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Changes of postural control and muscle activation pattern in response to external perturbations after neck flexor fatigue in young subjects with and without chronic neck pain

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ABSTRACT

Purpose: Previous studies have identified sensorimotor disturbances and greater fatigability of neck muscles in patients with neck pain. The purpose of this study was to investigate the effect of neck pain and neck flexor fatigue on standing balance following postural perturbations.

Methods: Twenty patients with chronic neck pain (CNP) (24.7 ± 3.6 year-old) and 20 age-matched asymptomatic subjects (22.1 ± 2.2 year-old) were recruited. Subjects stood barefoot on a force plate and experienced backward perturbations before and after neck flexor fatigue. Center of pressure, electromyography of cervical and lumbar muscles, and head/trunk accelerations were recorded. Two-way ANOVA (pain × fatigue) was used for statistical analysis.

Results: CNP group showed larger body sway during quiet standing but not during perturbed standing compared with asymptomatic adults. In both groups, neck flexor fatigue resulted in greater body sway during the quiet standing but smaller body sway during perturbed standing, increased neck muscle activations and decreased lumbar muscle activations, as well as increased time to maximal head acceleration.

Conclusions: Disturbed balance control was observed in CNP patients during the quiet standing. However, a rigid strategy was used to minimize the postural sway and to protect the head against backward perturbations in both CNP and asymptomatic young adults after neck flexor fatigue. The results facilitate the understanding of how the subjects with chronic neck pain and with neck muscle fatigue deal with the challenging condition. Further studies are needed to verify if such phenomenon could be changed after the intervention of specific flexor muscle retraining and balance control exercises.

1. Introduction

Chronic neck pain (CNP) is a common musculoskeletal disease with a reported 1-year prevalence ranging from 10.4% to 75.1% in the adult population worldwide [1]. It is one of the most common causes of long-term physical and psychosocial disabilities with a high recurrence rate [2,3]. Higher perceived neck disability and fear of movement in individuals with CNP may also lead to reduced physical activity [4].

Cervical spine, with abundant cervical mechanoreceptors, plays a critical role in the integration of multisensory afferent input involving the proprioception, vestibular, visual and somatosensory information [5]. The high densities of muscle spindles in the suboccipital muscles are integral in maintaining appropriate postural control [6,7]. The muscle spindles and mechanoreceptors in the cervical region relay somatosensory information to and from the central nervous system (CNS) via specific pathways. While individuals subject to vibration or induced fatigue of the neck muscles, these pathways are highlighted by the identification of

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postural deterioration such as the significant change in velocity and the direction of gain [8,9].

Postural control relies on the ability of the CNS to correctly identify and selectively focus on the multisensory afferent input. With pain, the performance of CNS in postural adjustments is greatly reduced as the input of pain has priority over other somatosensory stimuli [10]. Prolonged presence of pain can also affect postural stability and head movement control [11,12]. Similarly, the presence of muscle fatigue has been suggested to indirectly deteriorate the reliability of the proprioceptive signals due to altered muscle spindle afferent input [13]. With altered muscle contractile efficiency, the postural and cortical control is negatively influenced [14,15]. The purpose of this study was therefore to assess the influence of neck pain and induced neck flexor muscle fatigue on standing balance when subjected to external perturbation.

2. Methods

2.1. Participants

The CNP group comprised of 20 participants (age: 24.7 ± 3.6, 11 males and 9 females). The inclusion criteria were: (1) non-traumatic pain in the neck region for more than 6 months in duration, (2) the pain should be ongoing and frequent (at least once a week), and (3) the intensity of the pain should be rated at least 3 on the Visual Analog Scale (VAS, 0–10). Participants were excluded if they have, (1) arthritis in the neck as confirmed by a health professional, (2) received spinal or lower limb surgery, (3) diagnosed with any neurological, vestibular and musculoskeletal disorders that may influence balance, and (4) have had falls of unknown origin within the last year. Twenty age-matched asymptomatic volunteers (age: 22.1 ± 2.2, 8 males and 12 females) were also recruited provided they had no complaints of spinal or limb pain within the last year and had never experienced trauma or injuries to the cervical spine, head, and limb regions requiring medical treatments. Participants with neck pain were asked to indicate their level of pain and disability by completing the VAS and Neck Disability Index (NDI, 0–50), which were reported reliable and valid in Chinese-speaking population with neck pain [16]. The institutional medical research ethics committee approved the study. All the participants gave written informed consent before inclusion.

