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Inter- and intra-tester reliability when measuring seated spinal postures with inertial sensors

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ABSTRACT

Prolonged awkward sitting postures may be associated with neck or back pain, but it is often unclear which specific postures cause most problems and which mechanisms that may underlie the pain. In order to increase the knowledge in this field, it seems crucial first of all to be able to analyse, in depth, different seated spinal postures. A problem is however the lack of reliable and direct measurement methods of the posture, especially for sitting. Recently developed systems with inertial sensor attached along the spine have potential for this purpose. The aim of the present study was therefore to test the reliability of using such a system to assess various seated postures.

Inter- and intra-tester as well as intra-subject relative reliability was estimated with intra-class correlation coefficient (ICC). Absolute reliability was estimated with standard error of measurement (SEM) and smallest detectable change (SDC). Ten + ten healthy subjects and four testers participated. Three standardised unsupported seated postures (lumbar lordosis, lumbar kyphosis and neutral posture) and two standing postures (neutral and lumbar kyphosis) were evaluated using five sensors attached to the head, the thorax (high and low), the lumbar spine and the pelvis. The ICC for intra-tester reliability ranged from 0.37 to 0.90, SEM 2.5–12.0°, and SDC 7.1–33.3° where the largest measurement error was from the head. Intra-tester reliability was higher than inter-tester reliability but not as good as intra-subject reliability. The intra-tester absolute reliability was nevertheless not considered sufficient to distinguish smaller differences. The low reliability may depend on inertial sensor size and attachment but also on the tester's accuracy. This study shows that assessing unsupported seated spinal postures with inertial sensors could be performed with higher reliability if done by the same, rather than different, testers.

Relevance to industry: Prolonged awkward seated postures at work may be associated with back and neck pain and should therefore be analysed. Inertial sensor units is a promising tool to measure spinal posture. Smaller sensors attached by one skilled tester directly onto the body will most likely improve assessment in the future.

1. Introduction

Spinal pain and/or discomfort are common ailments in the general population throughout the world and strike almost everyone at some point in life (Cote et al., 2009; Hoy et al., 2010a, 2010b). Type of workplace may influence the prevalence of neck and back pain; for example office workers are more likely to suffer from neck pain. They have a higher one-year prevalence of neck pain than the general population (Kamwendo et al., 1991; Chiu et al., 2002; Ariens et al., 2001), possibly because of prolonged seated postures (Yue et al., 2012; Ariens et al., 2000). Likewise, excessive sitting periods have commonly been reported as an aggravating factor for low back pain (Williams et al., 1991; Biering-Sorensen, 1983). People are spending more and more time sedentary because of the demands of modern working life. The use of computers and normally in seated postures, among office employees in Sweden, reaches 75%, and close to 40% use the computer for the majority of their working day (Rackner et al., 2012). Research suggests that sitting duration alone is not a causal factor for developing pain (Roffey et al., 2010; Lis et al., 2007; Kwon et al.,

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2011; Chen et al., 2009; Bakker et al., 2009); there may be other explanatory factors, such as the adopted posture or work task.

There is no consensus on an ideal posture for sitting (Pynt et al., 2001; O'Sullivan, 2005; O'Sullivan et al., 2012; Claus et al., 2009). A proper posture in general maintains spinal curvatures, keeping the joints in neutral positions (O'Sullivan et al., 2006; Barrero and Hedge, 2002) to avoid excessive tissue strain which can lead to musculoskeletal disorders (Scannell and McGill, 2003). In previous epidemiological studies, spinal curvatures have seldom been reported, rather the duration and frequency of different postures have been investigated (e.g., sitting versus standing) (Roffey et al., 2010; Kwon et al., 2011). One explanation for the lack of evidence could be non-sensitive measurement techniques. Digital photography and video analysis are commonly used for field studies, but their ability to detect regional changes of spinal posture is limited. Regional changes have only been reported previously in laboratory studies, and differences between symptomatic and asymptomatic groups were revealed only when regional changes were detected (Mitchell et al., 2008; Dankaerts et al., 2006). In order to identify postures divergent from the neutral posture during real working conditions, more sensitive instruments appear necessary.

Technology has brought forth inertial sensors that may be used for taking direct longer-duration posture measurements at the workplace. Compared to ordinary laboratory technology, these sensors have the advantages of being small, low-cost, and wearable. Inertial sensors have been used for various purposes such as evaluating movements occurring during gait (Findlow et al., 2008; Mayagoitia et al., 2002), head rotations (Jasiewicz et al., 2007), flexion/extension, lateral flexion, or rotation in the upper body (Wong and Wong, 2008; Plamondon et al., 2007; Ha et al., 2013). None of these studies has focused on spinal postures in seated postures.

