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Technical note

Automatic distinction of upper body motions in the main anatomical planes

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ABSTRACT

The assessment of spinal mobility and function is gaining clinical importance for the diagnosis and monitoring of low back pain, but its measurement and evaluation remains difficult. As a critical step towards non-supervised assessment of spinal functional, the aim of this study was to assess the efficacy of symmetrical sensors fixed to the sides of the spinal column to distinguish between different upper body movements in the main anatomical planes.

429 healthy volunteers underwent a defined choreography including repeated upper body flexion, extension, lateral bending and axial rotation exercises. The movements were assessed using the Epionics SPINE sensor system. Two pattern recognition models were developed and applied to distinguish between the different movements in a frame-by-frame manner, as well as for whole motion sequences.

On average, it was possible to differentiate between different upper body movements with a sensitivity of over 96% for both modelling approaches. The largest type II error was the incorrect identification of extension, possibly due to deviations from the reference standing posture during measurements and small changes in the lordotic angle during extension.

The use of two sagittal sensors attached symmetrically to the back therefore seems to allow the distinction of upper body movements in a robust manner, and therefore opens perspectives for the unsupervised recognition of movements and functional activity over extended periods.

1. Introduction

Low back pain has a high incidence and is one of the most frequent reasons for visiting a medical doctor [1]. Measuring spinal function is becoming increasingly important not only regarding diagnosis and therapy monitoring of low back pain [2,3], but also for the objective documentation of motion [4,5]. A number of systems currently exist for measuring spinal range of motion (RoM) in the sagittal plane (e.g. Vicon, Zebris, Formetric), where it is also partially possible to determine the range of functional kinematics (RoKs) [6–9]. However, only a few systems allow motion measurement during activities of daily living [4,5,10,11], and most are limited to measurement only within laboratory settings (3D SpineMoveGuard, Lumbar Motion Monitor, CUELA, XSens).

The characterisation of spinal motion during daily activities is difficult due to the multitude of possible movement combinations. As a result, one functional approach is to measure and sum the motions in each of the main anatomical planes, and thereby allow distinctive categorisation of the movement components. Furthermore, functional limitations and diseases of the spine often lead to restricted movements in specific anatomical directions, and reliable categorisation of the available movements can aid in the assessment of motion deficits and its association with pain, but also allow an understanding of their relationship with the internal loading conditions [12].

The Epionics SPINE system has demonstrated its ability to measure back shape during flexion and extension of the upper body [10]. Two flat, elongated sensors are affixed parallel to one another to the left and right sides of the spinal column and used to estimate the shape and motion of the spine. Until now, such sensors have been used for measuring motions in the sagittal plane only. However, spinal motions during daily living are rarely performed solely in the sagittal plane. Lateral bending, for example, is often combined with flexion or axial rotation. Here, it is plausible that when

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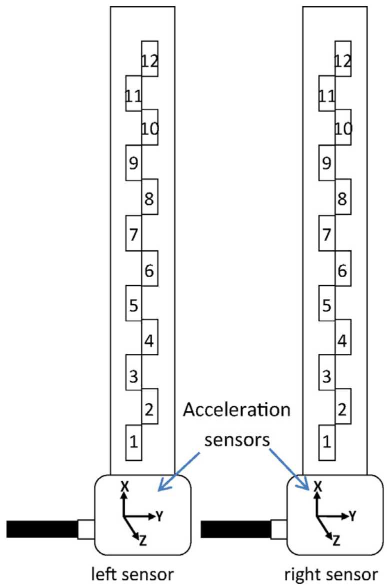

Fig. 1. Schematic figure of Epionics SPINE sensor strips (dorsal view) with numbered segments and orientation of acceleration sensors. The sensors are placed paravertebrally, approximately 7.5 cm from the spinal column.

combined with data from accelerometers, the synchronous values generated by the two sensors should be sufficient to distinguish not only between flexion and extension but also between motions such as lateral bending and axial rotation.

In order to provide an improved estimation of functional activity of the spine, the aim of this study was to investigate whether the results of the two sensor strips, together with integrated three-axis accelerometers, can allow automatic identification of motions in the main anatomical planes.

