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Assessing interactions among multiple physiological systems during walking outside a laboratory: An Android based gait monitor

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ABSTRACT

Gait function is traditionally assessed using well-lit, unobstructed walkways with minimal distractions. In patients with subclinical physiological abnormalities, these conditions may not provide enough stress on their ability to adapt to walking. The introduction of challenging walking conditions in gait can induce responses in physiological systems in addition to the locomotor system. There is a need for a device that is capable of monitoring multiple physiological systems in various walking conditions. To address this need, an Android-based gait-monitoring device was developed that enabled the recording of a patient's physiological systems during walking. The gait-monitoring device was tested during self-regulated overground walking sessions of fifteen healthy subjects that included 6 females and 9 males aged 18–35 years. The gait-monitoring device measures the patient's stride interval, acceleration, electrocardiogram, skin conductance and respiratory rate. The data is stored on an Android phone and is analyzed offline through the extraction of features in the time, frequency and time–frequency domains. The analysis of the data depicted multisystem physiological interactions during overground walking in healthy subjects. These interactions included locomotion-electrodermal, locomotion-respiratory and cardiolocomotion couplings. The current results depicting strong interactions between the locomotion system and the other considered systems (i.e., electrodermal, respiratory and cardiovascular systems) warrant further investigation into multisystem interactions during walking, particularly in challenging walking conditions with older adults.

1. Introduction

Mobility disabilities in older adults is a major factor in the loss of independence and contributes to higher rates of morbidity and mortality [1] and are considered to be a predictor of other disabilities that restrict independent living [2]. Unfortunately, the clinical identification of impaired gait function is not straightforward. The locomotor function and its associated parameters, including gait speed, are traditionally assessed

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under ideal conditions without distractions in a well-lit, unobstructed walkway. In patients with subclinical physiological abnormalities, these ideal conditions may not provide enough stress on their ability to adapt to walking. A challenging walking environment can provide a more realistic assessment in the early detection of alterations in walking and in the characterization of subclinical physiological abnormalities. Patients walking on challenging environments have previously been used to detect subclinical risk in aging research. Fall risks were predicted more accurately by gait characteristics on irregular and challenging surfaces when compared to smooth and non-challenging surfaces [3]. The fear of falling (FOF) is highly prevalent for all older adults [4,5], and is known to negatively impact gait parameters (e.g., reduced gait velocity or higher stride-length or stride-time variability) [6]. Fear also induces significant change in physiological signals, heart rate and skin conductance, associated with cardiovascular and autonomic control systems (e.g., [7–9]). The interaction between cardiovascular systems, autonomic control systems and their impact on gait function have not been sufficiently quantitatively linked due to the lack of computational methods and instrumentation for the reliable assessment of these systems in real-life scenarios.

Prior gait assessment systems have centered on a single transduction method. Analysis of multiple physiological modalities during gait often required interfacing multiple acquisitions systems together [10]. A widely accepted approach for such interfacing is the use of a stationary system that provides gait temporal–spatial parameters. The GaitMat, a typical representative of the stationary system, consists of a long array of pressure sensitive switches that detect foot strikes upon participant ambulation [11]. These systems provide accurate and reliable measures of temporal–spatial gait parameters during free walking but the limited size and the high cost associated with larger mats are a deterrent in the widespread use. VICON is another type of stationary system that captures three-dimensional data of gait through the use of video motion capture systems. These video capture systems can accurately and precisely capture gait kinematics [12] but the systems are expensive and require multiple cameras arrangements that must be calibrated in the constrained volume [13]. Although it is possible to extend a video capture system to larger volumes, the cost of the system would scale with the increase in volume. Due to the limited number of steps that can be taken on these stationary systems, concerns exist about the limited analysis of these systems due to the small window lengths in detrended fluctuation analysis [14].

In response to these shortcomings, a number of solutions to gait monitoring have been developed in recent years that aim to assess older adults and patients with walking problems. In addition to these rehabilitation devices, the LOCOMAT [15], active ankle foot orthosis [16] and sensor-embedded shoes have been used to assess the human locomotor function. Examples of this include the ACHILLE system [16], GaitShoe [17], the Intelligent-Shoe [18], and a sensor-embedded shoe measuring ground contact [19]. Devices for the assessment of physiological signals have also been developed that include wrist worn heart rate monitors and wrist worn activity monitors [20]. Additional devices include the FRWD [21], a sport computer that measures heart rate, distance, speed, and altitude, or the SenseWear armband from Bodymedia, a measurement device worn near the biceps [22] capable of measuring skin temperature, galvanic skin response, three-axis accelerations, and heat flux from body. Also, devices such as the Delsys Tringo wireless system have been used to assess electromyography and accelerometry signals during walking (e.g., [23]). Clothing-based physiological monitors such as a LifeShirt from Vivometrics [24], the adiStar Fusion products [25], the VTAMN [26], and the Wealthy measurement system [27] have been developed. Similarly, smartphones have become a popular platform for gait monitoring in recent years (e.g., [28,29]). However, none of the devices have incorporated the interactions between various physiological systems to understand their impact on the locomotor function. Assessing only gait parameters is not sufficient for the early prediction of falls due to a number of factors that cause gait instabilities. By assessing multisystem interactions, we will be able to make early predictions about falls and warn patients about their instability.

There is a need for a screening instrument that can accurately detect impaired locomotor function outside of controlled settings. In this paper, an Android-based system is proposed for the simultaneous acquisition of temporal gait parameters including force sensitive resistors (FSR) placed on the heel and forefoot, an electrocardiogram (ECG), electrodermal response (EDR), respiration via a strain gauge transducer, and a tri-axial accelerometer placed on the lumbar region of the spine during ambulation. The proposed system was tested using 15 healthy subjects, and data was collected for verification and preliminary analysis. Our goal was to test the reliability of the system, specifically, to understand whether the system was capable of collecting physiological signals reliably. Therefore, from the data collected and extracted to an external workstation, a number of features, previously considered in other publications, were extracted in time, frequency and time–frequency domains to conduct a preliminary analysis of the interaction between multiple physiological systems and locomotor function.

This paper is organized as follows: in the next section, an overview of the data collection system is provided. Section 3 illustrates the data collection procedure with the data analysis steps outlined in Section 4. Our results and discussions are given in Sections 5 and 6, respectively. Finally, conclusions are drawn in Section 7, followed by a list of references.

2. Collection system overview

The mobile data collection system is comprised of three main components:

- Multiple biosignal transducers attached to the participants with signal conditioning circuitry;
- A microcontroller unit (MCU) that digitizes each biosensors' output; and
- An Android smartphone that receives data from the MCU and stores it for post-processing.

A high-level overview of the system concept is shown in Fig. 1. A phablet computer running the Android operating