EMG Analysis of Trunk Muscle Recruitment Patterns of Anticipatory Postural Adjustments during Unilateral Arm Flexion in Chronic Neck Pain Patients

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ABSTRACT

Introduction: EMG recruitment pattern of trunk muscles can change to compensate pain. One of these pattern alterations occurs in anticipatory postural adjustments (APAs) or feedforward activity of trunk muscles prior to arm movements. No study has determined the EMG pattern alterations of trunk muscle recruitments during the arm movement in patients with chronic neck pain (CNP). This study was examined the effect of CNP on EMG activities of trunk muscles for APAs during rapid arm flexion.

Material and Methods: Sixteen patients with CNP for at least 3 months and sixteen healthy individuals matched in gender, age and weight were selected in this semi-experimental study. Surface EMG was utilized to evaluate 8 trunk muscles bilaterally and right anterior fibers of deltoid muscle during a unilateral rapid arm flexion. Anticipatory muscle activity was calculated by EMG onset latency of the trunk muscle from 100 ms before deltoid activity to 100 ms after it. Also, the values of root mean square (RMS) in 4 epochs around the onset of deltoid EMG were measured and compared. A two-tailed t-test and repeated-measure ANOVA were used for statistical analyses.

Results: The onset latency of muscles in left and right side, except left erector spine muscle, in patients showed a significantly higher delay compared to healthy controls (P<0.05). The analysis of RMS in the 4 epochs revealed that in the control group, the values of RMS for rectus abduminus and erector spine in both sides, left external oblique and left transverse abduminus/internal oblique increased significantly during Epochs 3 and 4 , but in CNP subjects, the RMS of these muscles did not change significantly in 4 epochs.

Conclusion: The patients with CNP had alterations in their recruitment patterns of particular trunk muscles in response to arm movement.Therefore, these patients have impaired motor control of trunk muscles during internal perturbation. These results indicated that not only the alterations in recruitment of trunk muscles occur, but also the intensity of their contractions decreases. In conclusion, CNP may alter in order to control the reactive forces resulting from limb movement.

Keywords
EMG Recruitment Pattern, Chronic Neck Pain, Anticipatory Postural Adjustment, Trunk Muscles

Introduction

Chronic neck pain (CNP) is a common neuro-musculoskeletal condition that influences functional activities and is a major source of disability in the society with an incidence of 13.3 % to 64.5

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% [1, 2]. It seems that neck pain has a correlation with alterations in control strategies and cervical muscles peripheral changes [3, 4]. Moreover, neck pain leads into deviations from normal movement control strategies, and these alternations correspond to pain and disability [5]. These changes were established in the recruitment pattern of the onset latency in deep and superficial cervical muscles [5]. Pain affects and disrupts neuromuscular control. When chronic pain exists the motor output and control are affected. Above all, nociceptive inputs can alter the central motor control mechanism [6]. Therefore, the chronic neuromuscular responses and adaptations may be extended to the other regions far from the cervical area [7].

One of the motor control mechanisms that can change after chronic pain is anticipatory postural adjustments (APAs) or feedforward mechanism [8]. APAs occur to provide stability of the trunk before limb movements and protect spinal structures. These reactions are involuntary and automatic adjustments that occur prior to a predictable perturbation. Unilateral reaching tasks are very common functions in daily activities and spinal stabilization is necessary before arm movements [8].

In the normal population, local muscle activities provide spinal control for this function [9]. Any changes in this system may lead into the pain and disability in spinal region [10]. Deficits in cervical motor control strategies in CNP are reported frequently in the previous literatures [3, 4].

The onset of deep cervical flexor muscles motion with arm movements is an important criterion that shows APAs activity. A significant shortage in the automatic APAs control of the cervical spine was revealed in patients with CNP. The motor control of cervical spine in patients with CNP changed the activation in both of the deep and superficial cervical flexor muscles, which is linked to swift arm movements [3]. The inhibition of deep neck muscles and the over activity of the superfi-

cial neck muscles are due to a change in the strategy utilized by the central nervous system to control the cervical spine in patients with CNP [3].

Recent researches have investigated that in addition to disturbance in local neuromuscular control patterns, general neural control patterns can be altered [11]. Changes in the motor control system may occur earlier than the pain beginning and predispose to elicit the development of the other spinal regions dysfunction. It is probably a common problem in the motor system that leads into the presence of pain in the neck and low back regions simultaneously [7].

