Biomedical Signal Processing and Control 32 (2017) 10–19

Contents lists available at ScienceDirect

Biomedical Signal Processing and Control

journal homepage: www.elsevier.com/locate/bspc

Pelvic movement variability of healthy and unilateral hip joint involvement individuals

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ARTICLE INFO

Article history:
Received 7 June 2016
Received in revised form 15 October 2016
Accepted 22 October 2016

Keywords:
Gait variability
Inertial sensors
Hip disorders
Pelvic movement analysis

ABSTRACT

Data variability analysis has been the focus of a number of studies seeking to capture differences of patterns generated by biological systems. Although there are several studies reporting variability in gait analysis we still have lack of researches that employ inertial sensors for the characterization of the variability of the duration of the gait cycle and pelvic movements for groups of individuals in healthy and hip joint involvement conditions. In this research this variability is characterized within the step and stride time intervals. Data were collected with subjects walking on a treadmill at a velocity of 2 km/h, being the group G1 with 10 healthy subjects (30.7 ± 6.75 years old) and G2 with 24 individuals with unilateral hip joint involvement (65 ± 8.5 years old). Two sets of inertial measurement units were employed for movement detection, and then features were extracted for the characterization of their variability. The coefficient of variation was used for assessing the variability. Significant differences ($p < 0.05$) were found between the mean step and stride times of the groups. The variability of the step and stride times, and also of the investigated features, were larger for the group G2 ($p < 0.05$). The proposed methods used in this study showed to be adequate for the measurement of the variability of biomechanical parameters, represented by their features. All the studied features were able to discriminate the groups. Both ageing and pathological factors may have jointly contributed to the G2 group increased variability.

1. Introduction

The analysis of patterns and their variability have been used in a number of distinct researches. The relevance of variability analysis in a clinical context has been recently reviewed by Bravi et al. [1] and the main conclusion is that variability can be the source of information for the discrimination of patterns and the characterization of differences among studied populations.

Lord et al. [2] suggested that gait variability has been increasingly used as a marker for gait performance, mobility and fall risk evaluation. As pointed out by the authors a variety of studies in biomechanics investigate the variability of gait for older adults, and there is lack of studies that focus in other populations, such as individuals suffering from hip joint involvement. As pointed out by Hausdorff et al. [3], most of quantitative studies of walking have typically focused on the properties of an average of typical step and stride times, however relevant information can be found in the data due to their inherent variability.

Accelerometers attached to the body have been used as an alternative approach to conventional gait analysis [4,5], such as motion capture systems and force platforms, with some advantages including low cost, protocols not restricted to a laboratory, unrestricted movement by volunteers and direct 3D acceleration measurements. The most robust use for accelerometers in gait analysis is for the determination of related spatiotemporal parameters of foot contact events [4], by assessing the captured oscillations of time-varying acceleration. From heel strike events, step and stride time can be calculated as the period of successive peaks or valleys, while volunteers are walking either over ground or on a treadmill.

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http://dx.doi.org/10.1016/j.bspc.2016.10.008
1746-8094/

By processing data from accelerometer, information about gait variability can be extracted. Gait variability may be regarded as a sign of adaptability required for a successful locomotion, or a sign of impaired balance control [6]. Various measures of gait variability have been suggested such as stride-to-stride variability in stride length [7], stride width [7,8], speed, stance time and swing time [9], or acceleration variability of the pelvis, trunk or head [10,11]. Such measures are reported as within-subject standard deviation (SD) or coefficient of variation (CV), if the variability is unrelated to the size of the measured variable or not, respectively [12]. Such analysis involves the quantification of the variability in the amplitude of a time series, and it is referred as to "amplitude variability" [13].

Although accelerometers are usually employed in biomechanical studies, due to the advances in the technology and availability of microelectromechanical (MEMS), a number of sensors are composed of three axial accelerometers, gyroscopes and magnetometers. The understanding of the whole information provided by such composite sensors has yet to be fully exploited in biomechanics. Thus, in order to contribute to the analysis of this complex information we propose a sequence of data analysis capable of jointly assessing the variability of information obtained from these sensors, and the characterization of the variability for healthy and unhealthy individuals. Specifically, we used the proposed method to assess gait variability from the analysis of features extracted from pelvic movements detected by inertial measurement units (IMUs). In addition, the variability of step and stride times for both groups was also studied. The techniques and results described in this study can be further developed for the investigation of temporal variability [13,14].

2. Methods

2.1. Data collection and research groups

This study was approved by the local ethical committee (CAAE: 49801115.4.0000.5152) and conducted at the Federal University of Uberlândia, Brazil. A detailed explanation regarding the experiment was given to the participants prior to enrollment and all subjects gave their written consent to participation in the study.