2.2. Instrumentation

The postural sway of participants during standing balance assessment was measured using a force plate (Bertec 9090-15, Advanced Mechanical Technology Inc., Columbus, USA). A loadcell (ST3-20KG, Plastronic Technology Co., LTD., New Taipei City, Taiwan) attached to an adjustable stand was used to measure the force exerted during the maximal isometric contractions and the fatigue exercise. The wireless electromyography (EMG) system (Trigno Wireless System, Delsys Inc., Boston, USA) which can output EMG signals and three-axis acceleration data was used to record the muscle activations, the onset of the perturbation, and the acceleration of the segments synchronically.

Surface EMG activities of right side sternocleidomastoid (SCM), splenius capitis (SPL), semispinalis capitis (SSC), rectus abdominis (RA), and erector spinae (ES) were measured. Based on the recommendations of the SENIAM, the skin surface was shaved of hair and cleaned with alcohol swabs before the wireless EMG sensors were applied. For SCM, the electrode sensor was placed lower one-third of the distance between the sternal notch and the mastoid process [17]. For SPL, the center of the electrode sensor was located at the intersection of the C7-ear line and the line of action of splenius muscles [18]. For SSC, the electrode sensor was centered at the C2 level over the belly of the muscle [18]. The center of the electrode sensor for the RA was placed 3 cm lateral and 2 cm superior to the umbilicus, and that for the ES was placed at the L3 level and 3 cm lateral from the spinous processes [19]. Reference electrode is not needed using the Trigno system. The sampling rate of the EMG signals was 2 kHz. The acquired data were further digitally band-pass filtered between 20 Hz and 450 Hz, full-wave rectified, and smoothed with a low-pass filter (time constant of 100 ms; Butterworth 8th-order).

The dynamic range of the three-axis accelerometer is ±1.5 g and the resolution is 0.016 g/bit with a sampling frequency of 148.1 Hz. The changes of the acceleration were recorded at the head (on the top of the head), upper trunk (at the T3 level) and lower trunk (at the L3 level). All measurements including the force plate, loadcell, and EMG system were synchronized using the 32-channel 16-bit A/D board (NI USB-6218, National Instruments Co., USA).

2.3. Experimental procedure

The assessment of the postural control contained several standing balance tests. Participants wore a custom designed harness on the upper torso to allow the attachment of a steel cable at the T9 level. This cable was linked to a weighted pulley system (Fig. 1). Participants were asked to stand upright on a force plate with arms by the side for 60 s, barefooted in narrow stance with two heels 3 cm apart and feet 30 degrees of abduction. The participants were tested either in quiet standing or with an external perturbation. The amplitude of the perturbation was 15% of participant's body weight and participant would experience a backward perturbation with the release of the weight.

After completing the balance tests under non-fatigue condition, participants had to perform maximal isometric contractions of the neck and lumbar muscles. For the maximal neck muscle contractions, the participant sat on a chair with the head neutrally positioned and his/her forehead pushed against a fixed loadcell to a plateau for 5 s in anterior, posterior, left, and right directions. For the maximal lumbar muscle contractions, the participant sat on a chair with arms crossed over the chest, and his/her trunk pushed against the loadcell for 5 s in anterior and posterior directions. The best of three measures was recorded. Before a new repetition, a 2-min rest was taken to minimize the muscle fatigue.

Participants were then asked to perform the neck flexor fatigue exercise. Same as the maximal neck muscle contraction condition, the participant maintained an isometric neck flexion at 60% of the maximal isometric contraction until arbitrarily stopped by the examiner. The stopping criteria were a score of seven on the exertion Borg scale (0–10) [20] or when they can no longer maintain the 60% exertion force. Verbal encouragement was given to the participant during the exercise.

The fatigue exercise was repeated prior to each quiet and perturbed balance test for the fatigue condition. It was performed right next to the force plate and there was a short time-lag (less than 20 s) between the induced fatigue state and the balance tests [21]. Familiarization session (3 sets × 10 s of balance protocols) was given to all participants before data collection to ensure quality of the measurements. Three trials were recorded in a pre-determined random order.

2.4. Data analysis

For the balance tests, the center of pressure (CoP) data were analyzed including the maximal anteroposterior and mediolateral displacement, and the sway area and mean velocity of CoP. One second out of the 5 s EMG signal during the maximal isometric contraction was used for the normalization of the EMG amplitude. The normalized averaged integration of EMG (NAIEMG) between the 70 ms and 200 ms after the perturbation was calculated to