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Research Paper

Quantifying postural stability of patients with cerebellar disorder during quiet stance using three-axis accelerometer

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ABSTRACT

This work focuses on the novelty of applying a 3-D postural analysis on the cerebellar disorders diagnosis and on introduction of an alternative to recent methods of quantifying the human postural stability during quiet stance, which uses a three-axis accelerometer. It introduces an advantage in the form of an ability to evaluate a complex three-dimensional (3-D) movement, as opposed to a major limitation of todayís alternatives that evaluate only two coordinates in space. 3-D data (anterior-posterior, superior-inferior, and medio-lateral accelerations of a patientís trunk) were obtained using a three-axis accelerometer (Xsens Mtx), enabling us to evaluate 3-D translational body movements on the basis of the average velocity (AV) of the point and the total length (TL) of the 3-dimensional trajectory. Then a pathological balance control has been identified from the 3-D plot of the three trajectories. The data were obtained from patients suffering from the progressive cerebellar ataxia as well as from healthy participants and were analyzed statistically. The analysis revealed several significant differences between the AVs and TLs of the patients versus the healthy participants.

1. Introduction

Sufferers of nervous system diseases often tend to show signs of instability during quiet stance, since trunk posture can be negatively influenced by numerous diseases of the nervous system [1–3]. Some of the techniques to identify such disorders are the removal of visual inputs and the use of a foam ground surface to distort the lower-leg proprioreceptive input, thus increasing the difficulty of a stance task [4,5]. Recently, the use of the traditional force platforms to study the center of pressure (COP) excursions was replaced by the tri-axial inertial measurement units (IMU) for the acceleration and orientation measurement, i.e. for the high-accuracy 3-D measurement of the human body's movement [6]. In previous experiments, the IMUs were used to measure the motion of the head, trunk and pelvis, by placing them on the top of the head, spinous processes of the T1 and/or the S1, respectively. Despite the fact that IMU systems are capable of measuring three angles and three accelerations, methods have been introduced to observe segment movements using only one or two measured quantities [6–10]. During standing, trunk acceleration observation can point out balance control difficulties in neurological patients [10,11], and furthermore track the progress or further impairment over time [12]. Several IMU systems were designed as diagnostic devices for monitoring trunk motion [13,14]. Recently, it has been possible to employ wider range of devices in order to evaluate the balance control, such as accelerometers or gyroscopes [9]. Studies on balance control measurements show differences between the results of patients and healthy participants. Naturally, the sway of neurologically diseased patients follows from the kind of the impairment and an instability in medio-lateral direction [8], or anterior-posterior direction [15] is present. Advantages of the use of the IMU in the diagnostics may prove more beneficial in acquiring the insights into the balance control impairment than the traditionally used methods. Despite this, its promising potential has not yet been applied to examine balance deficits in patients with particular kinds of disease. Cerebellar diseases can now serve as an example of a medical field where not only force platform, but also a new IMU can be utilized to assess the translational body movements of patients [16]. Thus, the work focuses on the novelty of applying the 3-D postural analysis on the cerebellar disorders diagnosis and the identification of the connection between the trunk movement in space and the

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neurological disorder, because the cerebellar disease is characterized by a tremor or sway.

As for the traditional counterparts of evaluating the postural stability, those are methods based on a 2-D convex hull [17–19], a 2-D confidence ellipse [20–22], or the plotting of two variables vs. each other representing the trajectory length [23,24]. As the description suggests, the shortcoming of the traditional methods lies in the evaluation of only two physical quantities, representing two human axes/planes. The absence of the third quantity contributing to the 3-D assessment may reflect in the loss of the important information about the motion. This was also the case when the tri-axial IMUs were used to observe the trunk stability, however, only two of the three measured variables were used for the analysis. Thus, the ability to model the movements of a body utilizing the 3-D data collected by the tri-axial IMU (for example the MTx units – Xsens Technologies B.V.) offers us the possibility to obtain a complete body movement pattern. It is also evident that the cheap IMU placed on a patient's body segment, preferably on the trunk, in conjunction with a method based on the evaluation of the 3-D data-set could substitute the expensive stabilometric platforms that measure only a 2-D horizontal movement.

The next objective of this study is to introduce a novel method used in the identification of the pathological balance control using the IMU to measure accelerations, as well as the average velocity of the point and a total length of the trajectory represented by means of plotting three accelerations vs. each other (the evaluation of the 3-D data-set of the superior-inferior acceleration, medio-lateral acceleration and the anterior-posterior acceleration of body segments). It proceeds from a common practice that consists in the assessment of the length of the trajectory of only two variables in the 2-D space [25]. The choice for this new design came from the actual ability of a single variable to describe changes in three kinds of accelerations, considering the wide availability of the tri-axial IMUs (ordinary cell phones) [26,27] and electronic watches [28]. Furthermore, the evaluation of accelerations suits the needs of this study well, since they reflect the changes in position as well as the intensity and the magnitude of the tremor. The practicality of a variable of the total trajectory representing both the volume and the speed of a body segment foreshadows the immense potential of which a simple cheap IMU is capable through the direct evaluation of the accelerations.

