The Use of Smartwatches for Health Monitoring in Home-Based Dementia Care

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Abstract. A large number of dementia patients receive home-based care, in order to maintain their independence and improve quality of life and health status. The current formal home-based care model presents certain limitations related to the monitoring of the patients and the reporting of the progression of physical and cognitive decline. In recent years, novel care models and assistive technologies have been proposed in order to improve the quality of care and assistance services. In this paper, we test the assumption that the use of smartwatches for monitoring physical health aspects of dementia patients can benefit formal home-based care, by providing formal caregivers with additional, important information about significant, health-related events that may have happened during the non-visit home care hours. We perform a qualitative feasibility study - consisted of a small-scale usability study with one dementia patient, and an expert (physician) review - in order to test and evaluate the efficacy of a smartwatch intervention in home-based dementia care, as well as to examine its potential for a subsequent, larger-scale study. The smartwatch documented participant's health-related issues regarding night sleep disturbances, potentially frequent toilet visits, daytime snoozing, low sleep quality and early waking up times. Those issues were verified by the project's physician and, subsequently, measures can be taken to ensure the patient's good health, safety, and quality of life.

Keywords: Cognitive impairment · Dementia · Home-Based care · Smartwatch · Wearable computing

1 Introduction

Dementia is one of the most significant problems facing social welfare systems [10,11]. There are an estimated 35.6 million people with dementia worldwide. This number will nearly double every 20 years, to an estimated 65.7 million in 2030, and 115.4 million in 2050 [1].

People with dementia experience progressive cognitive impairments that typically commence with short term memory problems, but can encompass language deficits, difficulties initiating tasks, planning, monitoring and regulating

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behaviour, visuospatial difficulties, agnosia and apraxia [5,11]. Dementia, being a syndrome of a chronic or progressive nature, presents its symptoms in diverse forms and time ranges, gradually leading to serious memory loss. (Fig. 1) [17,23].

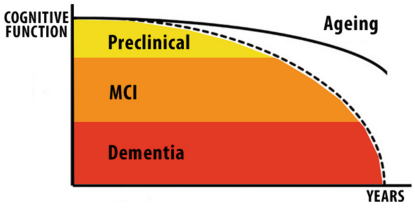

Fig. 1. The continuum of normal ageing and Alzheimer's cognitive decline [19].

A large number of dementia patients receive *home-based care*, in order to maintain their independence and improve quality of life and health status. The home-based care models place point-of-care at patients home and need an organized care system ("care network"), based on the active role and cooperation of the several heterogeneous actors such as: patients, family members, clinicians, general practitioners and social community members [12].

The current *formal home-based care* model, i.e. the monitoring of the patients and the reporting of the progression of physical and cognitive decline, depends on health operators (clinicians, general practitioners, nurses) visits. This presents certain limitations.

Firstly, *the home visits are scheduled based on the passage of time, rather than the physical and cognitive function of the patients over time* [4]. The progressing and chronic nature of dementia creates different screening needs for the patients, thus some patients may require more frequent visits than others, depending on their physical and cognitive function.

Moreover, the health operators of home-based care rely on self reporting and changing symptoms to reconstruct health events and changes, that took place during their absence, therefore the patients' physical and cognitive status during the home visits is merely a sample of ongoing behaviour. As a result of this, *the physical/cognitive home-based screening of dementia patients often follows a holistic and untargeted approach*, which *takes time out of the visits social aspect* (leading to limited quality time with the patients) [5], *it may not produce reliable or valid results* (since the self-report method is utilised in patients with impaired memory) [18] and *increases formal healthcare costs* [6,8,21].

In recent years, novel care models have been proposed in order to improve the quality of care and assistance services [5,12]. Assistive technologies offer much potential and can make a very significant difference to the lives of people with dementia and to their formal caregivers [5]. Indeed, it has been noted that technologies should be part of a formal home-based care package and should be provided in a thoughtful, sensitive, and ethical way [5,22]. The physical health monitoring of dementia patients while performing daily activities, using portable

and wearable devices could be a promising option to support formal caregivers in their work, by improving the access to patient information, as well as to support independent well-being of the person with dementia (at home). Various sensor technologies are currently used to monitor emergency situations (e.g. fall detection [3,15,16], wandering [3,15,17]), however the monitoring of physical health during daily activities requires a constant, non-intrusive, comfortable, and reliable mechanism [5,17].