The participants were divided into two groups: group G1 composed of 10 healthy individuals (30.7 ± 6.75 years old), and group G2 composed of 24 participants (65 ± 8.5 years old) diagnosed with unilateral hip osteoarthritis who had undergone total hip arthroplasty (THA). The average postoperative period was of 21.75 months. Eighteen subjects had the right side affected against only six who had the left side involved.

Any subject from G2 who presented joint disease in another joint of lower limbs was excluded from the study. Subjects of group G1 were required to have no history of musculoskeletal or neurological diseases, gait disorders or any painful condition that could affect their gait.

All participants walked on a treadmill in a constant velocity of 2 km/h during one minute using a customized belt containing two embedded IMUs (Fig. 1). The belt was coated with Velcro so that the IMUs could be adjusted according to the pelvic dimensions of the subjects. The IMUs were set on the anterior superior iliac spine (ASIS) in both left (IMU-L) and right (IMU-R) sides of the pelvis. The IMUs X, Y and Z axes were oriented to the vertical, mediolateral, and anteroposterior directions, respectively (Fig. 1).

Despite the pelvis is considered a single block and most of the studies use only one accelerometer fixed at the back region in its midline, the use of two IMUs ease the identification and discrimination of right and left heel strikes because they produce shifted responses in the Z axis. Furthermore, the use of two IMUs allows for the monitoring and recording of information from both sides

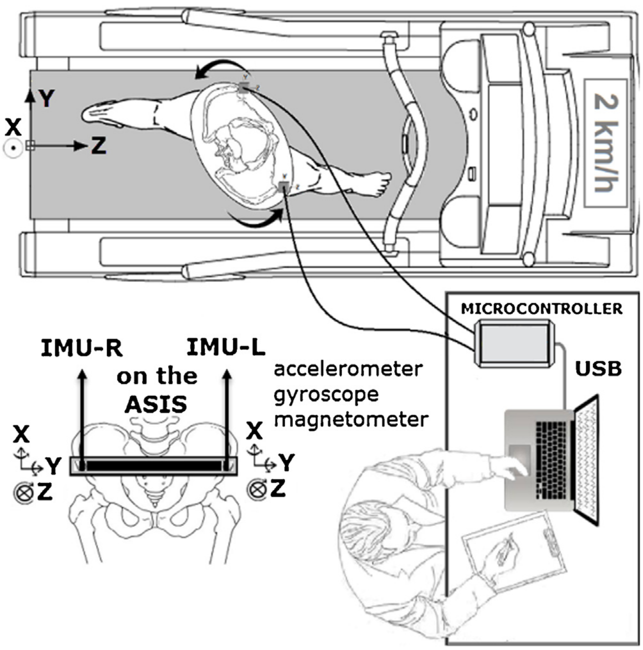

Fig. 1. Illustration of data collection with the participant walking on a treadmill at 2 km/h. The positioning of the IMUs on the ASIS is highlighted. Vertical, mediolateral, and anteroposterior directions in relation to the pelvis were set as the X, Y, and Z axis, respectively.

(i.e., left and right) simultaneously, increasing thus the number of variables that can be taken into account in the variability analysis.

2.2. Architecture and organization of the customized hardware for data collection

The whole system for detection and recording of the pelvic movement was developed in our laboratory (National Institute of Intellectual Property – Brazil – Process BR 10 2014 023282 6). The system is composed of three main units: (i) a customized hardware and software for movement detection, visualization of data in real time and data storage; (ii) an automatic tool for step and stride time interval detection and outlier removal; (iii) feature extraction, data organization and storage in a spreadsheet.

2.2.1. The hardware and software for movement detection

The general architecture of the hardware for data acquisition management and visualization is shown in Fig. 2.

The IMUs are based on the microelectromechanical (MEMS) sensors L3G4200D (three-axis digital output gyroscope, ST Microelectronics) and LSM303DLM (three-axis digital output accelerometer and magnetometer, ST Microelectronics). These IMUs allow for the communication between the sensor and the microcontroller by using the I2C protocol specified by Philips Semiconductors (now NXP Semiconductors). The sensitivity of the sensors can be individually configured through I2C communication as follows:

- Gyroscope: ± 245, ± 500, or $\pm 2000^{\circ}$/s;
- Accelerometer: ± 2, ± 4, ± 6, ± 8, or ± 16 g;
- Magnetometer: ± 2, ± 4, ± 8, or ± 12 G.

Data from the sensors are digitized by a 16 bit analog to digital converter. The microcontroller (Atmel SAM3 × 8E ARM Cortex-M3 CPU) is responsible for the configuration of the IMUs, for reading information from the IMUs, and also for transmitting this information to the PC through serial communication (USB). One of the