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Original article

Interactive cervical motion kinematics: Sensitivity, specificity and clinically significant values for identifying kinematic impairments in patients with chronic neck pain

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Chronic neck pain has been consistently shown to be associated with impaired kinematic control including reduced range, velocity and smoothness of cervical motion, that seem relevant to daily function as in quick neck motion in response to surrounding stimuli. The objectives of this study were: to compare interactive cervical kinematics in patients with neck pain and controls; to explore the new measures of cervical motion accuracy; and to find the sensitivity, specificity, and optimal cutoff values for defining impaired kinematics in those with neck pain.

In this cross-section study, 33 patients with chronic neck pain and 22 asymptomatic controls were assessed for their cervical kinematic control using interactive virtual reality hardware and customized software utilizing a head mounted display with built-in head tracking. Outcome measures included peak and mean velocity, smoothness (represented by number of velocity peaks (NVP)), symmetry (represented by time to peak velocity percentage (TTPP)), and accuracy of cervical motion.

Results demonstrated significant and strong effect-size differences in peak and mean velocities, NVP and TTPP in all directions excluding TTPP in left rotation, and good effect-size group differences in 5/8 accuracy measures.

Regression results emphasized the high clinical value of neck motion velocity, with very high sensitivity and specificity (85%–100%), followed by motion smoothness, symmetry and accuracy. These finding suggest cervical kinematics should be evaluated clinically, and screened by the provided cut off values for identification of relevant impairments in those with neck pain. Such identification of presence or absence of kinematic impairments may direct treatment strategies and additional evaluation when needed.

1. Introduction

Neck pain is a common musculoskeletal disorder with an annual prevalence of 30%–50% in western populations, (Hogg-Johnson et al., 2008; Holm et al., 2008) and thus serious consequences for health care systems and society. (Lidgren, 2008) Clinical assessment of disability and impairment of function is currently the accepted approach for evaluation and treatment of patients complaining of neck pain (Childs et al., 2008).

The existing literature shows neck pain to be associated with various impairments such as restricted range of motion (ROM), (Nordin et al., 2008) increased repositioning error, (Heikkila et al., 1998; Treleaven et al., 2003) compromised isometric strength, (Dvir and Prushansky, 2008) and reduced endurance of the cervical muscles. (Jull et al., 2008) However, much of our daily neck function is dynamic in response to multiple visual, auditory, or scent stimuli, and therefore emerging research is exploring the dynamic characteristics of neck motion in patients with neck pain. Theoretically, normal voluntary motion should have a near symmetrical bell-shaped velocity profile with a single velocity peak and equal acceleration and deceleration phases (Vikne et al., 2013). Studies have consistently showed that velocity and smoothness of cervical motion is reduced in patients with chronic neck pain (Sjölander et al., 2008; Roijezon et al., 2010; Sarig Bahat et al., 2010a, 2010b; Tsang et al., 2013) and motion accuracy is impaired when compared to

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asymptomatic individuals (Kristjansson and Oddsdottir, 2010; Roijezonet al., 2010; Sarig Bahatet al., 2010; Woodhouse et al., 2010b).

Our previous kinematic research explored the effect of neck pain on the dynamic characteristics of cervical motion using a virtual reality system to simulate functional neck motion. (Sarig Bahat et al., 2009; Sarig Bahatet al., 2010; Sarig-Bahat, 2011) The kinematic measures that were characteristic of patients included decreased ROM, mean and peak velocity, and altered smoothness of cervical motion, in flexion, extension and rotation. Time to peak velocity, which represents the symmetry of motion i.e. acceleration-deceleration ratio, was not found to be different between patients and controls, although others have shown less symmetry in the velocity profile of neck pain patients (Roijezonet al., 2010).

Previously we reported on the sensitivity and specificity of this methodology to evaluate cervical ROM impairment. Findings demonstrated 88% sensitivity for flexion/extension and 76% for rotation ROM (Sarig Bahat et al., 2010a, 2010b). Given the functional relevance of measures such as velocity of head motion, it would seem important to now consider the clinical value of these other kinematic measures to identify relevant impairments using this system. Further there is potential value to expand our investigation of kinematic impairments using this device and examine additional measures of motion accuracy in patients with neck pain compared to asymptomatic controls.

Investigation of the sensitivity, specificity and clinically significant values for identifying kinematic impairments in patients with chronic neck pain is an important step to assist future research on the effect of training of such impairments in the management of neck pain. Thus the objectives of this study were: to compare cervical kinematic characteristics during interactive motion in patients with neck pain and controls, including mean and peak velocity, smoothness and symmetry of cervical velocity profile; to explore the new outcome measure of cervical motion accuracy which has not been evaluated before in this interactive fashion; and to find the sensitivity and specificity of each of the differentiative kinematic measures in order to obtain the optimal cutoff values for defining impaired kinematics in those with neck pain. This will ultimately assist in determining the need for management directed towards these impairments.