2. Materials and methods

2.1. Measuring system

The system Epionics SPINE (Epionics Medical GmbH, Potsdam, Germany) is based on strain-gauge technology and consists of two flat and flexible measuring strips which are attached to the left and right side of the spine using hollow plasters, with a distance of 7.5 cm from the mid-sagittal plane. The caudal position of the sensors is standardised at the vertical level of the spina iliaca posterior superior. In 12 segments of the sensor strip, each 2.5 cm long, strain gauges measure the local curvature of the back as an estimation of the curvature of the spine. A tri-axial acceleration sensor is located at the lower end of each of sensor strip, in order to measure the subject's orientation relative to the earth's gravitational field (Fig. 1). The accelerometers provide a value between -1 and 1 depending on the tilt in the respective direction, with a 0 for inactive positions or at constant speed. All sensors are connected to a data logger that stores the segmental angles and lower back orientation at 50 Hz, and allows measurements over a period of more than 24 h. The validity and reliability of the system for measurements in the sagittal plane has been demonstrated previously [13].

2.2. Subjects

To assess the ability of the system to distinguish between motions in the different anatomical planes, 429 asymptomatic volunteers (231 female and 198 male; mean age 39.8 ± 14.0 years; height 173.3 ± 9.8 cm; weight 72.3 ± 13.7 kg; body mass index 24.1 ± 3.6 km/m^2) were evaluated. Only subjects with an age between 20 and 75 years, who had not suffered from low back pain within the previous 6 months and had no previous surgery at the spine, were included in the study. All volunteers provided written informed consent to participate in this study, which was approved by the local ethics committee of our hospital.

2.3. Protocol overview

After fitting of the Epionics SPINE system, all volunteers performed a predefined choreography consisting of flexion and extension, as well as lateral bending and axial rotation, to both the left and right sides. Each exercise was measured 5 times, returning to a relaxed standing pose between each measurement, and the volunteers were required to perform each motion to their maximum ability. In addition, each subject's reference posture was recorded while 'standing relaxed and upright'. In order to standardise the movements, a video, illustrating and explaining the exercises, was shown prior to the measurements.

2.4. Rotations in the main anatomical planes

From each of the measurements, the rotation in each of the three main anatomical planes was calculated. The characteristics of these rotations were then used for the recognition of the six different exercises (flexion, extension, lateral bending right, lateral bending left, axial rotation right, axial rotation left).

2.4.1. Rotation in the sagittal plane

Pure flexion and extension of the upper body is characterised by a symmetrical motion in the sagittal plane [2], in which case the left and right sensor strips should deliver similar results during these movements. Here, lordosis angle (LA) was determined as the sum of the angles of all sensor segments (segmental angle – SA) with a negative value during upright standing [2]. The magnitude of the flexion and extension angle (FlexEx angle), was calculated as follows:

$$\text{FlexEx angle} = \frac{\sum_{\text{Segment1}}^{\text{Segment}x} \text{SA}_{\text{left}} + \sum_{\text{Segment1}}^{\text{Segment}x} \text{SA}_{\text{right}}}{2} - \text{LA}_{\text{standing}} \quad (1)$$

where x is the last segment with negative bending during upright standing (transition from lordosis to kyphosis). A FlexEx angle greater than 0° indicates flexion, while lower than 0° indicates extension.

2.4.2. Rotation in the frontal plane

During lateral bending, the inclination angle in the frontal plane (inclination around z axis – IZ, see Fig. 1) measured using the accelerometers should be the similar for both sensor strips, with the sign of the inclination angle dependent upon the direction of inclination. The lateral bending angle was determined as follows:

$$\text{Lateral bending angle} = \frac{-\arcsin(\text{IZ}_{\text{right}}) - \arcsin(\text{IZ}_{\text{left}})}{2} \quad (2)$$

The result is that positive inclination angles in the frontal plane signify lateral bending to the right and negative values indicate inclination to the left.

2.5. Rotation in the transverse plane

Axial rotation of the upper body should lead to different lordosis angles on the left and right sides of the back. The inclination angle of the accelerometer in the sagittal plane (inclination around y axis – IY, see Fig. 1) is also expected to be different during axial rotation.