Clinical Biomechanics 30 (2015) 260–268

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Sensorimotor function of the cervical spine in healthy volunteers

Neil J. Artz, Michael A. Adams, Patricia Dolan *

Centre for Comparative and Clinical Anatomy, University of Bristol, Bristol, UK

ARTICLE INFO

Article history:
Received 7 May 2013
Accepted 21 January 2015

Keywords:
Cervical spine
Neck muscles
Proprioception
Position sense
Movement sense
Reflex activation

ABSTRACT

Background: Sensorimotor mechanisms are important for controlling head motion. However, relatively little is known about sensorimotor function in the cervical spine. This study investigated how age, gender and variations in the test conditions affect measures of position sense, movement sense and reflex activation in cervical muscles.
Methods: Forty healthy volunteers (19M/21F, aged 19–59 years) participated. Position sense was assessed by determining repositioning errors in upright and flexed neck postures during tests performed in 25%, 50% and 75% cervical flexion. Movement sense was assessed by detecting thresholds to passive flexion and extension at velocities between 1 and 25°s^{-1}. Reflexes were assessed by determining the latency and amplitude of reflex activation in trapezius and sternocleidomastoid muscles. Reliability was evaluated from intraclass correlation coefficients.
Findings: Mean repositioning errors ranged from 1.5° to 2.6°, were greater in flexed than upright postures ($P = 0.006$) and in people aged over 25 years ($P = 0.05$). Time to detect head motion decreased with increasing velocity ($P < 0.001$) and was lower during flexion than extension movements ($P = 0.002$). Reflexes demonstrated shorter latency ($P < 0.001$) and greater amplitude ($P = 0.009$) in trapezius compared to sternocleidomastoid, and became slower and weaker with age. None of the measures were influenced by gender. Reliability was good for movement sense measures, but was influenced by the test conditions when assessing position sense.
Interpretation: Increased repositioning errors and slower reflexes in older subjects suggest that sensorimotor function in the cervical spine becomes impaired with age. In position sense tests, reliability was influenced by the test conditions with mid-range flexion movements, performed in standing, providing the most reliable measurements.

1. Introduction

The slender and mobile cervical spine is particularly vulnerable to injury in bending (Przybyla et al., 2007), so sensorimotor processes are vital for maintaining stability and controlling movements of the head. Proprioception is an important component of sensorimotor function, providing the body with a sense of position, sense of movement, sense of force, and sense of effort. These sensations are provided by proprioceptors in muscles, ligaments tendons and skin, although muscle spindles are thought to be the receptors primarily responsible for position and movement sense (Burgess et al., 1982; Ferrell and Smith, 1988; Gandevia and Burke, 1992; Marks, 1997; Matthews, 1988). Neck muscles have a particularly high density of muscle spindles (Boyd-Clark et al., 2002; Liu et al., 2003), and these proprioceptors have anatomical connections with the vestibular and visual systems (Treleaven, 2008) suggesting that proprioceptive information is integrated with other sensory information in order to fine tune the position and movement of the head. Muscle spindles are also involved in several reflexes, including simple stretch reflexes, that are important in controlling head motion and protecting the underlying spinal tissues from injury (Keshner and Peterson, 1995; Peterson, 2004; Peterson et al., 1985; Wilson et al., 1990).

In the cervical spine, proprioceptive function has been investigated most often by evaluating joint position sense. This is generally assessed by measuring repositioning errors when subjects attempt to reproduce specific head positions, and in such tests, subjects are normally blindfolded to remove visual cues. Measurement techniques include electromagnetic tracking devices (Kristjansson et al., 2001; Swait et al., 2007), camera-based systems (Edmondston et al., 2007; Wong et al., 2006) and ultrasonography (Demaille-Wlodyka et al., 2007; Roren et al., 2009; Strimpakos et al., 2006). These methods have clinical potential because they are sensitive enough to demonstrate increased repositioning errors in people with neck pain (Kristjansson et al., 2003; Revel et al., 1991; Roren et al., 2009), and to detect improvements in response to training (Humphreys and Irgens, 2002; Jull et al., 2007). However, studies in peripheral joints and in the thoracolumbar spine suggest that measures of position sense are influenced by the test conditions with factors such as the limb (Lonn et al., 2000b) or trunk (Preuss et al., 2003) position, the range (Janwantanakul et al., 2001) and direction of movement (Carpenter et al., 1998; Swinkels and

* Corresponding author at: Centre for Comparative and Clinical Anatomy, University of Bristol, Southwell Street, Bristol BS2 8EJ, UK.
E-mail address: Trish.Dolan@bris.ac.uk (P. Dolan).

http://dx.doi.org/10.1016/j.clinbiomech.2015.01.005

Dolan, 1998, 2000; Weiler and Awiszus, 2000) and the use of passive versus active movements (Lonn et al., 2000a; Proske and Gandevia, 2012; Silfies et al., 2007) affecting their accuracy and reliability. Such influences may be particularly important in the cervical spine where position and movement of the head in space, and relative to the trunk, are likely to have independent effects on vestibular and proprioceptive systems.

Movement sense is considered distinct from position sense and is generally evaluated by measuring thresholds to the detection of passive movement, assessed as the angular movement or the time delay between the onset and detection of motion. In peripheral joints, detection thresholds are reported to be lower during faster movements and in proximal compared to distal joints (Hall and McCloskey, 1983). In the cervical spine, there is some evidence that movement sense is influenced by speed of movement (Taylor and McCloskey, 1988) but these findings are based on a small number of subjects and only for rotational movements. Movement sense has not been assessed during flexion/extension of the cervical spine although such measures may have particular relevance when investigating people with whiplash associated disorders.

