Preliminary investigations of the agreement between two wearable accelerometers for use in clinical studies

Lisa Moore
Department of Science
Letterkenny Institute of Technology
Co. Donegal, Ireland
L00115999@student.lyit.ie

Bríd McDevitt
Department of Computing
Letterkenny Institute of Technology
Co. Donegal, Ireland
L00092484@student.lyit.ie

Nishat Akhtar
Department of Computing
Letterkenny Institute of Technology
Co. Donegal, Ireland
L00138039@student.lyit.ie

Rónán Doherty
Department of Law & Humanities
Letterkenny Institute of Technology
Co. Donegal, Ireland
ronan.doherty@lyit.ie

William N. Scott
Department of Science
Letterkenny Institute of Technology
Co. Donegal, Ireland
william.scott@lyit.ie

James Connolly
Department of Computing
Letterkenny Institute of Technology
Co. Donegal, Ireland
james.connolly@lyit.ie

***Abstract*— Healthcare providers continue to address the challenges caused by aging populations, chronic disease management, hospitalization costs, as well as significant legal risks. Characterisation of physical activity and sedentary behaviour within ambulatory conditions is becoming increasingly popular in view of growing evidence for the health implications of these tendencies. Wearable technology can potentially offer a solution to these problems by using state-of-the-art sensors and wearable systems as well as secure and effective networks of communication between patients and clinicians. The primary aim of this study is to investigate levels of agreement between two wearable sensors for use in clinical studies. Establishing validity of these wearable devices is of particular interest as they may be utilised in future clinical studies to monitor sleep and activity patterns over prolonged time periods. Initial visualization of data from physical activity and periods of inactivity show high similarity between devices for ambulatory conditions and standardized activities. However, future steps concerning alignment of timestamps needs to be utilized in order to coordinate the devices' outputs.**

Keywords— Wearable technology, accelerometers, physical activity, sleep, validation, daily-living

I. INTRODUCTION

Advances in wearable technology have led to the development of many wearable activity trackers for consumers interested in their overall fitness, ongoing health status, and weight management. Wearable devices for the recording of various components of daily activity have been proliferating, but little research has examined how these devices compare with each other and how accurate and effective they are for research and clinical purposes [1]. Personal wearable trackers cannot be expected to match the utility of research-based devices since they are for different purposes and have different constraints, e.g. ease of use, low cost [2]. Availability of wearable technology offers the possibility of self-monitoring, and may also be relevant for applied field-based clinical trials and intervention programs aimed at encouraging physical activity in the community. Formal assessment of the validity of these devices is important so that consumers, fitness professionals and researchers can make informed choices when selecting one of the monitors. However, there is limited evidence available to support the accuracy of these wearable activity trackers within ambulatory conditions. Most commercially available activity trackers provide information on the levels of physical activity and daily Energy Expenditure (EE), but do not provide access to raw minute-by-minute data, thus little or no information is available to substantiate their validity [2].

Research and development in wearable device is continually enhancing the ambulatory monitoring of sleep and physical activity such as gait and balance, skin temperature, galvanic skin response and blood oxygen saturation [3]. Specific forms of wearable devices include portable watches/bracelets, gloves, textiles and clothing [4]. The ability to continuously track and transmit data in real time or intermittently is integrated in all of these sensor systems. Although, performance and accuracy vary considerably, it is clear that these sensors and devices are capable of being an important part of healthcare [5].

The large-scale adoption by consumers of wearable devices for the collection of health data laid the groundwork for a subsequent change in clinical trial procedures. As a result, accurate and continuous data on individual health could be obtained in real time through the integration of wearable healthcare devices. The new technological research platforms have the potential to improve accuracy and timeliness of data, enhance efficiencies, as well as increase patient participation in the process of clinical trials. Medical quality tracking devices in most clinical areas, such as gerontology and chronic diseases, are already supporting patient care [6].

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Previously, the collection of objective sleep, sedentary, light physical activity and moderate-to-vigorous physical activity measures has been costly, difficult, or non-existent. Through technological advances and compact wearable devices, such measurements are now possible. There is a wealth of research utilizing wearables to collect activity data in free living conditions, but little research has investigated how these devices compare with each other and how accurate and effective they are for research and clinical purposes[11].

The primary aim of this study was to is to investigate the agreement between two wearable accelerometers for use in clinical studies.

II. Methodology

This preliminary validation study was divided into two testing sections, namely standardised activity (SA) and daily living (DL). For the duration of the study the participants wore the Actiwatch 2 and Verisense wrist-worn sensors on their non-dominant wrist. During the SA section participants were asked to sit, walk and jog for periods of 2-6mins. For the DL section, participants wore both sensors continuously for 48h and completed a brief activity diary to correlate to the data collected.

