Reliability of an Accelerometer-Based System for Quantifying Multiregional Spinal Range of Motion

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Abstract

Objectives: The purpose of this study was to investigate the reliability of a novel motion analysis device for measuring the regional breakdown of spinal motion and describing the relative motion of different segments of the thoracolumbar (TL) spine.

Methods: Two protocols were applied to 18 healthy participants. In protocol 1, 2 sensors were placed on the forehead and T1 to measure cervical range of motion (ROM). In protocol 2, 6 sensors were placed on the spinous processes of T1, T4, T8, T12, L3, and S1 to measure TL regional ROM. Intraclass correlation coefficients were used to evaluate the repeatability of movement, whereas SEM was used to define the extent of error. Ranges of motion were demonstrated in flexion extension, right-left lateral flexion, and right-left rotation of the head-cervical, upper thoracic, middle thoracic, lower thoracic, upper lumbar, and lower lumbar.

Results: The intraclass correlation coefficient values, for all regions, were found to be high, ranging from 0.88 to 0.99 for all movements, and regions of the spine and SEM values ranged from 0.4° to 5.2°. Multiregional spine ROM ranged from 3° in the upper thoracic and mid-thoracic during flexion and 80° at head cervical during right rotation.

Conclusion: The described methodology was reliable for assessing regional spinal ROM across multiple spinal regions while providing the relative motions of different segments of the TL spine. (J Manipulative Physiol Ther 2015;38:275-281)

Key Indexing Terms: *Reliability; Spine; Regional; Range of Motion; Accelerometry*

Measurement of spinal range of motion (ROM) is common within the assessment of spinal disorders.[1] There are many methods to noninvasively measure spinal ROM, including simple clinical methods and more complex laboratory systems. The former includes techniques such as goniometry, inclinometry, and the cervical ROM device; however, all are only able to provide a single point in time, meaning movement behavior across time is lost.[2] Furthermore, measurement of 3 planes of motion is difficult and time consuming and typically demands complex laboratory methods. Optoelectronic methods are commonly used to measure ROM in 3 dimensions,[3,4] although they are time consuming, and data processing can be complex.[5] Electromagnetic systems have been used to measure spinal ROM in the cervical,[6] thoracic,[7] and lumbar spine,[8] although small operating fields and metallic disturbance in areas where metals are present should be considered as limitations.[9,10] Inertial sensors have quantified cervical[11] and lumbar ROM,[2] although the application of these methods to the spine often involves the use of 2 sensors, creating a hypothetical single "joint" of interest.[12-14] Here, the inherent limitation is that the distribution of movement across the length between the 2 sensors is unknown,[15] which is critical to understanding motion sharing within the spine. Furthermore, separate spinal regions are often studied in isolation, unlike in clinic where the aim is often to simultaneously assess multiple regions.

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Subsequently there remains a demand for a novel methodology that will allow for the simultaneous capture of ROM data describing multiple regions of the spine, for use in a clinical setting. One possible solution is the use of accelerometers, sensors which are sufficiently small and cost effective to allow the positioning of multiple sensors along the length of the spine. Triaxial accelerometers measure linear acceleration along 3-orthogonal axes, while also measuring tilt relative to gravity (following the pendulum principle). This tilt measurement can be used to measure the orientation of the spine at low accelerations,[16-18] which is ideal for a typical clinical scenario.

This study primarily aimed to investigate the reliability of a novel, multi-accelerometer device, by measuring the ROM of 5 adjacent segments spanning the entire spine. Secondarily, this device was then used to consider the relative contribution of 5 segments from within the thoracolumbar (TL) region.

Methods

Instrumentation

A string of 6 triaxial accelerometers was used to measure spinal ROM. The sensors were wired in a "daisy-chain" configuration with each sensor's footprint measuring 24 mm^2 (3A Sensor String; ThetaMetrix, Waterlooville, UK). In addition to each sensor providing the tri-planar accelerations, they also measure absolute orientation (tilt, with respect to gravity) in 2 planes (sagittal and frontal in standing). Data were collected at 50 Hz using the associated software. The accuracy of the sensor string ("3AS") has previously been investigated within a high precision, controlled environment through the use of an "XYZ" table (ie, high precision yaw and pitch and roll movements). High correlation was reported when comparing the 3AS and "table" data (r^2 = 0.98, root mean square errors = 0.70%-1.39%; unpublished data). These measures respectively describe the correlation and deviation of the 3AS, relative to the criterion standard data.

Participants

Eighteen male participants were recruited (age = 30.6 ± 7.4 years; weight = 76.6 ± 7.4 kg; and height = 1.71 ± 0.05 m) via a circular e-mail to staff and postgraduate students, meaning our cohort was a convenience-based sample. The cohort size was initially based upon a review of similar reliability studies,[19] before its appropriateness being reevaluated—and confirmed, after statistical analysis of our data. Participants had no history of spinal pain and were excluded if they had any history of spinal surgery, neurologic, or rheumatological disorders or any disorder affecting the cervical, thoracic, or lumbar region. The study was approved by the Cardiff School of Engineering Ethics Committee, with all participants providing informed consent.

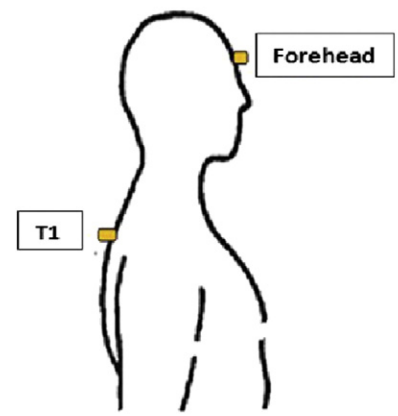

Fig. 1. *Schematic representing the location of forehead and T1 sensors.*

Procedures

Spinal ROM was assessed through the development of 2 protocols. Protocol 1 was devised to evaluate the reliability of the device for measuring cervical kinematics, before protocol 2 was implemented, focusing on using the device to investigate TL ROM. Protocol 1: One sensor was placed on the forehead and another on the skin overlying the T1 spinous process, defining a segment that quantified cervical (head and cervical [HC]) ROM (Fig 1). Sensors were attached using double-sided tape, and participants were asked to move their head through full ROM. Flexion extension and right-left lateral bending were recorded during sitting. Axial rotation (right and left) was then obtained from a prone position, with the head protruding beyond the end of the treatment table. Participants performed 3 repetitions of each movement.

Protocol 2: Six sensors were placed on the spinous processes of T1, T4, T8, T12, L3, and S1, creating 5 specific regions of interest: upper thoracic (UT), middle thoracic (MT), lower thoracic (LT), upper lumbar (UL), and lower lumbar (LL) (Fig 2). Double-sided tape enabled the sensors to be firmly attached to the skin. Participants were instructed to stand barefoot on assigned markers and focus on a wall marker set at a height of 2 m, with arms relaxed by their side. They were asked to move their trunk into flexion extension and right-left lateral bending. Axial rotation was captured in side lying, where participants were asked to rotate their trunk to the right and left, while the researcher fixed their hip and lower extremities. Participants performed 3 repetitions of each movement cycle.

Data Analysis

Raw data were transferred to Matlab and filtered at 6 Hz to remove high-frequency noise. Data were recorded as tilt angles relative to gravity (absolute angles), and regional ROM was defined as the relative motion between adjacent distal and proximal sensors (ie, relative angles). Subsequently, regional spinal movement-time curves were generated for HC, UT, MT, LT, UL, and LL from which peak ROM values were