1.1 Contribution and Paper Organisation

In this paper, we test the assumption that the use of smartwatches (i.e. computerised wristwatches) for monitoring physical health aspects of dementia patients can benefit formal home-based care, by providing the physician with additional, important information about significant events that may have happened during the day, and which may not be recollected by the dementia patient in a later session, or witnessed by the visiting nurse. The contribution of this work is summarised as follows:

- perform a small-scale usability study in a real-life scenario, to examine the smartwatch's feasibility for providing additional physical health information of the dementia patient,
- perform an expert review, where the project's physician analyses and interprets the smartwatch's measurements, in order to evaluate their value in supplementing the patient health profile and home-based care, and
- present and suggest the methodology of a qualitative study for examining the effect of a smartwatch health monitoring device on home-based dementia care, potentially utilised for future larger-scale studies of the same - or similar - scope.

The rest of the paper is organised as follows. Section 2 describes background and related work and Sect. 3 presents the study and its details. Next, Sect. 4 discusses the experimentation and results obtained, while the paper is concluded in Sect. 5.

2 Related Work

Cahill et al. [5] provide an overview of the dementia care and the effect of technology on the dementia treatment. This study provides a detailed report of the dementia's clinical aspects and stresses the need for further technological advances. It also documents the user requirements and user needs that the new technological systems and devices should fulfil, in order to support formal caregivers, promote patients' independence and maximise quality of life.

In the same context, Topo [20] maps out the academic space to document the relationship between technology and dementia, by performing a literature review of studies which focus on technology supporting people with dementia and

their caregivers. The review analyses 46 studies with original data, as to their goals, the technology used, the treatment environment and the experimental designs. The review of Topo documents the academic work in the researched field and, at the same time, acts as a source of valuable methodological information and issues, which can be of great significance for future related projects.

Through the studies of Cahill et al. [5] and Topo [20], valuable information about the technical, financial, social, and design features of a future dementia-related technological system can be obtained. The basic user requirements, user needs, as well as experimental and formal health-care logistics are satisfied by the technology of the smartwatch, as supported in the studies of Raghunath & Narayanaswami [14] and Shin et al. [17]. The study of Raghunath & Narayanaswami [14] is an early exploration of the smartwatch's technical features, revealing its potential as a promising interface paradigm. Shin et al. [17] put the previous knowledge into practice, by utilising a smartwatch device for monitoring the location of dementia patients (in case of wandering) and for detecting the user' steps, in order to further analyse the patients' activities. The step detection algorithm of the smartwatch showed a promising 94 % accuracy, highlighting the need for the extraction of more physical data from the smartwatch use and for "a more comprehensive analysis of a patient's activities..." [17]. Basis B1 (developed by Basis Science Inc.) is a smartwatch that can track accurately several activity states (i.e. sleeping, walking, being active). The Basis B1 smartwatch was used in a sleep-related study of Patel et al. [13], where it was shown that the sleep analysis algorithm of the smartwatch demonstrated excellent agreement with polysomnography data for sleep duration and sleep staging.

3 The Smartwatch Study

3.1 Motivation and Goal

The motivation for this study comes from the need for better formal home-based health care. The current formal home-based care model presents certain limitations (as described in Sect. 1), which do not allow formal caregivers to have a representative image of the dementia patients' physical health status, during the non-visit hours.

The ultimate goal of this study is: by optimising the current care model and by improving the access to significant patient health information, to support formal caregivers in their work, thus further supporting independent living and well-being of the person with dementia (at home) [20]. The current study can be seen as a first step towards the acceptance of a future, medical smartwatch device, both from the patient's and the doctor's perspectives.

3.2 Technology and User Requirements

The overall opportunities technology can create for people with dementia have to date not been fully utilised, since choosing the appropriate assistive technology is

not always easy [5,9]. Today, there is a wide range of different technologies that can be adapted and used for people with dementia, to help them maintain their independence and improve their health status and quality of life. People react differently to different assistive technologies and there are no quick fix solutions in dementia care, nor do solutions necessarily have to be highly technical [5].

The nature of dementia may make people cautious and suspicious of trying new devices [5]. Therefore certain user requirements should be taken into consideration, according to Cahill et al. [5]:

- the new device/product should fulfil the individual and formal caregiver needs,
- the design of the product is important, focusing on its familiarity and the fact that no new learning should be required on the part of the person with a dementia,
- a comprehensive assessment of needs should take place ideally at home with a health service professional fully trained in dementia care,
- pre-testing is critical to ensure that the chosen device/product is reliable and effective, and
- it is important to find a product that suits the individual and is not complex or stigmatising.

