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Technical note

Development and validation of a low-cost, portable and wireless gait assessment tool

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ABSTRACT

Background: Performing gait analysis in a clinical setting can often be challenging due to time, cost and the availability of sophisticated three-dimensional (3D) gait analysis systems. This study has developed and tested a portable wireless gait assessment tool (wi-GAT) to address these challenges.
Aim: To investigate the concurrent validity of the wi-GAT in measuring spatio-temporal gait parameters such as stride length, stride duration, cadence, double support time (DST), stance and swing time compared to a 3D Vicon motion analysis system.
Methods: Ten healthy volunteers participated in the study (age range 23–30 years). Spatio-temporal gait parameters were recorded simultaneously by the Vicon and the wi-GAT systems as each subject walked at their self-selected speed.
Results: The stride length and duration, cadence, stance duration and walking speed recorded using the wi-GAT showed strong agreement with those same parameters recorded by the Vicon (ICC of 0.94–0.996). A difference between the systems in registering "toe off" resulted in less agreement (ICC of 0.299–0.847) in gait parameters such as %stance and %swing and DST.
Discussion and conclusion: The study demonstrated good concurrent validity for the wi-GAT system. The wi-GAT has the potential to be a useful assessment tool for clinicians.

1. Introduction

Gait analysis is a commonly used assessment tool that helps to quantify human locomotion. It has been widely used as a research and/or a clinical tool to quantify movement in various neurological conditions such as stroke [1,2], cerebral palsy [3,4], spinal cord injury [5], and also among the elderly population to assess the risk of falls [6]. Three-dimensional (3D) gait analysis has evolved over the years as a tool that provides the most accurate measure of human movement. However access to this sophisticated system is often limited to movement laboratories within an academic institution or large hospitals with embedded research facilities [7]. In addition to limited access, the costs associated with gait assessments also make it difficult for clinicians to perform them routinely to monitor their patient's progress. It has been estimated that a gait study can cost anything up to $2000 and the cost to set up a movement laboratory can be on average about $300,000 [8].

In a recent review that reported on gait deficits in patients with traumatic brain injury, it was found that out of 15 studies that had used 3D gait analysis as an outcome measure only two of the studies reported on the kinematics and kinetics of gait [9]. The majority of the studies that were reviewed reported the temporal–spatial gait parameters, such as walking speed, cadence, stride duration, stride length and step length. A 3D gait analysis is often difficult to perform in a clinical setting, due to the reasons stated previously, however recording spatio-temporal gait parameters is less time consuming and feasible. The advantage of a 3D gait analysis is that it provides extensive data that includes kinematics and kinetics, which often gait assessment tools that record spatio-temporal parameters alone, do not provide. There are commercially available gait assessment tools that can record spatio-temporal gait parameters such as instrumented mats with pressure sensors [10] and body worn sensors that incorporate accelerometers [11]. The limitations of these systems include difficulties in set-up within a clinical environment, where space is often limited, and although they may not be as expensive as the 3D gait analysis system, they are still costly for individual departments or independent rehabilitation clinics to utilize in providing a cost effective clinical assessment.

Therefore there is a need for a low-cost, low-tech alternative that provides accurate measures that can be easily used by

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rehabilitation professionals without specialist motion capture/analysis training and most importantly within a clinical environment. We have developed a system that meets these goals. The initial wired prototype of this portable low-cost gait assessment system was piloted among incomplete spinal cord injured patients as part of a clinical study that monitored recovery in walking among these patients [12]. We have now successfully developed a wireless version of this portable gait assessment system. Therefore the aim of this study was to establish the concurrent validity of spatio-temporal gait parameters recorded by this novel system among adult able bodied subjects.

2. Materials and methods

The wi-GAT was recently upgraded as a standalone data acquisition device which required adaptations to its circuitry and data acquisition software, this justifies the need for a validation study. The spatio-temporal gait parameters which were validated include stride length, stride duration, cadence, stance duration, swing duration, stance%, swing%, double support duration and walking speed. These parameters were calculated using the definitions provided in Table 1. The Vicon (Vicon MX, Oxford Metrics, Oxford, UK) is a three-dimensional motion analysis system which is commonly used for recording spatial and temporal gait parameters with high accuracy [13]. It was thus deemed an appropriate standard on which to validate the gait parameters recorded using the wi-GAT.

