trapezius. Therefore, the observed displacement is due to the activity of the neck muscle prediction strategy, which is an important and pre-designed strategy to maintain postural stability of the neck area before the onset of upper limb activity (internal perturbation) (22), which was consistent with the findings of the present study. Additionally, van der Fits et al., by examining the angle formed between the two markers of the chin and ear with the horizon, confirmed the existence of initial posterior acceleration and the anticipation strategy of the neck muscles in the head area against the upper limb perturbation. In their study, they concluded that the anticipation strategy in the neck area shows the interaction of the and posterior muscles of the neck (23).

The results of the present study showed that the onset of head movement relative to hand between the experimental and control groups in the pre-test and post-test stages was somewhat identical and about 0.056 seconds earlier than the onset of the free Tsuki punch and Tsuki punch to the punching bag, which is different from that of the study by Gurfinkel et al. (0.045 seconds) (22). However, the results of their study showed that the time difference between the onset of activity of the first muscle (upper trapezius with a time of 0.062 seconds) and head movement was 0.006 seconds, in other words, after starting the activity of the first muscle anticipation strategy until observing the movement in head, there was a delay of 0.006 seconds (22). The difference in the delay recorded in the study of Gurfinkel et al. (22) and the present study (0.045 seconds vs. 0.056 seconds) may be due to differences in the upper limb movement pattern in the two studies. In the study by Gurfinkel et al., the rapid movement of bending the hand in front of the body was used (22); while the present study was on the Tsuki punch in karate. Furthermore, the difference may be due to fatigue of the subjects' neck muscles in the present study; Because the results of studies show that postural muscle fatigue will cause the activity of feedforward muscles to start earlier (8,24). In fact, the reason for the early activity of the feedforward muscles is the compensatory strategy of the nervous system to compensate for the decrease in the level of tired muscle activity by giving the muscles more opportunity and to prepare them to deal with perturbations (24).

Based on the results of the present study, there was no significant difference between the maximum angle created in the first oscillation of head and neck opening in the free Tsuki punch between the experimental and control groups in the post-test stage. In addition, the results showed that there was no significant difference between the control and experimental groups in head oscillation at the end of the free Tsuki punch. Although the reduction of angle was observed in both first oscillations of the head opening and the oscillation of the head at the end of the free Tsuki punch in the post-test phase of the experimental group, lack of significance means no effect of the exercise program on neuromuscular function and reduction of head oscillations, which did not match the results of the study by Jull et al. (25). In their study, they evaluated the effect of 6 weeks of two types of low-load craniocervical flexion exercises and high-load cervical flexion exercises on the activity of deep cervical muscles in cervical motor tasks [craniocervical flexion test (CCFT)] and the timing characteristics and activity level of these muscles for internal perturbation of upper limb movement in individuals with neck pain. Based on the results, a significant increase in activity in the deep cervical muscles and a decrease in activity in the superficial cervical muscles (sternocleidomastoids and scalenes) were reported in the low-load craniocervical flexion training group. Additionally, in terms of timing, the low-load training group showed less relative delay in starting the deep muscle anticipation strategy compared to the strengthening training group (25). The first reason is the discrepancy between the results of the study by Jull et al. (25) and the present study in the group of subjects. The subjects of the study of Jull et al. were patients with neck pain (25), whose proprioceptive performance and postural stability strategies due to pain were different from those without pain. Another difference was in the evaluation method, as a muscle electromyography device was used in the aforementioned study (25), which is different from recording the kinematic activity of the head and neck in the present study. Finally, the use of a craniocervical flexion training program was another reason for the differences. Given the results of the study by Falla et al., despite the short-term effects, the craniocervical flexion training program does not have long-term effects transferable to functional activities (26). One of the reasons for the insignificance of the results of the present study against the internal perturbations of the free Tsuki punch is the length of the frame. Kinematic differences of less than 0.008 seconds were not observed in the present study.

