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Short communication

Multiscale time irreversibility: Is it useful in the analysis of human gait?

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ABSTRACT

Purpose: To analyze the complexity of the gait through the measurement of Multiscale Time Irreversibility in accelerometry signals obtained at the hip of healthy subjects and patients with intermittent claudication in order to differentiate the two situations.
Methods: Ten healthy elderly subjects (age 60.2 ± 4.8 years; height 173.6 ± 6.6 cm; weight 88.9 ± 11.3 kg); and 12 patients with peripheral arterial disease (age 63.1 ± 5.4 years, height 168.6 ± 6.5 cm; weight 81.2 ± 15.9 kg) walked at a comfortable, freely-chosen pace for 10 min in an open circuit wearing a triaxial accelerometer on each hip. The Asymmetry Index was calculated (scales 1–20) from the accelerometry series on the axes X, Y and Z for each hip using the simplified algorithm proposed by M. Costa.
Results: A lower asymmetry can be seen in the group of patients on the Y axis of both legs with respect to the control group (p = 0.001). Comparing one leg with the other, only the patients showed a difference on the Z axis (p = 0.04) with less asymmetry in the claudicant leg (0.29 ± 0.15 vs. 0.55 ± 0.49).
Conclusions: The analysis of Multiscale Time Irreversibility through the Asymmetry Index is useful for the study of human gait and can reveal behavior that allows pathological situations to be distinguished.

1. Introduction

Healthy physiological control systems are highly complex and non-linear. As such, the dynamics of their output signals contain information on multiple time scales. Counter-intuitively, with ageing and disease, physiologic dynamics become either more regular, i.e., more predictable, or more random. Both of these behaviors, periodicity and uncorrelated randomness, represent loss of multiscale information, which is interpreted as reflecting a breakdown of physiologic control [1].

In 1975, the concept of "time irreversibility" was introduced [2] to refer to the loss of consistency in a time series if it is read backwards in time. The capacity of living beings for self-organization is related to the single direction of energy flows [3] and the loss of this capacity is related to age and ageing [4].

However, some studies undertaken in the 1990s analyzed electroencephalogram records [5,6], and tremor in patients with Parkinson's disease [7,8] showed an increase in irreversibility with the disease, which is not coherent with the non-linear behavior expected of these systems. The problem could lie in the use of a simple scale (k = 1) when we know that the physiological signals generate a much more complex pattern. Therefore, it would be much more accurate to calculate irreversibility at different scales (different k values), giving rise to the concept of Multiscale Time Irreversibility (MTI) [4,9]. To calculate it at a scale of k from any time series, a new series must be constructed in which each term is the difference between each element and the one that is located k positions behind it in the original series.

Different algorithms have been proposed to quantify time irreversibility in time series, the most classic indices being those of Porta, Guzik and Ehler [10,11], which have been used in studies which analyze different pathologies through the time irreversibility of the cardiac signal [12–15]. However, due to its simplicity and the good match which it shows with physiological processes, we believe that it is of interest to consider the algorithm proposed by Costa et al. [4,9], which proved itself useful in detecting different situations in patients with coronary heart disease and healthy subjects of the same age [16].

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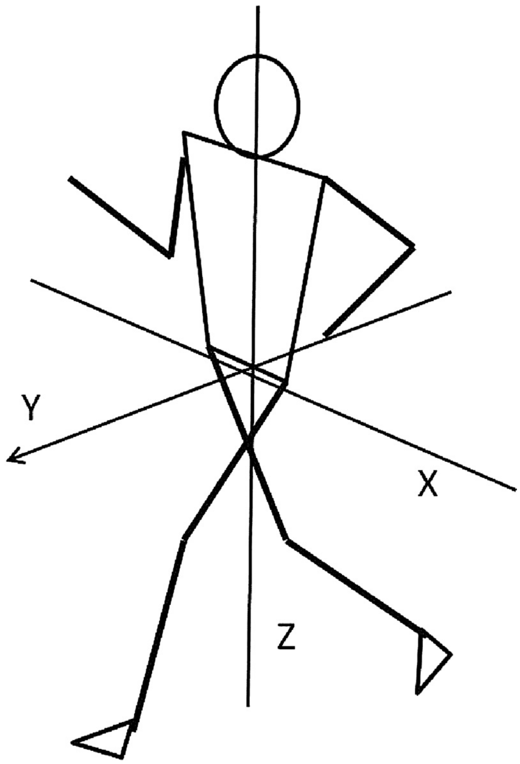

Fig. 1. Position of the three axes in the space.

