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Detection of physical activities using a physical activity monitor system for wheelchair users

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ABSTRACT

Availability of physical activity monitors for wheelchair users can potentially assist these individuals to track regular physical activity (PA), which in turn could lead to a healthier and more active lifestyle. Therefore, the aim of this study was to develop and validate algorithms for a physical activity monitoring system (PAMS) to detect wheelchair based activities. The PAMS consists of a gyroscope based wheel rotation monitor (G-WRM) and an accelerometer device (wocket) worn on the upper arm or on the wrist. A total of 45 persons with spinal cord injury took part in the study, which was performed in a structured university-based laboratory environment, a semi-structured environment at the National Veterans Wheelchair Games, and in the participants' home environments. Participants performed at least ten PAs, other than resting, taken from a list of PAs. The classification performance for the best classifiers on the testing dataset for PAMS-Arm (G-WRM and wocket on upper arm) and PAMS-Wrist (G-WRM and wocket on wrist) was 89.26% and 88.47%, respectively. The outcomes of this study indicate that multi-modal information from the PAMS can help detect various types of wheelchair-based activities in structured laboratory, semi-structured organizational, and unstructured home environments.

1. Introduction

Regular physical activity (PA) levels among persons with disabilities, for which 46% rated as performing some form of leisure-time PA in 2008, are significantly lower than the PA levels of the general population, for which 68% rated as performing some form of leisure-time PA [1]. Moreover, the obesity rate in persons with disabilities was 36% (2008); a rate much higher than the 23% in persons without disabilities [2]. Among those with disabilities are wheelchair users who lack regular PA and have reduced energy expenditure leading to even higher obesity and overweight levels [3,4]. To address the need of achieving regular PA for wheelchair users, we have developed a physical activity monitoring system that can track regular PA levels and detect wheelchair-based activities.

Research has evaluated the performance of various types of sensor-based activity monitors among persons who use wheelchairs to track movement to detect PAs [5–11]. Accelerometer-based activity monitors have been used to evaluate community living and wheelchair movement [5,6,9]. Warms et al. found that the activity counts from a wrist-worn accelerometer had low to moderate correlation (0.30–0.77, $p < 0.01$) with self-reported activity intensity for individual participants [5]. Coulter et al. investigated a wheel-mounted tri-axial accelerometer and found high validity of the device in detecting wheel revolutions, absolute angle and duration of movement (ICC(2,1) > 0.99, 0.99, 0.98, respectively) in wheelchair users [9]. Similarly, Sonenblum et al. used a wheel-mounted tri-axial accelerometer to detect wheelchair movement, and this device measured the

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distance travelled with an accuracy greater than 90% for various wheelchair and wheel types, propulsion techniques, speeds, and wheelchair-related activities of daily living [6].

Tolerico et al. used another type of monitor, based on reed switches and a magnet, to find that manual wheelchair users travelled for a mean (SD) distance of 6745.3 (1937.9) m/day at a speed of 0.96 (0.17) m/s and 2457.0 (1195.7) m/day at a speed of 0.79 (0.19) m/s at the National Veterans Wheelchair Games and in the community, respectively [7]. Some of the limitations of current devices are that a single accelerometer on the wrist or a single wheel monitor cannot recognize manual wheelchair movements and upper extremity movements, respectively. Moreover, wheel monitoring devices alone cannot distinguish between self-propulsion and external pushing.

Postma et al. used a six-accelerometer based activity monitoring system and detected wheelchair propulsion from a series of activities of daily living with an overall agreement of 92%, a sensitivity of 87% and a specificity of 92% [11]. Hiremath et al. evaluated a multi-sensor based activity monitor (SenseWear, BodyMedia Inc., USA) to detect four activities: resting, wheelchair propulsion, arm-ergometry and deskwork [10]. The classification accuracy for detecting four wheelchair-related PAs was 96.3% using quadratic discriminant analysis and 94.8% using Naïve Bayes algorithms. Unfortunately, consumers cannot use any of these activity monitors to obtain real-time feedback about their mobility characteristics, as the information is usually post-processed based on the data stored in the devices. Real-time feedback of the PA level is an actionable parameter available throughout the day and that can be utilized whenever the wheelchair user has time to perform PAs. Access to this information can motivate users to increase their PA levels while controlling their energy intake. Shuger et al. conducted a randomized controlled trial in 197 sedentary overweight or obese adults to evaluate whether electronic feedback about diet and PA was more effective for weight loss [12]. The study concluded that continuous self-monitoring using sensor based technology with real-time feedback may promote weight loss in sedentary overweight or obese adults. Most of the real-time feedback systems also provide a report of PA level at the end of the day and indicate if the user had met their regular PA levels.