The findings of the present study revealed that there was a significant difference between the control and experimental groups in terms of displacement of the head angle against external perturbation at the moment of impact of the punch to the punching bag in the post-test ($P < 0.050$). The pattern of anterior oscillation of the head after the onset of external perturbation showed that the mean angle change in the experimental group occurred about 0.008 seconds earlier than the mean angle change of the same group in the pre-test stage and also compared to the control group. There was a significant difference between the control and experimental groups in terms of angular acceleration of the head before and after the Tsuki punch hit the punching bag ($P < 0.050$). In contrast to internal perturbation, in which postural control depends more on the anticipatory strategy, in external perturbations predictable by the athlete, the compensatory strategy plays an important control role (27). In unpredictable situations in the face of external perturbations of the upper extremities, the anticipatory strategy of the nervous system does not take place, and in these conditions, the muscles are activated by the compensatory strategy of the nervous system. In contrast, in the predictable situation, both anticipatory and compensatory strategies are present. In their study, Santos et al. stated that with the impact, the head moves backward (opening) and then forward (2), which contradicted the findings of the present study. The results of the present study indicated that after the entry of an external force (after the moment of impact of the Tsuki punch to the punching bag), the head oscillates towards the front (reduction of the head angle). Perhaps the reason for this discrepancy is how the external perturbation is created. In the study by Santos et al., the subject was asked to keep the upper limb in front of the body and parallel to the ground, and the external perturbation was created with a pendulum hitting the hand (2). In contrast, in the present study, the athlete’s upper limb moves before Tsuki hits the bag, which itself causes internal perturbations in the body. Besides, in the present study, there was fatigue in the neck muscles. Regarding the effect of exercise on postural regulatory strategies of the body against external perturbations, the results of the present study were in line with the findings of the study by Kanekar and Aruin (3). They examined the effect of receiving medicine ball on the shoulder training on postural stabilization strategy of the trunk and leg muscles, as well as shifts in body’s center of mass (COM) and center of gravity (COG) following external perturbation of the upper limb. The results of their study indicated the positive effects of these exercises on postural stability strategies and postural fluctuations (3).

The results of the present study were consistent with the results of the study by Hassanlouei et al., who investigated the reducing effect of endurance training on postural fluctuations against perturbations during muscle fatigue (1). In their study, which was performed on the knee muscles, a decrease in muscle activity and an increase in postural fluctuations following fatigue of the knee flexor and extensor muscles were observed in the pre-test stage. After 6 weeks of the endurance training, the subjects’ muscle strength increased and they were able to continue training for longer periods of time during fatigue. The subjects also had a higher ability to maintain their posture in the face of perturbation during fatigue. According to them, increasing the sensitivity activity of muscle spindles when the afferents information is impaired (muscle fatigue), increases the function of the person to maintain posture (1); they used endurance exercises in their study. The primary effect of the proprioceptive exercises used in the present study was to increase the sensitivity of the muscle spindles and increase the perceptual aspects. However, previous investigations have noted the effects of proprioceptive training on increasing muscle strength and endurance, which can also lead to better muscle performance in cocontraction activities, improved neck reflexes, and ultimately increased head stability in the face of perturbations.

The proprioception system is responsible for regulating muscle stiffness and muscle reflexes to maintain joint stability. Cocontraction of the agonist and antagonist muscles of a joint increases the stiffness of a joint and increases the stability of a joint. Stiffer muscles resist sudden joint displacement. Therefore, excessive displacement reduces joint dislocation or damage. Stiffer muscles, on the other hand, enhance the potential capacity of the external component and, as a result of high activity, transfer loads and pressures to the spindle muscle more quickly and easily. Thus, they reduce the time gap associated with the onset of reflex activity (28). Considering the importance of cervical proprioception and confirming the effect of exercises on the time to fatigue in the descriptive results of the study, it can be concluded that increasing the efficiency of neck proprioception may have played a positive role in reducing head and neck fluctuations against external perturbations caused by the Tsuki impact to the punching bag.

Limitations

The limitations of the present study included differences in the anatomical structure and muscle strength of the subjects, lack of control over their mental state during testing and training, lack of control over the subjects’ resting state, and failure to record electromyographic activity of neck muscles at the time of evaluation.

Recommendations

The present study can be performed on individuals by body type. Additionally, comparing the effect of training in the two groups of male and female athletes and examining the effect of proprioception training on electromyographic activity of cervical muscles against internal and external perturbations is suggested to be addressed in future studies.

Conclusion

Proprioception exercises can be used alongside other bodybuilding exercises for karateka athletes to reduce the effect of external perturbations on the cranocervical area of these athletes and possibly reduce gradual injuries in this area when the athlete is tired.

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Authors’ Contribution

Nadjmeh Afhami: study design and ideation, attracting financial resources for the study, study support, executive, and scientific services, providing study equipment and samples, data collection, specialized evaluation of the manuscript in terms of scientific concepts, responsibility to maintain the integrity of the study process from beginning to end publishing, and responding to the referees’ comments; Reza Siamaki: data collection, analysis and interpretation of results, specialized statistical services, and manuscript preparation; Nadjmeh Sadeghi, specialized statistical services, approval of the final manuscript to be sent to the journal office.

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Conflict of Interest

The authors declare no conflict of interest. The corresponding author attracted the budget for basic studies related to this study from Sirjan University of Technology and has been working as an assistant professor of physical education and sports sciences at Sirjan University of Technology since 2018. Reza Siamaki is an assistant professor of sports pathology and corrective exercises of Asrar Institute of Higher Education, Mashhad, Iran, since 2020. Nadjmeh Sadeghi has been an assistant professor of physiology at Sirjan University of Medical Sciences since 2020.

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