Inertial sensors have been found to be a feasible method for measuring range of motion (ROM) in the cervical spine and trunk motions (Intolo et al., 2010; Theobald et al., 2012; Ohberg et al., 2013). Intolo and colleagues (Intolo et al., 2010) used one sensor on the lateral iliac crest and found that the reliability of five repeated movements in standing gave an excellent *intra-class correlation coefficient* (ICC) and a repeatability coefficient in percentages that were higher for small movements than for large. Strain gauge instruments can give high ICC values for inter- and intra-tester reliability in laboratory settings for measuring spine ROM in standing and ordinary sitting, but there is a lack of angular output i.e. no absolute positions (O'Sullivan et al., 2011). Previous laboratory studies are well defined, but exposure measurements in workplace settings may be less ideal partly because there can be various testers with different skills. Reliability issues could lead to risk assessments being imprecise.

The purpose of the present study was to evaluate the inter- and intra-tester reliability among testers using a novel inertial sensors system to measure spinal postures in healthy persons when they are seated in different postures. Our hypothesis was that there would be no difference between testers or within a tester.

2. Methods

2.1. Participants

Four testers were involved in the inter-tester reliability test: one physiotherapist (two years of clinical experience), two physiotherapy students, and one biomedical engineer (experience with clinical measurements), each with different knowledge about clinical anatomy. They were chosen to mimic the real-life conditions where various skills among practitioners could affect the outcome when they use inertial sensor units (ISU:s) measuring postures. All testers had knowledge about the technical features of ISU:s but were inexperienced with postural measurements. Young subjects were chosen to eliminate age-related problems such as degeneration and rigidity of the spine. The subjects were excluded according to a health-screening protocol if they reported any neurological conditions or reduced ability to work during the last 12 months because of back or neck problems (Lundström et al., 2004). The subjects of height below 160 cm were excluded because of the risk that the sensors would collide during movements. Ten healthy subjects, two women and eight men, were included in the inter-tester reliability tests, with a mean age (SD) of 28 (6) years, height of 179 (7) cm, and BMI of 23.3 (2.0) kg/m^2. For the intra-tester reliability, performed by one and the same physiotherapist as from the inter-reliability test, another ten healthy subjects were recruited, six men and four women, with a mean age of 31 (5) years, height of 176 (9) cm, and BMI of 24.3(3.4) kg/m^2. Written informed consent was obtained from each participant, and the Regional Ethical Review Board (No 2012-24-31M) approved all procedures.

2.2. Equipment

The Department of Biomedical Engineering and Informatics, University Hospital of Umeå, Sweden, developed the movement capture and analysis system, in this setting consisting of one data collecting unit and five tri-axial inertial sensor units (ISU:s). Each ISU (ADIS 16364 Analog Devices, USA) included three axis gyros and three axis accelerometers, which together detect the three-dimensional posture angles and motions of the object. The size of an ISU is L76 × W52 × H46 mm and the weight is 40 g. The sensors use a local Cartesian coordinate system, which is determined at the time of initial setting. The sensors are connected by cables to a collection unit, which in turn communicates with a laptop via Bluetooth. Customised software (AnyMo, The Department of Biomedical Engineering and Informatics, Umeå University Hospital, Sweden) calculates the real-time orientation of the sensors, using data from the gyros and accelerometers (Ohberg et al., 2013).

A stool was adjusted to the level of the posterior knee crease (popliteal height). The stool had no backrest and had a flat wooden surface covered with two layers of 2 mm foam and an anti-slip surface.

2.3. Protocol

The study used a repeated-measurement design, test retest with four testers for the inter-tester reliability and one tester for the intra-tester reliability. Following our written study protocol, the tester mounted the ISU:s on the subject, calibrated them, and gave instructions as to the postures that the subject should then take. There was no prior training for this specific procedure. The subjects performed for each tester, as similarly as possible, three tests, two while seated unsupported and one while standing. The reliability within a subject was also analysed to investigate their precision in repeating postures. The standing test, similar to the test by Intolo and colleagues (Intolo et al., 2010), was added because we suspected it might be difficult for the subjects to adopt the seated postures repeatedly with good accuracy.

Five ISU:s were used. The position of the lower three units was chosen based on information from a study by Dankaerts and colleagues (Dankaerts et al., 2006), where sensors were taped on the skin over the spinal processes of S2, L3, and T12, because the lower part of the lumbar spine is the most common area for low back pain (Biering-Sorensen, 1983). The two upper units were meant to be positioned on the forehead and over the spinal process of C7, according to Jasiewicz and colleagues (Jasiewicz et al., 2007). The