In low back pain, APAs of trunk muscles are altered while elevating the arm [12, 13]. In normal pattern of APAs, trunk local and global muscles ,including the transverse abdominus (TrA) [14], the internal oblique (IO) [15], the external oblique (EO), the rectus abdominis (RA) and the erector spinae (ES) were triggered prior to estimate trunk orientation and sustaining balance within the base of support when to start an upper limb movement [16, 17]. The onset of deep abdominal muscle activity, especially transversus abdominis (TrA) was reported to face a delay in association with the rapid limb movement in people with low back pain [10, 14]. Therefore, inappropriate muscle recruitment and timing might be a predisposing factor causing low back pain [18-20].

Recent studies suggest that a prolonged musculoskeletal pain may have an influence on central mechanisms of motor control [19, 21]. There are anatomical and neurophysiological connections between cervical, thoracic and respiratory regions. Therefore, CNP can display the alteration of muscle recruitment in thoracic and respiratory muscles [22]. Chronic neck pain patients revealed decreased thoracic spine mobility and respiratory dysfunction [23-27]. Furthermore, neck pain affects motor control of axio-scapular muscles during arm movements [28]. In spite of a relationship be-

tween neck and low back areas, no research is conducted about the influence of CNP on altering the anticipatory trunk muscle responses. Therefore, the aim is to examine the effect of chronic neck pain on APAs of trunk muscles response to rapid arm movements. It was hypothesized that CNP changes the reaction time of trunk muscles during fast arm movements.

Material and Methods

Subjects

Sixteen individuals with CNP for at least 3 months (9 females and 7 males, age ranging of 30-50 years) and sixteen matched healthy individuals were recruited for this pilot, experimental study. All the participants had normal or corrected vision and were right-handed. The CNP patients were selected according to the following criteria: (1) persistent neck pain more than three months, of a traumatic or insidious onset, (2) no previous history of radicular involvement, and (3) normal neurological examination (4) having Neck Disability Index (NDI) score of at least 10/100 at the time of study.

For the control group, the main recruiting criterion was the absence from neck pain during 18 months ago. The exclusion criteria included any known medical complications, previous spinal or abdominal operation, serious spinal or systemic pathology like metastasis, rumatoid arthritis, and pregnancy within the previous 12 months, inability to stand more than 20 minutes and any history of neurological or orthopedic disorders. Furthermore, the experimental group had not received physical therapy or exercise for the previous six months. The demographic characteristics and neck pain findings are summarized in Table 1.

All participants signed a written informed consent before entering the study.

EMG recordings

The EMG data were collected using a data acquisition system (EMG MEGA Win, USA). After shaving and cleaning the skin with alcohol, disposable Ag/AgCl surface electrodes were fixed on 9 muscles. Each electrode was positioned in the direction of the muscle fibers over 8 muscles bilaterally and on the right anterior fibers of deltoid. Standard electrode placement at nine muscles was used as follows: rectus abdominus (RA), 3 cm lateral to the umbilicus, transverse abdominus / internal oblique (TrA/IO), approximately 2 cm medial and 2 cm inferior to the anterior superior iliac spine; external oblique (EO, approximately 3 cm anterior to and mid-way along a line drawn from the lateral pelvic crest to the lateral lower rib cage, erector spine (ES), 3 cm lateral to the L3 spinous process, anterior fibers of right del-

Table 1: Descriptive characteristics of both groups (means ± SE).

	CNP* (n=16)	Control (n=16)	p-value
Age (years)	38.77 ±3.18	35.33±1.63	0.355
Height (m)	178±2.4	179.66±2.01	0.603
Weight (kg)	76.11±5.81	79.33±3.82	0.65
Gender (females/males)	(11/9)	(11/9)	
Pain VAS (/10)	6.27±1.07		
Pain duration (months)	38.85± 7.06		
NDI*	43.82±9.57		

NDI=Neck Disability Index

CNP=Chronic Neck Pain

toid five centimeters below the acromion process [29].

The participants were ordered to stand in a preferred foot position with their arms relaxed along the side of the body and by focusing on a circle with a diameter of 5 cm at a distance of 2 meters. The feet position was marked so that the same position would be used for everyone as well. An auditory warning signal was used to ensure that a quiet standing posture was performed before the reaction task movement. Participants were asked to flex the arm at the maximum possible speed.