Human gait is considered to be a complex system and we know that the mechanism involved in musculoskeletal control and balance is fundamentally non-linear, and is governed by deterministic chaotic dynamics [17,18].

There are studies which provide copious information about this type of gait analysis in subjects of an advanced age [19,20], and on pathologies that affect gait patterns, such as Huntington's disease [21], Parkinson's disease [22], amyotrophic lateral sclerosis [23] or after surgery on the anterior cruciate ligament [24]. Some of these authors [19,20,24] concluded that there is greater variability in the gait of older persons or persons with pathologies, which could be in contradiction with the complex structure of this function.

The purpose of this study was to analyze the complexity of the gait through the measurement of MTI in accelerometry signals obtained at the hip of healthy subjects and patients with intermittent claudication in order to differentiate the two situations.

2. Materials and methods

2.1. Subjects

The subjects were 22 male volunteers divided into 2 groups: group 1 (G1) comprising 10 healthy elderly subjects (age 60.2 ± 4.8 years; height 173.6 ± 6.6 cm; weight 88.9 ± 11.3 kg); and group 2 (G2) comprising 12 patients with peripheral arterial disease (PAD) (age 63.1 ± 5.4 years, height 168.6 ± 6.5 cm; weight 81.2 ± 15.9 kg). All of the patients had been diagnosed with PAD by the Vascular Surgery Service at a hospital of the public health service. They had been monitored for at least two years and had a history of claudication in the right leg.

All of the participants passed a prior examination of their musculoskeletal system in order to rule out the existence of mechanical alterations which might affect the gait and the ankle-brachial pressure index was measured in all of the healthy subjects in order to rule out limitations in the flow in the lower limbs [25].

All of the subjects were informed of the nature of the study and gave their voluntary consent. The design and protocols of the study were approved by the Ethics Committee of the University.

2.2. Procedure

All of the subjects walked at a comfortable, freely-chosen pace for 10 min in an open circuit while wearing a SunSPOT device on each hip. These devices are motes of wireless sensor networks developed by Sun Microsystems (Oracle Corporation, California, U.S.A.) which use the IEEE 802.15.4 wireless communication stan-

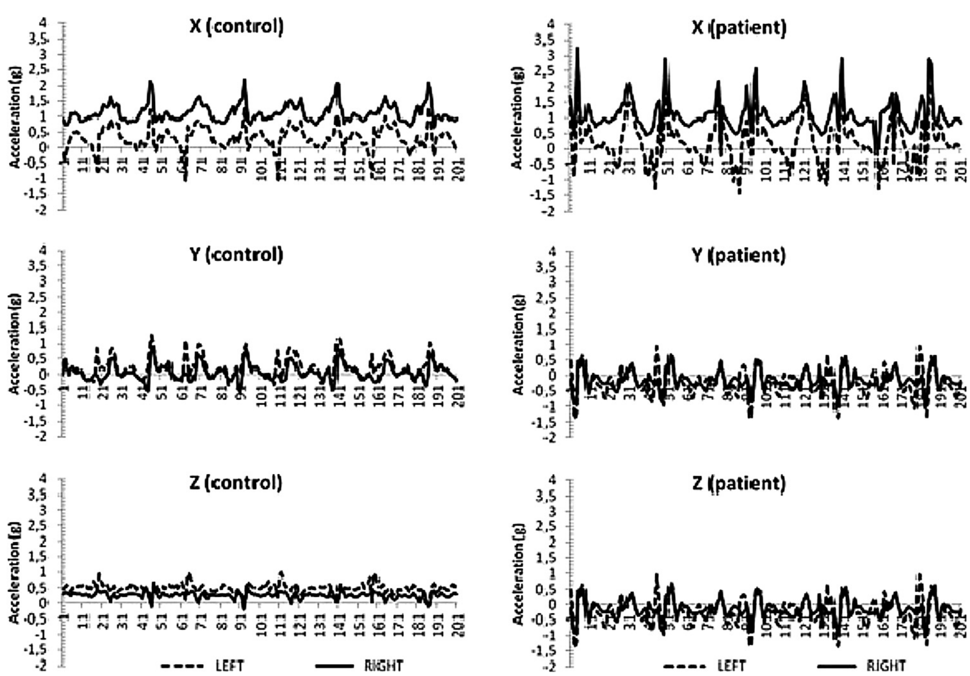

Fig. 2. Acceleration data are displayed on the three axes (X, Y, Z) corresponding to one subject of the control group (left) and one patient (right). The solid lines correspond to the right hip and the broken lines to the left hip. 200 points are displayed corresponding to the last minute of each record.