In this study, we propose the use of smartwaches for monitoring the physical functions of dementia patients. A smartwatch has many attractive features as a form factor for a wearable computer. It has the advantage of always being with the user, having a ubiquitous and non-intrusive presence, its design - being a wristwatch - is quite familiar, and its use is not complex or stigmatising [14].

3.3 The Device: Basis B1 Smartwatch

The smartwatch chosen for this study is the Basis B1 band (Fig. 2), based on the the fullfilment of the requirements described in Sect. 3.2. Its choice over several competitors was based on the several metrics captured by the sensors, as well as the simple user interaction required.

The charging and uploading-data process of the Basis B1 is straight-forward (by just connecting it to an external device, e.g. laptop or mobile), while it is able to automatically recognise the user's activity state (e.g. sleeping) without the user pressing any button to mark the start or end time of the activity (which is the case with many similar smartwatches). Therefore, the Basis B1 is a simple, plug-n-play device, which does not require new learning from the user's side and whose full functionality does not require any interaction, apart from charging it, once every 3 days.

The Basis B1 band is a new class of health and wellness device that is a sophisticated convergence of five sensor technologies and advanced data aggregation and analysis. Through sophisticated algorithms, the Basis B1 band translates the user's biosignals into metrics on how everyday activities affect the body. These daily activities (sleeping, walking, and being active) offer information that can help provide an objective overview of daily behaviour [2].

Fig. 2. The back side (*left*) and the front side (*right*) of Basis B1.

The Basis B1 band is built around five sensors that act in concert and simultaneously in real time to provide a view of a persons health immediately and over extended periods of time: optical blood flow sensor, 3D accelerometer, body temperature, ambient temperature reading, and galvanic skin response [2]. Rather than make assumptions from limited metrics, Basis uses all five of its sensors and its analysis to estimate the current state of the user [2].

Since the Basis is not a medical device, there is the issue of the validity and accuracy of the physical health data. In this study, we do not deal with the correlation between the "gold standard" medical devices and the Basis B1; we examine the smartwatch's feasibility for providing additional, potentially useful physical information about the dementia patient.

3.4 Design Study

Feasibility studies of potential therapies are useful and important, not only to test and evaluate the potential effectiveness of an intervention, but also to refine and improve it prior to a subsequent study [7]. Although data from qualitative evaluation are less often considered as a means to assist investigators to develop and refine research interventions, it has been shown that such data provide useful information to capture and describe processes, explore individual differences between experiences and outcomes, evaluate an evolving intervention, and understand the meaning of an intervention for its participants [7]. As stated before, dementia presents its symptoms in diverse forms and time ranges, making the qualitative evaluation of a health intervention on dementia patients a difficult task. In this feasibility study, we are using a qualitative approach to test and evaluate the efficacy of a complementary technological (smartwatch) intervention in home-based dementia care, as well as to examine its potential for a subsequent, larger-scale study.

The study follows a two-conditioned (C1: patient receiving home-based care and not wearing the smartwatch, C2: patient receiving home-based care and wearing the smartwatch), within-subject design with one late-stage dementia patient in home based-care as participant. The within-subjects study design is chosen for addressing the problem of individual variability, since it would be nearly impossible

to maintain sample homogeneity across several dementia patients. The sample size, even though cannot produce statistically significant results, can lead to clear and safe indications. The choice of only one participant is based, firstly, on practicality reasons, since "building" and maintaining a long, medical relationship with a patient is a resource-demanding and time-consuming process. The second reason is that we want to avoid the generalisation of the study's results. Even if we have tried to select subjects of the same age, gender, background, and cognitive status, we could not then extrapolate the results to encompass wider groups, because of dementia's various manifestations. The cost-benefit analysis of the feasibility study's elements led us to the chosen sample size.

The utilised feasibility study can be divided in two stages. At first, we conduct a *small-scale usability study* of the Basis B1 smartwatch use with a dementia patient in home-based care. At this stage, we focus on the smartwatch as an artifact, evaluating its functionality and its usefulness. The evaluation process is based on observational reports and informal open interviews conducted by the assigned physician Dr. Brynjar Landmark. The usability part of the study took place from mid-October to early November 2014 with one advanced dementia patient in home-based care using the Basis device. The participant has mobility aids (walking frame, stair elevator), gets four home nurse visits/day, needs assistance for nearly all daily chores and has no ability to communicate about recent events since all short term memory is lost (MMSE score<10). During the usability stage of the study, the quality/social time with the participant was increased, in order for the project's physician to be able to document all the necessary elements for the usability study and the following expert review.