At first, the participants were warned of an auditory signal and after 3 seconds, a visual cue was provided. The visual cue included red and green lights. After the signal of green light, the subjects had to perform right arm flexion (90 degrees flexion) as quickly as possible. If the red light was turned on, the subject did not move the arm. Randomly the signal of green light or red light was turned on in order to prevent the subject from predicting the time of movement. To familiarize the participants with the task, 3 practice trials were performed before the experimental trials. A 5-second period was allowed between the trials.

The EMG onsets for all the muscles were normalized to the onset of the anterior deltoid muscle of the Rt arm and an average of 3 trials was used for further evaluation. Anticipatory muscle activity was defined from 100 ms before the deltoid onset activity to 100 ms after it [30]. The difference between the onset of the abdominal muscles and the right side deltoid was calculated for analyses.

Data Processing

Post processing consisted of removal from heartbeat artifacts; then the EMG signals were amplified with an overall gain of 1000. All EMG signals were digitally band-pass filtered within 20–450 Hz (2nd order Butterworth zero-lag filter) then full wave were rectified.

MATLAB 8.6 was used to analyze EMG signals. In order to compute the onset latency of each activity, signals were further smoothed with a 50 Hz low-pass filter. All filters were designed to be zero-lag and linear-phase. The onset of a signal was defined to take place when, for 25 milliseconds, the amplitude of a group of successive samples remained higher than a threshold which was chosen to be the mean+3SD of a signal before triggering.

The root mean square (RMS) was calculated to measure the average trunk muscle activity. To compare the changes in EMG activity of these muscles between two groups, data were analyzed by comparing the RMS during 50-ms epochs around the onset of deltoid EMG. The onset of deltoid EMG was recognized from the raw data and the RMS for each 50-ms epoch was determined (Epoch1: 100 to 50 ms; Epoch2: 50 to 0 ms; Epoch3: 0 to 50 ms; Epoch4: 50 to 100 ms).

Statistical analysis

The statistical analysis was performed using SPSS version 21. The normality of distribution for every dependent variable was assessed using the Schapiro-Wilk test. To compare variables between the groups, independent t-test was used for data with normal distribution and then U-Mann Whitney for data with no normal distribution for analysis of these variables. A repeated ANOVA was conducted to assess whether there were epochs differences in muscle activity within group. P-values less than 0.05 were considered to be statistically significant with Bonferroni correction.

Results

Regarding the baseline data, the groups did not show any difference in demographic data (Table 1). The EMG onsets of all muscles are summarized in Table 2. According to this table, in the control group, earlier onsets for all trunk muscles were revealed and their reaction time were in APAs range. In the CNP group, the trunk muscles were activated in a feedback manner and they did not have a reaction to APAs response, except for the Lt ES. There-

Table 2: Mean (SD) of the latency between the onsets of trunk muscle EMG and that of deltoid for two groups.

Onset latency	CNP group	Control group	P
Right RA	198.59±224.72	98.31±28.04	0.087
Right EO	124.86±187.28	95.52±79.85	0.569
Right TrA/IO	198.76±159.89	100.07±34.87	0.022
Right ES	126.80±64.23	93.47±62.14	0.146
Left RA	268.86±84.64	97.72±23.8	<0.0001
Left EO	384.98±425.27	55.43±82.05	0.027
Left TA/IO	159.88±114.61	87.93±30.51	0.032
Left ES	90.41±114.3	59.65±50.86	0.892

fore, the onset of seven out of eight trunk muscles increased compared to the control group, but only the timing of EMG onset of Lt RA, Lt EO and Lt TrA/IO and Rt TrA/IO revealed the significant difference.(P <0.05)

The average muscle activity was calculated by the root mean square (RMS) in 4 epochs (50 ms). The RMS values for each 50-ms epoch before and after the onset of deltoid for two groups are shown in Figure 1. These analyses were showed to confirm the effect of group on EMG activity of muscles and determine the changes in RMS EMG activity between two groups.