A. Wearable Devices

Actiwatch 2

The Actiwatch 2 is a lightweight wrist-worn monitor which utilizes a piezo-electric sensor to detect vertical accelerations at the wrist. Peak accelerations at each epoch are detected via activity counts and are utilised to determine sleep and wake intervals [12]. Actiwatch 2 devices (four devices) were purchased from Philips Respironics (Oregon, US).

Verisense

The Verisense is a wrist worn 3-axis accelerometer and 3-axis gyroscope sensor which records physical activity and sleep patterns [13]. Verisense devices (four devices) were purchased from Shimmer (Dublin, Ireland).

Figure 1 Actiwatch 2 and Verisense wrist-worn monitors shown as worn by participants.

B. Study Participants

Ten individuals without significant self-reported health issues or sleep disorders were recruited to participate in this study. In all 10 participants completed the study, 9 of whom were male and 1 female, with a mean (± SD) age of 23.3 ± 3.5 years (range 21-32) with a mean BMI of 23.96 ± 2.54. Approval for this study was obtained from the appropriate institutional ethics review board and informed consent was obtained.

C. Study Design

During DL testing, all participants simultaneously wore the Actiwatch 2 and Verisense sensors on their non-dominant wrist, continuously over a period of 48 hours in free living conditions (i.e., two nights of data). Participants completed a custom sleep and activity diary concomitant with wearing the accelerometers.

For SA testing, participants simultaneously wore the Actiwatch 2 and Verisense sensors on their non-dominant wrist for the completion of the activities in the gym. Activities are described in Table one. Walking and jogging activities where completed on treadmills and across the gym floor. Activities where completed in a randomised order. After each activity, participants stood completely still for 60s with their arms resting freely beside their body. The SA section was completed within 45mins.

The Verisense watches were configured to store data as the integral of activity occurring in 25Hz segments and Actiwatch 2 devices were configured to store data in 15s segments. Time synchronization was performed across the Verisense and Actiwatch devices at the beginning of each participant's study period. Sleep and activity data was obtained from the Verisense Dashboard and the Actiwatch data was retrieved using Philips Actiware (version 6.0.9).

Table 1. Standardised Gym Activities

Activity	Time (min)
Sit	2
3.5 km/h walk on treadmill	2
4.5 km/h walk on treadmill	2
5.5 km/h walk on treadmill	2
7.5 km/h jog on treadmill	2
11.5 km/h run on treadmill	2
Walking on flat surface	6
200m slow walk	
200m normal walk	
200m fast walk	
200m jog	
Ascend 15 stairs	
Descend 15 stairs	

III. Initial Results

Data at a sampling rate of 32Hz were generated in 15s epochs from the Actiwatch 2 in the form of time-stamped Activity Counts generated using a proprietary algorithm. Data from the Verisense were obtained in the form of raw accelerometer x, y and z axes at a sampling rate of 25Hz. Verisense data was presented with an estimated start time and end time in the file header from which timestamps were calculated.

To compare the 2 devices, the Verisense data was transformed to align with the Actiwatch 2. Raw acceleration data from the Verisense was processed using R statistical software and Microsoft Excel. Vector magnitude of the triaxial acceleration vector was calculated to give Euclidean-

Norm-Minus-One (ENMO). ENMO is used widely in physical activity and sleep monitoring [14–18] and defined as:

$$\sqrt{(x^2 + y^2 + z^2)} - 1g)$$

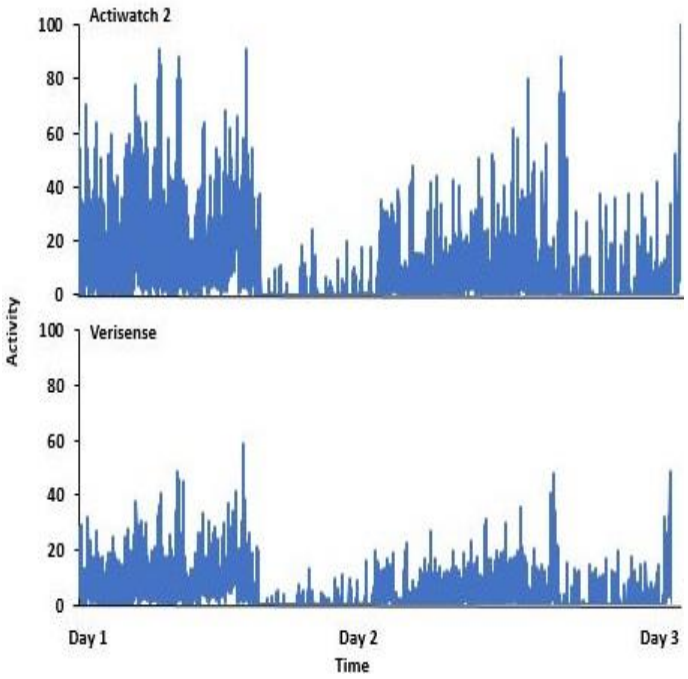

Figure 2 Representative 15s epochs activity tracing of Actiwatch 2 (top) and Verisense (bottom) from one participant over 48hr period