An *expert review* takes place at the next stage, where the project's physician evaluates the usability results of the first stage and interprets the smartwatch's measurements. The interpretation of the measurements are validated by observational means, repetitive behavioural patterns over the study duration and reporting sessions with the participant and the visiting nurse. The expert/project's physician has accumulated a vast expertise in treating dementia and cognitive impaired patients and has spent a considerable amount of time with the participant prior to the study, getting accustomed to the sleeping, eating and, generally, daily habits.

3.5 Results

The usability study gave us valuable insight on the smartwatch's use by frail elderly.

- The smartwatch did not cause any discomfort or anxiety to the participant, as it acquired the role of a regular watch. Consequently, the smartwatch was used only as a time indicator and the participant was able to read the numericals on the display. The charging of the device was taking place during the doctor's or nurse's visit and the smartwatch was removed during the process.
- A discovered issue was that almost no walking steps and activity were recorded, due to the use of the walking frame by the participant. Furthermore, for

short periods of time there were disruptions in the smartwatch's functionality (Figs. 3 and 5). Apart from those minor issues - which did not affect the final measurements - the sensors were functioning properly, getting the additional measurements, i.e. heart rate, skin temperature, and perspiration.

The project's physician was able to extract useful information regarding the participant's daily activities and physical state from the devices measurements. The analysis of the measurements is patient-specific and the patient's medical background plays an important part in the process. However, the range of information (direct or indirect) that can be obtained from the smartwatch are indicative of its potential for use with dementia patients. The main observations from the Basis' use are presented hereafter.

- The patient was up many times in the night, which the advanced dementia patient cannot recall the next morning. Night disturbances are part of the behavioural disturbances of dementia and are difficult to quantify (Fig. 3).
- Steps are not registered when using a walking frame, however the patients heart rate increased at any effort, revealing patterns of activities, such as toilet visits (Fig. 3). This is a common problem in patients with this degree of disability, who are not able to notify their surroundings; it is all up to the caretakers to recognise the change in behaviour or frequency. Changes in this pattern, together with temperature/perspiration, may alert caretakers to e.g. recognise a urine infection and take a urine sample to the physician.
- The total registered sleeping time for the participant was 12-16 hours (Fig. 4); the registered data sums up naps and total daytime snoozing in a manner the caretakers are not able to evaluate accurately. The majority of the smartwatch's sleeping-related measurements revealed that there is not much difference between day and night sleep, registering almost the same sleeping pattern in the afternoon as in the night. This situation could be addressed by adding activities or daytime stimulation.
- When the home care nurse arrives for morning assistance (around 10:00-11:00 am), the Basis monitor can indicate when the patient woke up. In many instances, the patient had been awake for three hours before assistance arrived (Fig. 5). The arrival hours may be adjusted to the patients need.

4 Discussion

It is true that home-based care cannot be provided to the patient on a 24/7 basis. However, a smartwatch monitoring device, like the Basis B1, can provide formal care with user's health information, for those hours that are not covered by the caretakers' visit. Especially for cognitive impaired, elderly patients - where the self-reporting method can be unreliable or even impossible - such devices can provide an estimation of the patient's daily activities. Naturally, the measurements of the device can lead to several interpretations, depending on the user's health profile/background and daily habits.

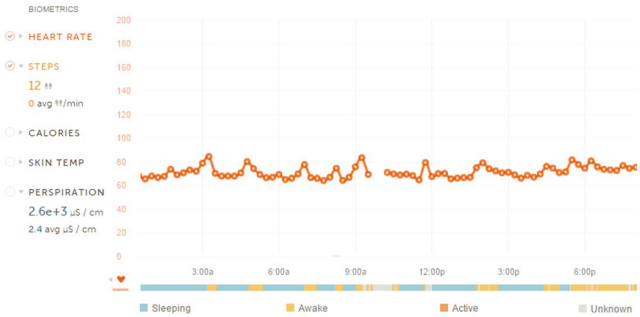

Fig. 3. An indicative day's measurements, showing the disrupted sleep pattern and the heart rate increases of the participant.

