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An index to quantify deviations from normal trunk mobility: Clinical correlation and initial test of validity

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ABSTRACT

Background: In case of people suffering from chronic low back pain, specific movements of the hip, pelvis, and trunk are associated with pain. Comparing range of motion measurements for multiple planes and from different segments and lines in reference to those of healthy individuals seems interesting but present interpretations challenge in relation to important number of variables and correlation with clinical data.
Methods: The proposed index is based on using principal component analysis to quantify differences in trunk mobility between patients with chronic low back pain and a control group. Kinematic data were recorded for the cervical and thoracic vertebrae, the lumbar spine, and the pelvic and scapular belts during repeated trials (hip flexion and extension, hip bending, and trunk twists). Angular motion values were calculated. Principal component analysis was used to convert 10 discrete variables (kinematical data) extracted from control data into 10 independent variables.
Findings: The proposed index comprises the sum of the variables. Initial demonstration of its clinical utility and statistical tests of this index validity were revealed. It establishes correlations between the psychosocial impact of chronic low back pain, trunk mobility (as summarized by the index) and the positive effects of functional restoration program.
Interpretation: This index let to assess the absolute potential benefits of rehabilitation in term of kinematic motion. Functional restoration program promotes the physical functioning of patients by increasing their range of motion. This index uses kinematic motion to assess the potential benefits of such rehabilitation program.

1. Introduction

Recent quantitative comparison studies have used kinematic data to evaluate the potential benefits of therapy and complete clinical examination for people suffering from Chronic Low Back Pain (CLBP) (Cho et al., 2014; Sadeghisani et al., 2015). Medical evaluations of patients with CLBP are predominantly based on clinical data, not on kinematic data. Thus, several basic clinical values (e.g., trunk muscle endurance and flexibility) are used to determine the impact of low back pain on a patient's quality of life. This pain level is usually assessed with the help of specific, mostly clinical, scores and questionnaires. The Dallas Pain Questionnaire (DPQ) uses 16 items to evaluate the impact of CLBP on a patient's daily, work and leisure activities and on levels of anxiety, depression, and sociability (Marty, 2001; Marty et al., 1998). The DPQ has been translated into French and was subsequently validated (Marty et al., 1998). Alternatively, the Quebec Back Pain Disability Scale (QBPDS) can be used to evaluate the impact of back pain on daily life (Kim et al., 2015). The score, calculated from a questionnaire of 20 items, depends on the duration and severity of the pain, the patient's sex, and the type of LBP (chronic or acute, specific or nonspecific). For sufferers of CLBP, the QBPDS score shows a higher sensitivity to clinical changes than the DPQ score (Wilhelm et al., 2010). Finally, a visual analog scale (VAS) is a commonly used instrument in questionnaires to assess a patient's pain level (Mannion et al., 2007; Ogon et al., 1996). Although these clinical data help assess various effects of back pain, such evaluations do not provide information on how pain affects movement. Fear-avoidance behaviors result in compensatory movement patterns and reduced mobility; the mechanisms involved in this adaptive strategy have been clearly identified (Fujii et al., 2013).

Kinematic analyses rely on a relatively large number of parameters. Indices such as the Gillette Gait Index or the Gait Deviation Index have been proposed in the literature (Chester et al., 2007; Massaad et al., 2014; Schutte et al., 2000; Schwartz and Rozumalski, 2008). These quantitative indices allow gait problems to be summarized based on one variable per side: the more severe the gait troubles are, the higher

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the index will be. Such indices require a correlation with clinical data to eliminate the possibility of a simple mathematical or biomechanical parameter (Massaad et al., 2014).

Although walking may be considered a typical daily activity and a more important movement in rehabilitation, other movements could provide additional information depending on the person's physical impairment. For patients with CLBP, specific movements of the hip, pelvis, and trunk are associated with pain (Olsen, 2006; Sadeghi et al., 2009). Small modifications in gait are related to experienced pain levels and gait velocity (Crosbie et al., 2013; Lamoth et al., 2006; Seay et al., 2011; Van den Hoorn et al., 2012). It is therefore logical to analyze other specific movements involving the trunk and hip. Impaired movement of the trunk is associated with the adoption of a protective movement strategy and overall decreased mobility, such as a person reducing the amount of physical strength used when moving freely (Crosbie et al., 2013; Moe-Nilssen et al., 1999), which has a potential impact on daily activities (Lamoth et al., 2006; Lee et al., 2007; Miyakoshi et al., 2010; Van den Hoorn et al., 2012). Patients performing physical movements with a greater Range of Motion (RoM) are more likely to be affected by pain than when they remain static (Sadeghi et al., 2009). This study comparing the segments, joints, and movements in patients with CLBP with those of healthy individuals revealed that in the CLBP population these joints and movements were associated with pain (physical and/or psychological). These observed differences may be reduced through a functional restoration program (FRP) (Oakley, 2003). Consequently, to assess the potential benefits of rehabilitation, it seems relevant to evaluate RoM measurements for multiple planes and segments or lines, to compute the global mobility index of the trunk. The proposed index of trunk mobility is based on kinematic parameters and can be used in conjunction with the corresponding clinical parameters to evaluate mobility for patients with CLBP.