The importance of proprioception in the control of movement suggests that any impairment of position or movement sense may have adverse effects on motor control mechanisms, leading to an increased risk of injury. In the lumbar spine, delayed reflex activation of trunk muscles has been observed in people with low back pain (Hodges and Richardson, 1998; Lexell and Downham, 1991; Magnusson et al., 1996), and in healthy subjects prolonged muscle response times have been associated with an increased risk of future back injury (Cholewicki et al., 2005). These findings suggest that delayed muscle reflexes may be a cause or consequence of low back pain, but whether this is due to peripheral changes in the muscle, such as fibre atrophy, or to poor proprioceptive function is unclear. In the cervical spine, impaired proprioception has been linked with neck pain (Kristjansson et al., 2003; Revel et al., 1991; Roren et al., 2009) but the extent to which poor proprioception influences motor responses of cervical muscles remains unknown.

The aim of the present study was to assess position sense, movement sense and reflex responses of cervical muscles in healthy volunteers to determine how they are affected by age, gender and variations in the test conditions. In position sense tests, the effects of varying the test position, as well as the range and direction of movement were investigated. In movement sense tests, the effects of speed and direction of movement were evaluated. A secondary aim was to assess the reliability of these measurements and investigate correlations between them.

2. Methods

2.1. Participants

Participants aged between 18 and 60 years, with no previous history of back or neck pain requiring medical attention or time off work, were recruited by "word of mouth" and via poster advertisements around the University. Forty healthy volunteers (19 male, 21 female), mean (±STD) age 29.9 (±10.8) years, consented to participate. All participants were subsequently screened to exclude neck pain and a history of traumatic neck injury.

2.2. Experimental protocol

Subjects performed a series of tests that included measures of joint position sense, movement sense, and assessment of neck muscle reflexes. Each test was performed three times and a mean value obtained. The first set of tests was carried out on a single day in a standardised order. Twenty-one participants repeated the tests on the same day, and nineteen repeated them on two separate days, at least one week apart, to enable within-day and between-day reliability to be determined. Twenty one participants also took part in a preliminary validation study of the movement sense tests. During all procedures, testing was carried out by the same examiner. The study was approved by the Research Ethics Committee of the Faculty of Medical and Veterinary Sciences at the University of Bristol.

2.3. Assessment of position sense

Cervical spine position sense was measured using the 3-Space Fastrak (Polhemus, Inc., Colchester, VT, USA). Movement sensors, mounted on perspex base-plates, were fixed to the sternum (5 cm below the sternal notch) and the forehead (2 cm above the glabella) using Hypafix (BSN Medical, Hamburg, Germany) and double-sided tape (Fig. 1). During testing, the Fastrak source was placed within 20 cm of the subject's head, and the angular orientation of each sensor relative to the source was recorded at 60 Hz using custom-made software (Swinkels and Dolan, 1998). The angular difference between the head and sternal sensors indicated the head angle relative to the trunk. Position sense was assessed as the absolute difference in head angle when the same target posture was adopted twice in quick succession (Swinkels and Dolan, 1998).

To measure position sense in standing, subjects stood barefoot, with arms by their side. In sitting, subjects sat in a low chair with the back supported and forearms resting on the arms of the chair. The testing protocol was explained and demonstrated to each subject by the same examiner, after which subjects were blindfolded to eliminate visual cues. During each trial, subjects initially adopted the upright posture for 2 s before moving their head into full flexion and then returning to the upright posture. This indicated the full range of cervical flexion against which subjects were required to gauge subsequent target positions. They then made three attempts to adopt a given target position (25%, 50%, or 75% range of flexion) before returning to their "exact upright starting posture", in their own time. Subjects were instructed to hold each posture for 2 s to ensure that their position is stabilised but were not given any feedback during the trials that

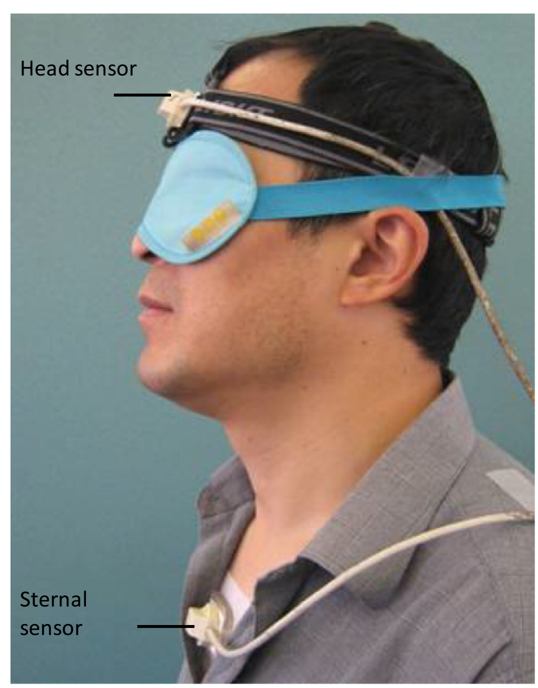

Fig. 1. During position sense testing, movements of the head were assessed using the 3-Space Fastrak electromagnetic goniometer. One movement sensor (the Head sensor) was placed 2 cm above the glabella and another (the Sternal sensor) was placed 5 cm below the sternal notch, along the central axis of the body. (Subjects were blindfolded during testing to remove visual cues.)