Results indicated a significant main effect of group found for Rt TrA/IO($F_{(1.07, 30.95)}$ =2.262, P=0.14), RT EO ($F_{(1.107, .116)}$ =2.316, P=0.13) and Rt ES ($F_{(1.055, 30.609)}$ =0.038, P=0.85), but a significant interaction between time and group was found for the other muscles as following: Rt RA ($F_{(1.35,36.13)}$=16.073, P<0.001), Lt RA ($F_{(1.594,46.227)}$=24.043, P<0.001), Lt EO ($F_{(2.343,67.952)}$=3.512 , P=0.029), Lt TrA/IO($F_{(1.995,57.894)}$=9.73, P<0.001) and Lt ES ($F_{(1.659,48.119)}$=7.582 , P<0.002)

The analysis of epoch data revealed that in control group, RMS of Rt and Lt RA increased in epoch 3 and 4 significantly compared to epoch1 and 2 (P<0.05), but in the CNP group, RMS of these muscles did not change in first 3 epochs. However, in epoch4, RMS was high-

er significantly than the other three epochs. (*P*<0.05)

Lt EO and Lt TrA/IO increased significantly during epochs 3 and 4, but there was no difference in RMS between 4 epochs of Lt OE in CNP group. However, in Lt ES, RMS of the third and fourth epochs were not different significantly, although for the other epochs it increased significantly.

The results suggest that the amplitude of trunk muscles raised significantly in epoch 3 and 4 in the control group, but in the CNP group, their amplitudes were consistent or changed less during 4 epochs.

Discussion

This study aimed to investigate motor activation patterns of eight trunk muscles, including bilateral EO, TA/IO, RA and ES during a rapid arm flexion in CNP patients compared to healthy subjects. The main finding of the present study revealed that patients with CNP had higher onset latency of trunk muscles during arm flexion compared with their matched healthy control group.

The results demonstrated that the recruitment pattern of trunk muscles altered in CNP in comparison to healthy subjects.

Reactive forces from arm movement perturb trunk and the nervous system become alert for expected postural disturbances with prepara-

tory muscle activity and movements that oppose the direction of disturbance.

It has been suggested that the latency of the trunk muscles for APAs reaction time is 100 ms before the onset of the prime mover to 100 ms after it, but in the present study, the RA, TrA/IO, EO on both sides and ES on right side activated after this time period suggest that these postural muscles were activated in a feedback manner in CNP group. Compared to the control group, the abdominal muscles contralateral to the side of arm flexion showed increased delay onset. This indicated that patients with CNP have impaired the motor control of trunk muscles during internal perturbation.
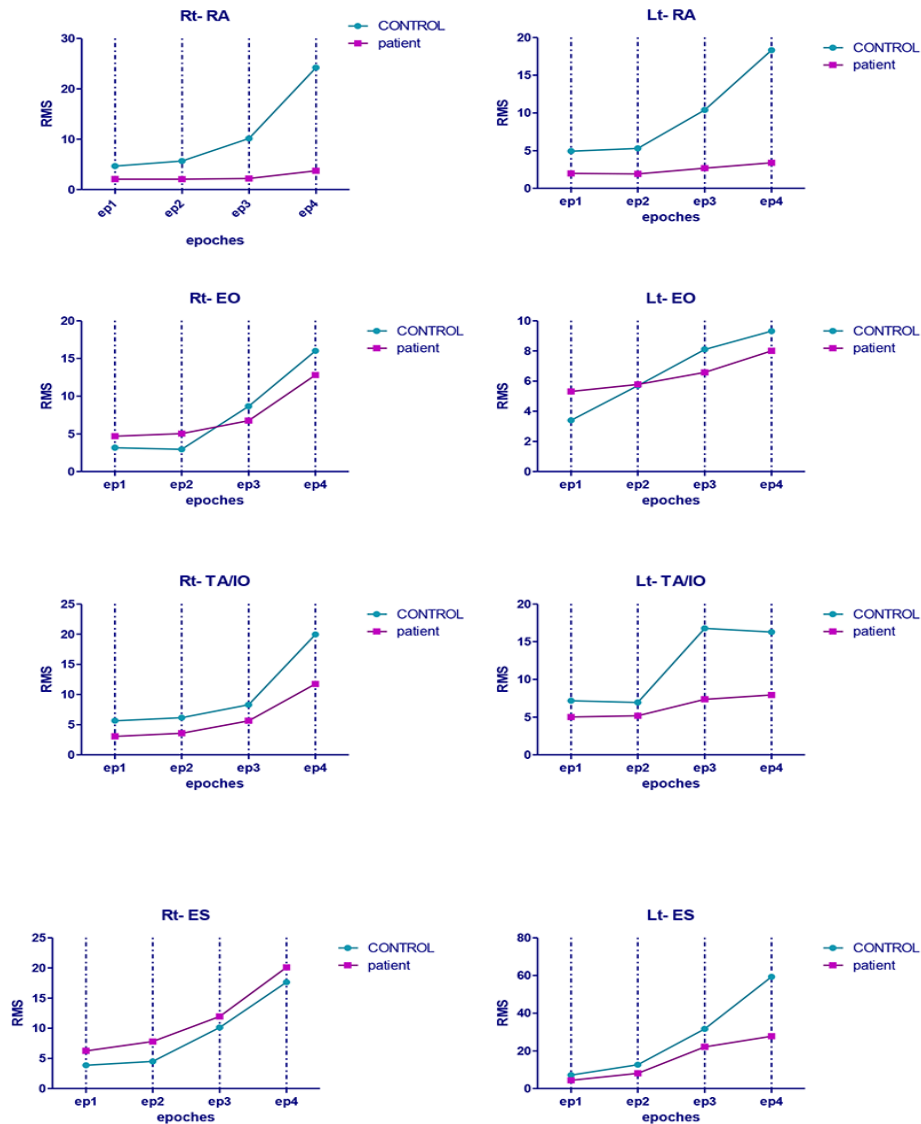
Figure 1: Group data for trunk muscle EMG amplitude during unilateral arm movements. Data for the control (blue line) and neck pain patients (purple line) are shown for each epoch as mean and standard deviation of 8 trunk muscles in both sides. right and left rectus abdominus (Rt RA, Lt RA), right and left external oblique(Rt EO, Lt EO), right and left transverse abdominus/internal oblique(Rt TrA/IO, Lt TrA/IO), right and left erector spine (Rt ES,Lt ES). EMG amplitudes are calculated as the root-mean-square value over four 50-ms epochs (epoch1: −100 to −50 ms; epoch2: −50 to 0 ms; epoch3: 0 to 50 ms; epoch4: 50 to 100 ms).

