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Frailty assessment based on wavelet analysis during quiet standing balance test

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ABSTRACT

Background: A standard phenotype of frailty was independently associated with an increased risk of adverse outcomes including comorbidity, disability and with increased risks of subsequent falls and fractures. Postural control deficit measurement during quiet standing has been often used to assess balance and fall risk in elderly frail population. Real time human motion tracking is an accurate, inexpensive and portable system to obtain kinematic and kinetic measurements. The aim of this study was to examine orientation and acceleration signals from a tri-axial inertial magnetic sensor during quiet standing balance tests using the wavelet transform in a frail, a prefail and a healthy population.
Methods: Fourteen subjects from a frail population (79 ± 4 years), eighteen subjects from a prefrail population (80 ± 3 years) and twenty four subjects from a healthy population (40 ± 3 years) volunteered to participate in this study. All signals were analyzed using time–frequency information based on wavelet decomposition and principal component analysis.
Findings: The absolute sum of the coefficients of the wavelet details corresponding to the high frequencies component of orientation and acceleration signals were associated with frail syndrome.
Interpretation: These parameters could be of great interest in clinical settings and improved rehabilitation therapies and in methods for identifying elderly population with frail syndrome.

1. Introduction

Frail syndrome has been found to be a risk factor for mortality, comorbidity, disability and hospitalization (Fried et al., 2001). The role of falls as a major source of morbidity and mortality in frail syndrome (Tinetti et al., 1988) has prompted a growing interest in postural control deficit measurements during quiet standing (e.g. postural steadiness; Campbell et al., 1989; Izquierdo et al., 1999; Prieto et al., 1993). Traditional postural steadiness evaluation typically includes separate tests with eyes open and eyes closed performed on a force platform and are usually based in the ability of an individual to maintain the position of the body within specific spatial boundaries without moving the base of support (Prieto et al., 1993; Mathie et al., 2004).

Traditional postural control tests on force platforms require a specialized and dedicated laboratory, not being suitable for ambulatory measurement of human body balance. Inertial/magnetic tracking technology opens new perspectives to evaluate postural sway. This measurement system offers a reliable and low-cost alternative to more sophisticated instrumented approaches that are available for measurement of balance during standing and walking (Moe-Nilssen, 1998a). An inertial/magnetic tracking system uses a combination of accelerometers, rate gyros and magnetic sensors (Zhu and Zhou, 2004; Moe-Nilssen, 1998a, 1998b; Sabatini, 2005). The signals obtained from a sacrum-mounted accelerometer can be used to distinguish between different balance conditions (e.g. feet together and apart, and eyes open and eyes closed while standing with feet together; Mayagoitia et al., 1999, Kamen et al., 1998), as well as to distinguish between healthy elderly subjects and idiopathic elderly fallers (Cho and Kamen, 1998; Overstall et al., 1977; Campbell et al., 1989). In a previous study, Martínez-Ramírez et al. (2010) showed complementary relationships between acceleration/gyros and force plates to detect dynamic stability deficits in subjects with chronic ankle instability. Moreover, they found that the accelerometer was more sensitive in some tests of the study. However, to the authors' best knowledge, no studies have examined the relationship between trunk orientation and acceleration signal and frail syndrome in older adults.

The displacements of the center of pressure (COP) and the body center of mass (COM) are notable indicators in postural steadiness

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characterization and are considered to play an important role in the control of standing balance (Lee et al., 2007; Betker et al., 2006; Winter, 1995; Prieto et al., 1992). Time–domain measurements have been classically used in the assessment of postural control in elderly people. Large excursion areas and average distances from the mean COP/COM location in double and single static leg stance are indicative of postural instability (Kamen et al., 1998; Izquierdo et al., 1999; Bohannon et al., 1984; Era and Heikkinen, 1985; Maki et al., 1990). More recently, higher frequencies of postural sway have been related to aging and balance-related pathologies (Kamen et al., 1998; Winter, 1995), as well as to subtle and idiopathic falling disorders (Kamen et al., 1998).

In recent years, the interest in the use of wavelet analysis as a new technique for kinematic signal processing has increased considerably. It provides multiresolution time-localized information on the frequency content of the signal under study by successive decomposition into coarse approximation (e.g. low-frequency features of the signal) and detail information (e.g. high-frequency features of the signal; Rioul and Vetterli, 1991; Mallat, 1989). Previous studies have shown relationships between the spectral pattern of sway measured with force platforms and age-related deterioration of postural steadiness (Izquierdo et al., 1999; Kamen et al., 1998). However, relatively little work has been done on finding to what extent frailty syndrome may also be associated with a decline in the frequency content of postural adjustments for maintaining stability and balance as measured by inertial sensors. Based on these results, the aim of the present study was to use the wavelet transform to examine the orientation and acceleration signals obtained from a tri-axial inertial magnetic sensor suitable for ambulatory measurements during quiet standing tests within a healthy, a prefrail and a frail population.

