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ORIGINAL RESEARCH STUDY

Assessment of postural stability in patients with cerebellar disease using gyroscope data

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Summary This study examines a relatively new method of studying and quantifying human postural stability in patients with degenerative cerebellar disease. Trunk sway and feet sway were measured during quiet stance. To test the method, ten patients and eleven healthy subjects performed two different stance tasks: standing with eyes open on a firm surface and standing with eyes closed on a foam support surface. Data were recorded using three body-worn gyroscopes (Xsens Technologies B.V.) to measure roll and pitch angular movements of the lower trunk, and left and right foot. The pitch versus roll plots of the trunk and feet were created, and the areas of the convex hull shapes were calculated. It was found that the area of the convex hull of the pitch versus roll plots is suitable for the identification of postural instability disorders caused by degenerative cerebellar disease.

Introduction

The position and orientation of body segments can be influenced negatively by many diseases of the nervous or musculoskeletal system, (Duclos et al., 2008). Subjects with these disorders often show instability during stance tasks. Making the stance task more difficult by removing visual inputs has been claimed as a means to identify the vestibular deficit, evaluate the movement of stroke patients, cerebral palsy patients and healthy subjects during stance (Morris, 2000; Ashburn et al., 2001). Triaxial inertial measurement units for orientation measurement (i.e. gyroscope systems) were used for high-accuracy measurement of human body segments during quiet stance. In the

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measurement theory, motion capture (MoCap) systems measure the pitch, roll and yaw of a body segment with respect to the earth's gravity and horizontal reference plane. These angles represent the orientation of the segment in three-dimensional (3-D) space. Thus the pitch, roll and yaw are not joint angles, but rather Euler angles. These angles are used to study the orientation of the body segments in a complex kinematic chain. Therefore, the pitch, roll and yaw angles are used in the field of medicine (Aw et al., 1999; Allum et al., 2008; Findling et al., 2011; Osler and Reynolds, 2010). Generally, the pitch is a rotational motion of the segment around the medial—lateral axis, the roll is a rotational motion around the anterior—posterior axis and the yaw is a rotational motion around the vertical axis. Techniques were introduced to study movements of a specific body segment in pitch and roll axis during stance and gait tests with freely moving individuals (Allum et al., 2001; Gill et al., 2001; Adkin et al., 2001; Allum and Adkin, 2003). Measurement of angular movements during tasks can identify changes in postural stability with age (Gill et al., 2001) and identify musculoskeletal disorders or vestibular deficits (Allum et al., 2001). In these studies, combinations of pitch and roll sway measurements during specific balance tasks identified differences in balance control between patients (Pts) and healthy subjects (HS). Therefore, assessment of angular movements proved to be a new diagnostic tool and may yield clearer insights into balance deficits.

As for the data processing methods, the most commonly used methods for the assessment of postural stability are those based on evaluation of the range of angle movement or mean sway velocity (Horlings et al., 2008), and frequency domain analysis (Hwang et al., 2006). Other less frequently used methods for assessing the postural instability are based on the shape of the envelope (convex hull — CH) (de Hoon et al., 2003) or 2-D confidence ellipse (Morton and Bastian, 2004; Oliveira et al., 1996). These methods are based on the description of the behavior of two variables in two human body planes/axes. However, these less frequently used methods utilizing data from gyroscope systems have never been used to study postural stability of Pts with degenerative ataxia.

Degenerative ataxias are a heterogeneous group of hereditary and nonhereditary diseases. They are characterized by progressive ataxia due to degeneration of the cerebellar cortex, cerebellar nuclei and spinal pathways, which result in impaired coordination of the limbs, postural instability, abnormal gait with high risk of falling (Morton and Bastian, 2004; van de Warrenburg et al., 2005a,b). The main tool for the study of body movement of patient with cerebellar disease is now force (posturography) platform, (Kammermeier et al., 2013). However, using the method based on data from a gyroscope system and the pitch versus roll plots can provide new and useful information on balance deficits and the cerebellar disorder itself. Data processing based on the concept of the area of convex hull might be a suitable tool. Nevertheless, the method and its possible suitability for clinical application to study postural stability of Pts with cerebellar disorder have never been examined. Also, results obtained from different segments of the body using this method have not been compared. Thus, the aim of this work is to identify suitability of the area of the convex hull of the data set measured by gyroscope for clinical application, describe the relationship between the areas of the convex hull (ACH) of the pitch versus roll plot of different body segments and determine values of these variables in HS and Pts with cerebellar disorder. The reason behind this new design is that the study of movement with one variable characterizing the change in two main angles may find new use for the study of postural stability using very cheap gyroscopes which are also used in cell phones (Manohar et al., 2011; He et al., 2012) and electronic watches (Kulkarni and Basu, 2013).

The most frequently studied movement of a body segment is movement of the trunk (Horlings et al., 2008), much less studied is movement of the head and lower extremities. We focused on the comparison of the feet and torso movement. The advantage of placing the sensor on the torso is the measurement of changes in orientation and position of the trunk, which are given by a complex kinematic chain, behavior of which is determined by three different strategies that people normally use to regain balance, namely ankle strategy, hip strategy and step strategy. The sensor which is placed on the trunk identifies an unstable behavior and the sway of the body as a whole (Riemann et al., 2003). On the other hand, sensors placed on feet may be more likely to detect tremors, in the case of standing on a foam surface, (Günther et al., 2009). Gyroscopic data has previously been used to compare the leg and trunk movements, (Honegger et al., 2013). Some findings show that changes in leg movement are significantly larger than movements in the pelvis and shoulders, (Honegger et al., 2013; Fransson et al., 2007). However, in the case of single limb stance, trunk movements are larger than movements in the lower limb, (Eslamia et al., 2006). Thus, study of the ACH of the pitch versus roll plot can bring new findings. This study also focuses on identification of a more appropriate sensor placement (whether the trunk or feet are convenient) for the identification of cerebellar disorder.

Methods and materials

Participants

Ten volunteer patients (mean age of 52.2 (SD 11.7) years) with degenerative cerebellar ataxia (Cakrt et al., 2012) and eleven healthy subjects (mean age of 26.0 (SD 6.4) years) participated in the study. All Pts were recruited from the Department of Neurology at the Faculty Hospital Motol, Prague, Czech Republic. Pts with progressive cerebellar ataxia were measured at the beginning of the clinic's two-week rehabilitation program at University Hospital Motol. A board-certified neurologist had previously screened and diagnosed cerebellar disorder. Diagnostic evaluation included a detailed disease history, a neurologic examination, routine laboratory blood and urine tests, and a magnetic resonance imaging of the brain. All Pts and HS expressed their informed consent before the experiment. HS were recruited from the students/volunteers at The Czech Technical University and Charles University in Prague. Volunteers from among the young students were