Anticipatory co-activation of trunk muscles is required to control and increase the steadiness or positioning of the trunk against the internal and external forces, which results from limb movements. Spinal stability needs the co-activation of both agonist and antagonist muscles in trunk; therefore, the central nervous system (CNS) can stabilize the spine (feed-forward input) before the perturbation occurs. Trunk muscles stabilized the spinal segments by increasing the intra-abdominal pressure [31].

Previous studies showed a delayed activity of trunk muscles related to pain and a disturbed co-activation of trunk muscles connected to limb movements [10, 12]. This converted recruitment can lead into abnormal development of uncontrolled movement and loss of functional or dynamic stability, and in a vicious cycle can cause pain in many segments.

Changes in APAs in some musculoskeletal conditions should be considered for the patient's functional outcome and the risk of future recurrence [13, 32]. Many researches revealed APAs responses can be altered in the presence of LBP [10, 33]. Similarly, inhibition of the deep abdominal muscles might affect the steadiness and posture of the lumbar spine by increasing the LBP [34]. According to the results of the present study, delay in trunk APAs reaction time made changes in CNP patients. These patients have impairments in the control of their lumbar spine that predispose them to repeated stress and strain that can predispose them to the future low back pain.

The onset latency alterations was shown to represent a difference in motor planning. This can be clarified by variations in motoneuron and motor cortex excitability. Widespread modification in excitability has been identified at many levels of motor system while in pain [35]. The results of our study suggested that pain in any side of the spine might be accountable for the initiation of motor control dysfunction in other areas.

The necessary APAs and feedback mecha-nisms can be integrated with the appropriate motor program. Previous studies showed that patients with musculoskeletal pain have reorganization of the neuronal properties in the sensorimotor system representing the muscles most affected by pain [32]. For instance, low back pain (LBP) patients have reduced cortical spinal drive in the lumbar spinal muscles [36]. According to our findings, these changes may occur not only in a local region of pain and dysfunction, but also it may affect the regions far from it. CNP patients in this study showed similar findings with LBP patients although they did not have any back pain in the time of test.

This adaptive pattern may have occurred due to musculoskeletal dysfunction independent of pain.

In the presence of neck pain, changes in sensory function will have major effects on movement control [37]. The variations consist of reduced sensory acuity, responsiveness to sensory input, and reorganization of the somatosensory regions of the brain cortex [35]. All of these can impact other equilibrium reactions that relate to sensory inputs, including APAs reactions. These changes might lead to further difficulties in CNP patients especially LBP in later.

Several studies approved the deficits of proprioception in CNP [38, 39]. This deficiency could be justified by the interrupts ascending afferent impulses toward the central nervous system (CNS), consequently, it may be the other cause of decreased or altered activation of postural muscles. Alterations of motor patterns influence changes in the trunk APAs activity and finally lead to dynamic instability of the spine.