Based on our previous research, we developed a physical activity monitoring system (PAMS) that tracks PA levels and provides feedback through smartphones [10,13,14]. The PAMS consists of two components: a gyroscope-based wheel rotation monitor (G-WRM) for capturing wheelchair wheel movement, and an accelerometer device (wocket) worn either on the upper arm or wrist to track upper arm or wrist acceleration, respectively [13,15]. The primary aim of this study was to develop and validate algorithms for PAMS to detect wheelchair based activities. The secondary aim was to evaluate the performance of individual components in the PAMS (i.e., G-WRM, wocket on the upper arm, or wocket on the wrist) as compared to using the two components in the PAMS.

2. Methods

The study was approved by the Institutional Review Board of the University of Pittsburgh, US Army Medical Research & Material Command's Human Research Protection Office, and the VA Pittsburgh Healthcare System. The study was conducted at a university laboratory, at the National Veterans Wheelchair Games (NVWG) held in Richmond, VA, USA in 2012, and in the participants' home environments.

2.1. Participants

A total of 45 persons with spinal cord injury (SCI) took part in the study. Participants were included in the study if they were 18–65 years of age, used a manual wheelchair (>80% of their ambulation), and had a diagnosis of SCI. Participants were excluded from the study if they were unable to tolerate sitting for 3 h, had active pelvic or thigh wounds, had a history of cardiovascular disease, or were pregnant (based on self-report).

2.2. Procedures

The first part of the study was performed by 45 manual wheelchair users with SCI in the laboratory (lab) environment ($N = 25$) or in the semi-structured convention center environment at the NVWG ($N = 20$). A portion of the population who took part in the lab also participated in the study for a second time in their home environments ($N = 20$).

2.3. Protocol in lab or NVWG

2.3.1. Pre-activity session

Before testing, a researcher explained the purpose and overall procedure of the study to the participants. After signing an informed consent, participants filled in a questionnaire that included questions on demographics (e.g., gender, ethnicity, age, injury level, and time of injury), wheelchair information (e.g., brand and model), and health and physical activity history.

2.3.2. Activity session

Participants were asked to perform at least ten physical activities (PAs), other than resting, from this list of PAs that involved different parts of the body and varying levels of intensity: (1) propelling their wheelchair on a tile surface at a self-selected medium and fast pace, (2) propelling on a medium pile carpet at a self-selected medium or slow pace, (3) propelling up and down a ramp (slope of 2.7°, length 12.19 m) at a self-selected pace, (4) being pushed in a wheelchair on a tile surface or a medium pile carpet or up and down a ramp, (5) playing wheelchair basketball, (6) folding laundry, (7) performing deskwork involving reading and using a computer, (8) playing darts, (9) using a resistance band (Theraband), and (10) exercising on an arm ergometer at a self-selected pace and resistance. The participants chose the ten activities that they felt safe to perform, thus reducing the risk of injury. The PAs were chosen to cover a range of activities, representative of everyday activities, in wheelchair users and feasible in each of the three environments. The resting trial involved collecting the baseline data for 6 min while the participants sat still in their wheelchairs.

During testing, a G-WRM was secured to the participant's wheelchair and two wockets were worn on the participant's upper arm and wrist. First, participants received instructions on how to perform the wheelchair-based activities. When participants wished to try out a particular trial before performing it, they were asked to do so for 1 to 2 min prior to the actual trial. All participants used their own manual wheelchairs and performed each activity for a minimum of 6 min, with at least a 3-min break between activity trials. One of the investigators noted the start and stop time for each activity trial. The activities were recorded on video, serving as a reference for subsequent timing and independent classification of the activities performed. Each testing session lasted for about 3 h.

2.4. Protocol in home environment

Participants were invited to do a follow-up session if they lived within 60 miles of the lab and were willing to use the PAMS while they performed 10 daily activities and a resting trial, similar to the lab testing, in their home environment. The follow-up session was scheduled within 6 months of their testing in the lab.