2. Methods and materials

2.1. Subjects

Fourteen subjects from a frail population (five males, nine females: age: 79 ± 4 years, body mass 66.3 ± 10.3 kg, height: 1.51 ± 0.073 m), eighteen subjects from a prefrail population (nine males, nine females: age: 80 ± 3 years, body mass 70.6 ± 9 kg, height: 1.55 ± 0.093 m) and twenty four subjects from a healthy population (14 males, 10 females: age: 40 ± 3 years, body mass 75.3 ± 11 kg, height: 1.72 ± 0.125 m) volunteered to participate in this study. Frailty was defined on the basis of the five dimensions in a phenotype described by Fried et al. (2001). The frail elderly showed:

1) an unintentional body mass loss of 4.5 kg or more in the last year.
2) "Low energy", identified when they provided a positive answer to any of the following two questions from the CES-D (Center for Epidemiologic Studies Depression Scale; Orme et al., 1986): "I felt that anything I did was a big effort" and "I felt that I could not keep on doing things at least 3–4 days a week".
3) Low physical activity, defined as the lowest quintile in the PASE score (Schuit et al., 1997).
4) Weakness, defined as the lowest quintile of maximum strength on the dominant hand adjusted for sex and body mass index (kg/m^2).
5) Slowness, defined as the lowest quintile in the three-meter walking speed test, adjusted for sex and height according to the standards of the Short Physical Performance Battery (Guralnik et al., 1994).

As in Fried's study (Fried et al., 2001), cut-offs for positive frailty indicators in items three, four and five were set at the lowest 20% of the independent older group.

We assigned one point to each variable, and built a score as the sum of points for all of them. According to this score, subjects were classified as non-frail (0 points), prefrail (1–2 points) and frail (3–5 points). We excluded subjects who could not perform the physical performance test battery due to poor health.

The healthy group was randomly selected from voluntary patient relatives or visitors. They completed a survey and a follow-up interview with a research team member regarding their health history. Inclusion criteria for healthy subjects were no previous history of balance disorders and postural problems. Subjects were informed about the experimental procedure and the purpose of the study. Subsequently, subjects gave their written informed consent to participate.

2.2. Testing procedures

Postural steadiness was measured in different standing conditions. The subjects were asked to wear comfortable usual shoes before the session. In order to repeat the relative positions of the feet in each trial, subject are asked to position the feet over a mark on the floor before each trial. The patient was made to stand with his feet close together, arms by the side and eyes open, standing as quietly as possible and look straight ahead for 10 s in two separate foot positions: feet close together and feet in semitandem, both with eyes open and eyes closed. The duration of the test was 5 min per subject.

In all, four different test conditions were evaluated:

1) feet together with eyes open (FTO).
2) Feet together with eyes closed (FTC).
3) Feet in semitandem with eyes open (FSO).
4) Feet in semitandem with eyes closed (FSC).

2.3. Instrumentation

Orientation data, provided by an inertial unit (Orientation Tracker MTx XSENS, Xsens Technologies B.V. Enschede, Netherlands), attached over the third lumbar vertebra region of the lumbar spine, were recorded in each trial at a sampling rate of 100 Hz. The MTx unit itself combines nine individual MEMS sensors to provide drift-free 3D orientation as well as kinematic data: 3D acceleration, 3D rate of turn (rate gyro) and 3D magnetometers. A detailed description of the MTx unit's calculation methods can be found elsewhere (Martínez-Ramírez et al., 2010)

Before the data recording begins, the sensor-fixed reference frame (*xyz*) is set to coincide with the global-fixed reference frame (*XYZ*), with the *Z* axis pointing upwards, the *X* axis lying on the lateral direction and the *Y* axis on the antero-posterior direction. The orientation data analyzed in this study are rotation angles around the global axes (*XYZ* or roll-pitch-yaw order) that transform the global reference frame into the sensor reference frame (Fig. 1a). The acceleration data are the acceleration components of postural adjustment movements on the sensor reference frame.

2.4. Signal processing

2.4.1. XY projection

Change of position can be estimated by integration of acceleration and angular velocity signals obtained from inertial sensor modules, but some important limitations of the system need to be addressed (Schepers et al., 2010). Evaluate and studied time–domain measures of the COP include the distance between two consecutive points on the COP path and area measures calculated from the COP path (Prieto et al., 1993). A more detailed description of the displacement of COP is presented in Appendix B in supplementary data (see Fig. 1b for a graphical representation).

2.5. Fourier analysis

A review of the literature reveals that researchers use the fast Fourier transformed (FFT) technique to analyze the human movements (Godfrey et al., 2008; Hester et al., 2006). We decided to compute the sum of the coefficients of the power spectrum obtained from the FFT of the orientation and acceleration signals, regardless of the non-stationary nature of these signals.

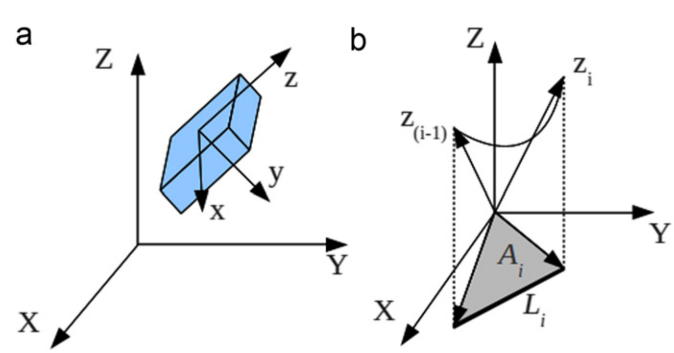

Fig. 1. Global-fixed reference frame (*XYZ*) and sensor-fixed reference frame (*xyz*) (a). Path length L_i and sway area A_i elements computed from two consecutive sensor orientations (b).