2. Materials and methods

2.1. Participants

The research population included patients presenting with chronic neck pain, and control participants with no physical complaints in the neck region. Participants were recruited at the University of Queensland and at the University of Haifa as a sample of convenience. Inclusion criteria for the patient group were complaints of neck pain for 3 months or more, with or without referral to the upper limb. Exclusion criteria for the patient group included limited neck range of motion less than 40° in each direction, neurological disorders including positive neurological signs or imaging evidence indicating of nerve root/spinal cord compression; systemic disorders such as rheumatic syndromes, diffuse connective tissue diseases, metabolic/endocrine diseases, neoplasm, fractures or dislocations; and spinal surgery. Only individuals who reported no physical symptoms, no neurological, visual (unless corrected), or vestibular disorders were recruited to the control group. The study was approved by the Institutional Review Boards of the University of Queensland and the University of Haifa.

2.2. VR assessment system

We used a new customized VR system to evaluate cervical kinematics with a simple interactive scenario monitored via motion tracking. This new system included new hardware and more advanced software following similar principles of the previously developed prototype (Sarig Bahatet al., 2009). The hardware consisted of a head mounted display with a built in motion tracker (Wrap™ 1200VR by Vuzix, New York, www.vuzix.com), equipped with gyroscopes, accelerometers and magnetometers. Sampling rate was 30 Hz and display resolution was 1280 × 720.

Customized software was used in this study, consisting of an interactive three-dimensional virtual environment that was developed using the Unity-pro software, version 3.5 (Unity Technologies, San Francisco). The Vuzix Software development kit was also used. Dynamic motion tracking data were analyzed by the developed software in real-time. Two interactive modules, the velocity and accuracy modules were used in this study (Figs. 1 and 2). During both VR modules, the virtual pilot flying the red airplane is controlled by the patient's head motion and interacts with targets appearing from four directions (flexion, extension, right rotation, left rotation). In the velocity module, the participant had initially to stabilize the virtual pilot inside a circle, which reflected mid-position. As soon as this mid-position was stable for 3 s, the game was activated and a target appeared (Fig. 1). Then the participant was instructed to hit the target as fast as possible, before it disappeared after 7 s, and had to return to mid-position each time. Target's life time was visualized using a green circle around the target that diminishes gradually and functions as a timer (see Fig. 1). This feature aims to motivate the participant to move quickly towards the target before it disappears. The target was positioned at 40 degrees of range. The velocity module included two warm-up trials, followed by 16 assessment trials, four in each direction.

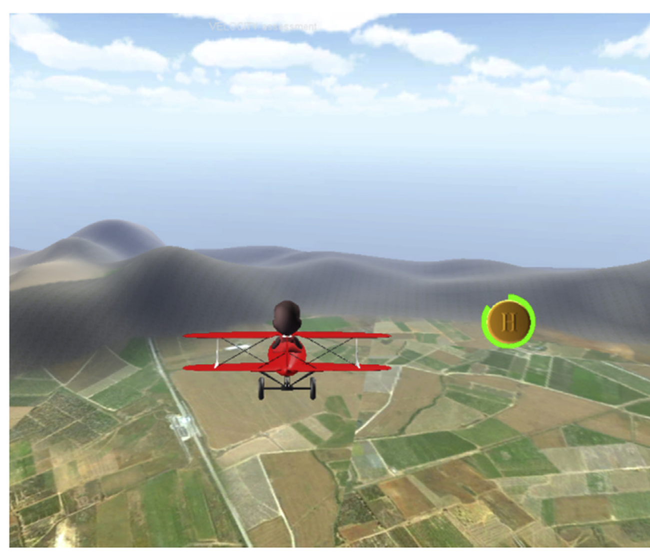

Fig. 1. The velocity module in the virtual reality assessment. The velocity module is designed to randomly display a total of 16 yellow ball targets, in four different directions of flexion/extension and rotation. At the beginning of each trial, the participant has to activate the game by positioning the pilot's head in the center of a red ring, which is the recorded mid-position for 3 s. Once this is achieved, a yellow target appears in a random direction, and the participant is required to move the head in that direction within 7 s before the target disappears. Target's life time is visualized using a green circle around the target that diminishes gradually and functions as a timer. This feature aims to motivate the participant to move quickly towards the target before it disappears. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)