The results of this study showed that in CNP group, the abdominal muscles in left side revealed a significant delay compared with the muscles in the control group, but left ES in CNP group contracted as APAs manner as control group.

According to previous studies, the trunk

postural response in healthy participants is controlled by specific trunk muscles, including TrA, IO, EO and ES. These muscles act in an anticipatory fashion by firing prior to (or in conjunction with) the rapid movement of the limb in order to reduce moments made by the perturbation. TrA has an essential role to stabilize the spine although it is claimed that EO, IO, and ES have also an important role to move and control the spine [40].

The TrA stabilizes the spine and produces the intra-abdominal pressure. Therefore, APAs activation of the TrA helps to control the spinal segmental motion. Larger and more superficial trunk musculature, including EO, IO, RA and ES responds in a APAs manner, which are connected to the direction of extremity perturbation or center of mass (COM) displacements [40]. In rapid upper extremity flexion, the COM is moved anteriorly; thus, the trunk extensors, especially ES fire prior to the limb movement for decreasing the postural perturbations. In unilateral arm flexion, the contralateral muscles of trunk contract for reducing the unilateral flexion moment in opposite limb. Therefore, in Rt arm flexion, the Lt trunk muscles have more activity than Rt side [33]. The results revealed that the significant increase of delay onset in Lt abdominal muscles occurred in CNP group compared to the control group, but left ES in CNP group acted like this in the control group. It has been suggested that Lt ES response to postural challenge did not change in CNP. It can be due to its APAs activity based on the direction of extremity movement. In this situation, Rt arm flexion disturbs the COM, the contralateral ES contracts against this flexion moment and COM displacement although spinal stability controlled by TrA, IO, EO and RA [33]. Therefore, Lt Trunk muscles that have to contract earlier, showed more delay in APAs activities in CNP patients. It seems that the role of ES is not influenced by CNP. In comparison with the control group, the reaction time of the other trunk muscles in left side was deficient significantly in the CNP group with unilateral arm flexion movement. Although Lt ES maintains the balance of body, the trunk muscles cannot stabilize the spine appropriately. This finding is consistent with previous results, which have indicated that early APAs activity of ES at the fast speed of arm flexion occurs in a similar manner of the control group in LBP patients [41]. Thus, Lt ES was the only recorded trunk muscle that activated within the APAs manner in this study.

Comparing the interaction of trunk muscles and the corresponding group, the results have determined that the amplitude of trunk muscles increased during arm movement in the control group. In the third and fourth epoch, as the range of arm increased, the activity of trunk muscles raised simultaneously. It can occure due to the displacement of COM. During arm flexion, as the perturbation progressively raised, the activity of trunk muscles increased to compensate this instable situation.

In the CNP group, there is not any change in the amplitude of trunk muscles especially in Lt Side. This finding has provided evidence that not only the alterations in recruitment of trunk muscles occur, but also the intensity of their contractions has decreased, especially in the Lt Side.

Due to the inherent instability of the spine, specifically in the neutral position, these changes in recruitment and activity might indicate inadequate protection of the spinal structures from injury and functional disturbances that might lead to the development of LBP in CNP patients during their life.

This study is one of the basic researches for assessing trunk muscles in the patients with CNP. The results suggest that people with a history of CNP have altered time of recruitment of specific trunk muscles in response to the rapid arm movement. These changes in recruitment may indicate the inadequate protection of the spinal structures from injury. Therefore, neck pain may be responsible for the initiation of the motor control dysfunction

in lumbar region, although this claim needs further investigation, but also it depends on the results of the present study.

Evaluation of back muscles should be considered in CNP patients.

The patients with the chronic condition of neck pain were evaluated in our study. Further studies are suggested to investigate patients with acute neck pain.

In the current study, there was the limitation that we used surface EMG electrodes to record abdominal muscle activity. Recording EMG from the deep requires intramuscular electrodes, especially for differentiating superficial and deep muscles.

Conclusion

The present study verifies that APAs responses of the trunk muscles are affected by CNP. The muscles of the contralateral side of limb movement are more affected compared with the muscles of healthy subjects. The APAs manner of these muscles in CNP was similar to those established in people with chronic LBP. This infers that CNP patients might be prone to develop LBP in the future.

Acknowledgment

Conflict of Interest

None

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