As an initial comparison, data for one participant over 48 hours obtained from both the Verisense and Actiwatch 2 devices show the overall patterns observed between the devices to appear similar (Fig. 2) The participant completed a sleep and activity diary indicating time in bed, time out of bed and times spent in sedentary, light, moderate and vigorous activity during the 48-hrs of continuous sensor wear in free-living conditions. The participant reported no time of device non-wear, therefore no data timepoints were removed for the 48-hr duration.

Movement data from 48-hr continuous period were moderately correlated ($r = 0.50$; Pearson's correlation coefficient). One reason for the moderate r value was found to be small discrepancies in timestamps when files were merged from multiple Verisense files, therefore future investigations will focus on isolation of this issue and mitigation of the scenario for future analyses.

Clearly aligned spikes in activity show 2-min bursts of vigorous activity periods of movement as supervised in a gym setting with the participant wearing both devices on the non-dominant wrist (Fig. 3). For example, at approximately 13:15pm, both activity counts and ENMO were very active producing elevated spikes, then both signals gradually declined as an indication of the gym-supervised participant being asked to place their hands by their sides for 1 minute to show a clear delineation of inactivity versus activity. Movement data from gym-based periods were well correlated ($r = 0.91$; Pearson's correlation coefficient).

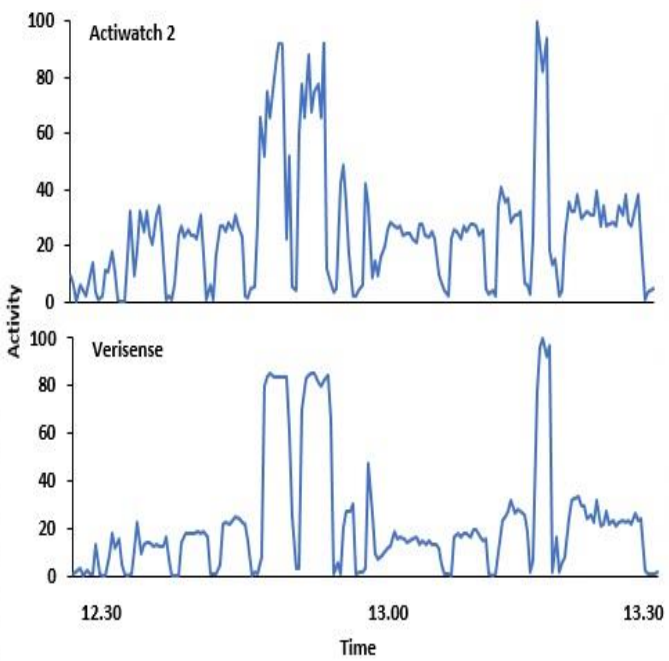

Figure 3 Representative 15s epochs activity tracing of Actiwatch 2 (top) and Verisense (bottom) from one participant during 13 supervised gym-based standardized activities

IV. Conclusion

The study explores the potential correlation between two activity trackers for activity monitoring. Initial findings illustrate that Verisense provides activity levels comparable to the Philips Actiwatch 2. These findings increase the researchers' confidence levels in attaining highly correlated results once the timestamps have been harmonized and open up possibilities for the application of Verisense in large clinical studies. To further the research, the researchers now intend to extend the data gathering component of the study to include more participants and continue to compare the devices using the aforementioned techniques. Sleep metrics will also be evaluated with the devices in order to validate use of Verisense for periods of rest and inactivity. Future findings will add to a growing body of literature on the use of wearable accelerometers for activity monitoring and will assist other researchers in justification of application of such devices in clinical trials.

There are key differences between the Verisense and the Actiwatch. A degree of technical knowledge is necessary to extract and convert the Verisense data from the raw accelerometery format to the interpretable ENMO metric, a process that is very straightforward and time efficient with the Actiwatch 2 and accompanying software. While present on the Actiwatch 2, the Verisense lacks a luxometer, a useful component for identifying bed and wake times. On the other hand, the Verisense is capable of recording raw accelerometer data at 25 Hz resolution and remotely uploads collected data to a secure cloud-based interface, eliminating the requirement for participants to attend research locations to have data downloaded, which is necessary with the Actiwatch 2. The Verisense also offers a notably longer battery life than the Actiwatch 2 and negates any need for regular charging, reducing participant burden and potentially enhancing compliance. For longer duration longitudinal studies, the Verisense could be a significantly more favourable and beneficial option.

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