2. Methods

2.1. Study participants

Following ethical approval from Ethics Committee of Angers, France, (2017/07), the control group was composed of 21 healthy subjects (12 men and 9 women; mean 22.74 years (Standard Deviation: 2.27); mean 67.12 Kg (SD 10.34 kg); mean 170.27 cm (SD 8.67)). The control population had not experienced LBP during the previous 12 months. A group of 26 patients with CLBP (13 men and 13 women; mean 38.04 years (SD 6.35 years); mean 76.88 Kg (SD 16.67 kg); mean 171.88 cm (SD 10.28 cm); mean VAS pain scale 4.4 (SD 2.1)) took part in the *Protocole Lombaction* (a multidisciplinary reconditioning program coordinated by the French Regional Network for Occupational Health). The sample size relates to the statistical power (85%) computed for each variable and index. All patients reported the site of the injury to be within the lumbar or lumbosacral region, but none of them reported radicular symptoms. Based on (O'Sullivan, 2005), pain symptoms were due to pathological processes in 13 patients, psychological and/or social factors in 3 patients, and chronic abnormal tissue loading and ongoing pain and distress in 10 patients. These patients participated in a 5-week multidisciplinary FRP involving muscle development, stretching, posture, cardiovascular, and proprioceptive exercises. The program also included ergonomics and psychosocial care. The dropout rate was null. None subjects (patients and controls) had any apparent neurological or orthopedic disorders (like scoliosis) or previous surgery likely to interfere with movement. Motion caption data were recorded during the first and final week of the program. Pain levels and the effects of pain on daily activities were evaluated with a VAS for pain, the Quebec Back Pain Disability Scale (QBPDS), and the Dallas Pain Questionnaire (DPQ). The study was approved by head physician and several physicians of the rehabilitation establishment.

2.2. Experimental setup and selection of studied movements and variables

A 3D motion capture system (ViconT10, 100 Hz, Oxford, United Kingdom) equipped with 8 cameras recorded data for 34 passive markers (14 mm) to define a plug-in gait model. A double-pass Butterworth filtering method was used (3 Hz). Primary motions such as hip flexion and extension, hip lateral flexion (left and right side), and trunk twists (left and right side) were captured to measure the relevant RoM values for each plane. Subjects were asked to perform 3 sets of these movements at the speed of their choice and were given rest periods of 5 s between each set and 10 s between each movement. The 5-second interval was implemented to make certain that all markers were captured correctly and to ensure that the subject began and completed each movement in an orthostatic posture. To exclude any compensatory movements, trunk extension was not examined. Subjects began movements in a comfortable standing position: they stood in an erect posture looking forward, their arms hanging freely, both before and after each movement. They were asked to avoid compensatory movements of the lower limbs (e.g., knee flexion or extension) and of the trunk in order to isolate hip and trunk mobility. Subjects were asked to perform these movements to maximum voluntary ranges while respecting plane of movement. The order of the tests was not randomized; the effects of pain, learning and fatigue would be equally distributed across each protocol.

Three trunk lines were defined for the sagittal and frontal planes: between the C7 vertebra and the sacrum [C7-SACR], between the T7 vertebra and the sacrum [T7-SACR], and between the T10 vertebra and the sacrum [T10-SACR]. The sacrum was considered as the middle of the segment between posterior superior iliac spines. The angles between the vertical axis (sagittal plane) like (Hidalgo et al., 2012) or the horizontal axis (frontal plane) and each line on the back were calculated. Additionally, for the horizontal plane, the angles between the anteroposterior axis and the scapular and pelvic belts were computed (Fig. 1). The variables were extracted, and the minimum and maximum values for the 3 curves were obtained from flexion, extension, and lateral flexion data. The differences between the maximum values for scapular and for pelvic rotations were extracted to obtain 16 discrete variables per subject. Only 10 variables that revealed a significant difference between CLBP and healthy subjects were considered (*t*-test, $p \leq 0.05$). Furthermore, there were no significant differences between right-side and left-side maximum values of the scapular and pelvic rotations. Only right-side maximum values were used. The selected variables made it possible to describe a RoM that can be compared with clinical observations and control data (Table 1).

2.3. Calculating the index

In accordance with (Schutte et al., 2000), our method (Fig. 2) uses discrete variables and principal component analysis (PCA). Based on a healthy population, a centered and reduced matrix was computed from the mean and standard deviation of each variable in order to obtain a reference variation from PCA data (stage 1 in Fig. 2). The 4 sets of principle components used describe > 99% of the information contained in the motion data. To convert CLBP-patient data from a traditional reference into this specific reference ("healthy reference"), we created a matrix composed of the mean, standard deviation, eigenvalues, and eigenvectors of each variable. The mathematical procedure derived from the new coordinate system (stages 2 and 3 in Fig. 2) allowed us to obtain the Euclidian length (called the *index of trunk mobility*) between CLBP-patient and control data in this new uncorrelated system. The Shapiro–Wilk test was applied to the statistical distribution ($p \leq 0.5$) and the *t*-test ($p \leq 0.5$) was used to compare groups. Pearson's correlation coefficient was used to measure correlations between the index and two clinical scores (pain intensity assessed with a VAS for pain and with the DPQ) to integrate clinical interpretation with the proposed kinematic index. We used a method similar to that described