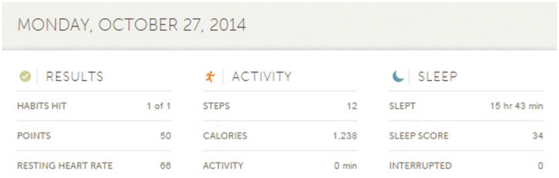

Fig. 4. A day's measurements, presenting the total sleeping time in a 24-hour period.

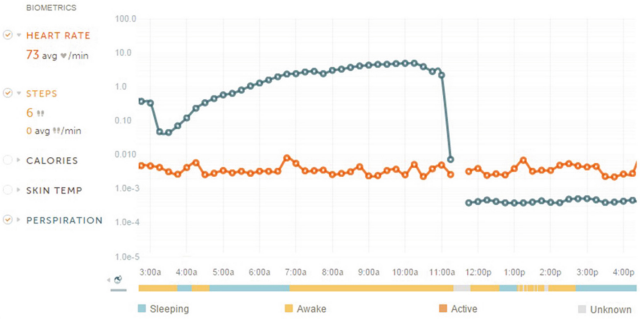

Fig. 5. An instance of the participant waking up at 7:00 am, but getting out of bed at 11:00 am (perspiration drops), when the home care nurse arrives.

In our case, even though the Basis B1 smartwatch provided new insight in the patient's daily patterns, the collected data cannot be interpreted as accurate, validated medical data, but their readings may provide triggers for caretakers to address specific health aspects, improve care and safety of the patients. Well-being (non-medical) devices like the Basis B1, by no means, should replace important aspects of home-based care like screening processes, physical monitoring, as well as the social time with the patient. The acquired measurements can provide valuable information/indications and cover an "empty space" inside the context of the regular care model, where there is a lack of health data.

The study presented herein is of qualitative nature, focusing on a real-life scenario. The fact that we deal with a progressive disease with various manifestations and patients of various health backgrounds, makes it very difficult to study the effectiveness of a smartwatch monitoring device in a quantitative way, on a large sample and under realistic conditions, without facing generalisation and assignment bias issues. The focus on one participant allows us to detect the changes that the Basis B1 smartwatch brings into the regular patient care, since, in fact, we utilise a two-conditioned, within-subject study. Prior to the Basis B1 experimental process, there is an extensive treatment period of the dementia patient and a deep knowledge of the patient's medical background and daily habits. As a result of this, we are able to interpret the following Basis measurements more accurately (for the specific patient), as well as recognise the new health-related information that the smartwatch can introduce to the current treatment model. A larger qualitative study - following the same two-conditioned, within-subjects design - could be feasible, as a longitudinal and resource-demanding project, since establishing a medical and social relationship with each patient is a challenging, time-consuming, yet necessary task. The small sample size of the study ensured that the observational evaluation method, the extra social time, and all the safety/ethical cautions would take place in an unobtrusive, focused manner, setting the groundwork for a robust, qualitative methodology which could serve a large-scale project of the same or similar scope. Even though, it is clear that such a sample size cannot produce statistically significant results, we consider it adequate enough for providing clear and significant indications about the smartwatch's use by advanced dementia patients, as well as for testing and evaluating the feasibility and potential effectiveness of the intervention, in order to refine and improve it prior to a subsequent study.

The results of the feasibility study showed that the Basis B1 can be used by a late stage dementia patient, in the same way as a regular wristwatch, without causing any issues. There were a few technical problems that did not affect the overall measurements. The optical blood flow sensor, body temperature, ambient temperature reading, and galvanic skin response produced valuable information about the patient's health state. Especially, the measurements collected during the non-visit hours, when the patient was not physically monitored, managed to provide a representative image of the patient's health-related actions during those hours. As presented in Sect. 3.5, the Basis B1 documented health-related issues regarding night sleep disturbances, potentially frequent toilet visits, daytime snoozing, low sleep quality and early waking up times. Those issues were

verified by the project's physician and, subsequently, measures can be taken to ensure the patient's good health, safety, and quality of life.

5 Conclusion

The study - even though constrained by certain limitations - assisted in acquiring meaningful data that would be difficult or even impossible to otherwise acquire. The ultimate outcome of the study is the promising potential that a smartwatch device can have for dementia patients in home-based care. Additional features like an alert notification system (setting patient-personalised measurements' "thresholds"), GPS functionality (addressing the wandering problem), and a local database with limited access (for secure access and storing of sensitive health information) could be implemented as part of a future certified, medical, smartwatch device.

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