2.1. Materials

A custom designed printed circuit board (PCB) (Beta LAYOUT, Ireland) was used in the development of the wi-GAT. It incorporates a Bluetooth module (BlueGiga model: WT11, Espoo, Finland) and microcontroller chip (Microchip model: pic18f4520, Chandler, AZ, USA) powered by a 9 V battery. The PCB is housed in a plastic enclosure with dimensions of 12 cm × 10 cm × 4.5 cm and the total weight (including battery) is 225 g. The small size and weight enables the device to be attached to a belt on the subject's waist during data collection. The device amplifies and transmits data from two instrumented insoles each comprising of four 13 mm diameter force sensing resistors (FSRs) (Interlink Electronics, Camarillo, CA, USA) which are used to capture temporal information during gait. These are positioned under the heel, 1st metatarsal head, 5th metatarsal head and the big toe as described by Granat et al. [14]. Insoles were custom-made for each subject using FootDoc foot impression sheets (Visual Footcare Technologies, LLC, NY, USA) to position the FSRs as accurately as possible under the location of each anatomical landmark previously described. Standard shoe insoles were trimmed to the correct size and FSRs were attached under a clear plastic film in the correct positions for collecting the foot contact data (Fig. 1). The process to fabricate the insoles for various shoe sizes takes approximately 15 min. The insoles are connected via ribbon cable to the waist worn device (Fig. 1). The wi-GAT uses a Bluetooth connection to a PC for data collection by an interface program implemented in LabVIEW (National Instruments Inc., TX, USA). The signals were sampled at 30 Hz and logged directly to a spreadsheet file.

The spatio-temporal gait parameters were also recorded simultaneously using a 12 camera Vicon MX system operating at 100 Hz. The Vicon Plug-in-Gait lower limb marker set and model was used. Plug-in-Gait uses methodology which has been described by Davis et al. [15] and Kadaba et al. [16] and requires sixteen 15 mm reflective markers to be attached to anatomical landmarks of the lower extremity.

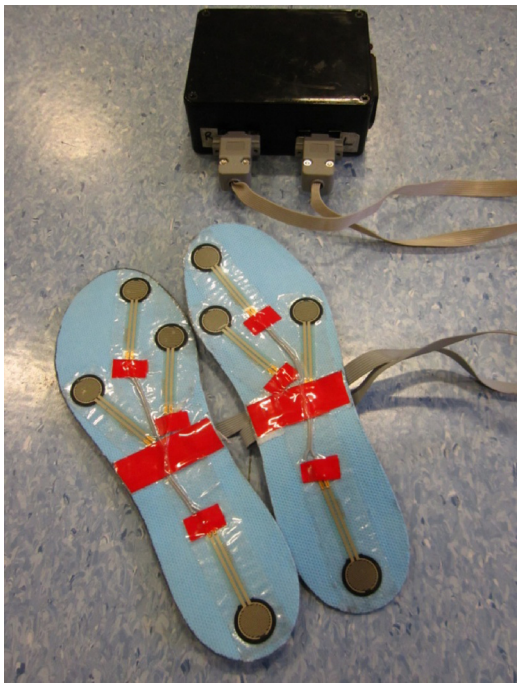

Fig. 1. Wi-GAT device and FSR insoles.

2.2. Experimental setup

The spatio-temporal gait parameters were recorded over a 10 m walkway located within a gait lab at the Department of Biomedical Engineering, University of Strathclyde. The capture volume of the Vicon system was set to approximately 6 m × 6 m × 2 m and was calibrated to the distance of the walkway using standardized protocols recommended by the manufacturer (Vicon MX, Oxford Metrics, Oxford, UK) at the beginning of each testing session.

2.3. Subjects

Ten healthy subjects with no known gait abnormalities volunteered to participate in the study. These included four males and six females with a mean age of 26.5 years (range 23–30 years). The average height of the subjects was 1.72 m (1.6–1.87 m range) with an average weight of 73 kg (54–86 kg range). Ethical approval for the study was provided by the Biomedical Engineering ethics committee at the University of Strathclyde and the volunteers were fully informed of the procedure and provided written consent.

2.4. Experimental protocol

Subjects were required to wear flat-soled training shoes and shorts. Anthropometric data was recorded from each subject on arrival and reflective markers were then attached to their lower extremities. The instrumented insoles were placed in the subject's shoes and the wi-GAT box was positioned on a belt around their waist. Each subject was given the opportunity to perform practice walks to allow familiarization with the equipment and the experimental procedure. During data capture each subject was instructed to walk at a self-selected comfortable speed [11]. The first 2 m of the 10 m walkway were used by the subject to accelerate to their self selected speed and the last 2 m to decelerate to a stop at the end of the walkway [12], [13]. The middle 6 m of the walkway was used for data capture. Subjects performed a total of ten trials each.