The cheap IMU placed on a patient's body segment in conjunction with the new method based on the evaluation of the 3-D data-set could substitute the expensive stabilometric platforms that measure only a 2-D horizontal movement in the cerebellar disorders diagnosis.

However, the observation of the three directions of a body movement by a cheap IMU may be a topic of numerous related studies, for which it can prove very instrumental. There are a number of medical studies, which could find it appropriate to evaluate the body segment movement in three directions (superior-inferior, medio-lateral and anterior-posterior) instead of evaluating the movement of the CoP in two horizontal directions.

2. Methods

2.1. Participants

It is necessary to compare healthy participants without any postural balance problems to participants who have postural balance problems, in order to test a method according to the assessment of the three accelerations measured by a one three-axis IMU. Comparing only the same age groups should not be a condition, because the boundaries of body sway of the healthy participants within the age span between 20 and 60 years differ only slightly, as some studies show [29,30]. Previous detailed analysis of the age-related increase of COP parameters by the polynomial type of regression showed that the significant degradation of stability, characterized by the increase of COP oscillations, starts after the age of 60 [30].

Ten volunteer patients (age of 52.2 (SD 11.7) years) with the degenerative cerebellar ataxia [31] and eleven healthy participants (age of 26.0 (SD 6.4) years) participated in the research. The patients came from the Faculty Hospital Motol, Prague, Czech Republic. Eight patients were diagnosed with the Idiopathic late-onset cerebellar ataxia (ILOCA), it is a sporadic ataxia of an unknown cause, clinically characterized by the slowly progressive pure cerebellar syndrome. ILOCAs are clinically and neurophysiologically indistinguishable from hereditary ataxias. Two patients were diagnosed with the spinocerebellar ataxia type 2. Earlier on, a board-verified neurologist had evaluated and determined the progressive cerebellar disease. Symptomatic assessment involved an elaborated disease history, a neurologic analysis, regular laboratory blood and urine tests, and a brain MRI. The participants were measured in the preparatory stage of the clinic's two-week rehabilitation plan. The rehabilitation plan that took place at the hospital was determined on the basis of long-term serious problems in postural stability. Healthy participants were students/volunteers from the Charles University in Prague. In the case of the healthy participants, the symptomatic assessment involved an elaborated disease history, a neurologic analysis and a regular laboratory testing. The research was conducted correspondingly with the Helsinki Declaration. The research procedure was validated by the local Ethical Committee and the University Hospital Motol and a notified clearance was acquired from all patients. The participants were selected for the assessment randomly, and on various days.

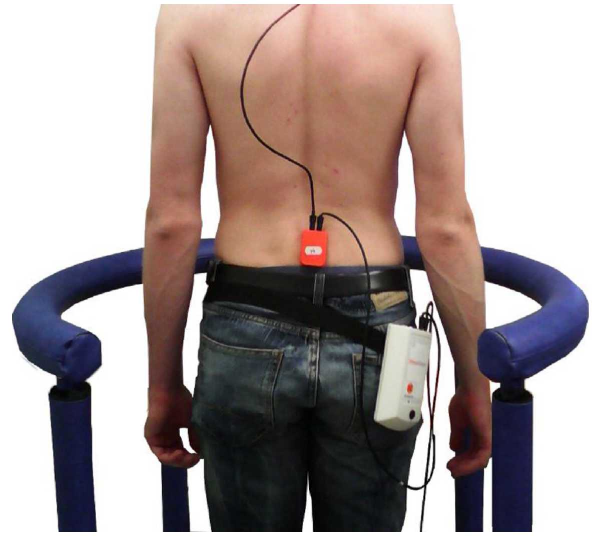

Fig. 1. Arrangements of the Xsens system with Xbus Master and a one three-axis IMU (i.e. MTx unit) placed at the height of the lower back to measure angles and accelerations of the trunk.

2.2. Test procedure and measurement equipment

The Xbus Master, lightweight (330 g) and transportable appliance using the MTx units for the orientation and acceleration assessment of body parts (see Fig. 1), was used for the assessment of the trunk movements. We've already used that system in the past for measuring motion data, e.g. to measure a head movement, [32]. MTx unit is a small (38 × 53 × 21 mm; 30 g), precise IMU supplying drift-free 3-D orientation and 3-D acceleration. The sensor fusion algorithm (Extended Kalman Filter) is mounted on the unit. The output signal was not filtered in any other way, to have the