D8.5
Final Pilots Evaluation

Dementia Ambient Care: Multi-Sensing Monitoring for Intelligent Remote Management and Decision Support

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Abstract (for dissemination)		This report details the evaluation results from each of the pilot sites. It also describes in detail what each pilot covered, the collected research data, and changes in the assessment protocols from the previous pilot. The report includes user and clinical assessment (e.g. health status and/or health evolution of the observed people) of the Dem@Care approach based on the feedback and observations acquired in the final piloting of the final prototype.

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Executive Summary

The objective of the Dem@Care project was to develop a complete system providing personal health services to people with dementia, as well as to medical professionals and caregivers, by using a multitude of sensors, for context-aware, multi-parametric monitoring of lifestyle, ambient environment, and health parameters.

This deliverable describes the activities and results of the final evaluation and clinical validation of the Dem@Care system carried out at test sites in Thessaloniki by CERTH, in Nice by CHUN, in Dublin by DCU, and in Luleå by LTU. The evaluation included a clinical assessment of the final prototype, which in many ways was a continued process from the evaluation of the first and second pilots. It describes the work accomplished during the evaluation, data collected at each site and the results of the analysis of this data. The test and evaluation of the final prototype was carried out in three different operational contexts with their own specific aims and goals. The @Lab evaluation was primarily concerned with the use of the final prototype to facilitate assessment and diagnosis of people with dementia. It was conducted in both Nice by CHUN and in Thessaloniki by CERTH and was carried out in specially designed lab environments placed in a clinical context of memory clinics with the same standardised evaluation protocols in both test sites. The @Nursing home evaluation of the final prototype had a special focus on the effectiveness of the system in clinical use in a nursing home context when assessing the problems of people with severe dementia who suffer from behavioural and psychological problems. The test and evaluation was carried out in Luleå by LTU. The @Home evaluation of the final prototype focused on assessment and support of people with initial and before interventions diagnosis of mild dementia living in their private homes. This included the ability of the system to maintain and support the status of the individual with dementia in five domains of daily life, and supporting independence and autonomy. The evaluation activities were carried out in Dublin by DCU and in Thessaloniki by CERTH.

The Dem@Care system with its toolbox of different sensors was adjusted to each operational context. In the @Lab and @Home evaluation the full toolbox of sensors was used, which included Depth Camera, IP Camera, and the GoPro Camera, all used to capture postures, locations and primitive events. It also included the DTI-2 bracelet sensor used to measure movement intensity and stress. In both the @Nursing home evaluation and the @Home evaluation a sleep sensor, the Gear4 sensor, measured quality of sleep. In addition to the Gear 4 sensor, the DTI-2 bracelet and the Depth Camera were also used in the @Nursing home. In all three operational contexts a microphone intended for voice analysis of stress and diagnostic information was piloted. Additionally, in the Thessaloniki pilots, different and new types of sensors (motion sensors, smart electric plugs) were used. The selection of these sensors was based on positive and the negative results and experiences from Nice @Lab and Dublin @Home pilots, with the goal to have robust and reliable technical solutions and measurements of relevant sensor data.

The aims, goals, methods and results of the evaluation of the final pilots of the Dem@Care system in the three contexts of @Lab, @Nursing home and @Home are presented in detail in separate chapters of this report. The evaluation has in all three contexts been a process that has been evolving during the project, in the sense that each step in the process has built on previous experiences and that experiences have been transferred from one test site to another.

An example of this approach was that the experiences from the @Lab-based pilots were used as a reference for the test of the system and its sensors. The main findings of the evaluation in the three operational contexts are presented in a separate chapter and described from the perspective of importance for people with dementia, importance from a clinical perspective, and from the perspective of identifying and verifying assets for future exploitation.

The chapter about @Lab evaluation provides a description of the process of evaluation carried out in both Nice by CHUN and in Thessaloniki by CERTH. This is one part of the Dem@Care evaluation, which has involved 290 persons in total (132 in Nice site and 158 in Thessaloniki pilots) and an extensive analysis (139 participants separately underwent the audio recordings and 60 just the single/dual task wearing the DTI-2 bracelet). The specific focus in the final evaluation was to explore if the Dem@Care system tested in one site with one protocol (Nice) could successfully be transferred and implemented in another clinical site (Thessaloniki) and obtain similar results. The chapter about the @Nursing Home evaluation describes the evaluation activities which in the final evaluation had a specific focus on the clinical aspects of the effectiveness of the Dem@Care system in supporting staff members in assessing the problems of residents with severe dementia who suffered from Behavioural and Psychological Symptoms in Dementia, BPSD, and the evaluation of planning and execution of care interventions. The @Home evaluation provides a description of the process and evaluation carried out in Dublin by DCU and in Thessaloniki by CERTH. The @Home evaluation activities are described in separate chapters, one for each test site. The evaluation was carried out with a methodology of case studies and provides detailed descriptions on the use of the Dem@Care system in the context of private homes. The lead users participating in the test of the final pilot system were offered a cognitive rehabilitation intervention where the need for therapist contact in the early post-diagnosis phase was evaluated.

The overall conclusion of the final evaluation of the Dem@Care system shows that it has the potential to contribute to an added value for both clinicians in their clinical work and people with dementia and their informal caregivers in managing their daily lives. The system has with its design proved to work in such varied clinical contexts as a clinical lab for assessing cognitive functions of people with dementia, a context of clinical assessments in nursing homes for people with severe dementia suffering from BPSD, and in clinical assessment and support of people with mild dementia still living in their private homes. Several of the tested approaches of using multi-sensing technology in the three different contexts are innovative. The @Lab test was among the first that tried to demonstrate the use of ICT-based tools for the purpose of clinical assessment of potential dementia patients. The use of sensors for monitoring behavioural patterns in people with BPSD in nursing homes has to our knowledge never been described before.

Abbreviations and Acronyms

AD	Alzheimer's Disease
ADL	Activities of Daily Living
BADLs	Bristol Activities of Daily Living Scale
BPSD	Behavioural and Psychological Symptoms in Dementia
CHUN	Centre Hospitalier Universitaire de Nice
CR	Cognitive Rehabilitation (intervention)
DCU	Dublin City University
DJLS	DeJong Loneliness Scale
DT	Dual Task
DoW	Description of Work
GDS	Geriatric Depression Scale
LSNS	Lubben Social Network Scale
LTU	Lulea Tekniska Universitet
Mx	Month X
NPI	Neuropsychiatric Inventory
PSP	Primary Supranuclear Palsy
PSQI	Pittsburgh Sleep Quality Index
PwD	Person with Dementia
QoL	Quality of Life
RAPA	Rapid Assessment of Physical Activity
ST	Single Task
SUS	System Usability Scale
Tx.x	Task x.x
WP	Work Package

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1. Introduction

This deliverable is the final comprehensive report of the clinical evaluation of the Dem@Care prototype and includes the evaluation of the final prototype of the system. The process of evaluating the Dem@Care system has been carried out in a three-staged evaluation process. The original plan described in the DoW was that the first evaluation phase, where the first Dem@Care prototype was deployed, verified usability, functionality and reliability in order to further refine the functional requirements. The second evaluation phase, involving the deployment of the second Dem@Care prototype, focused mainly on Dem@Care's external qualities, and to the formative evaluation of suitability, accuracy, security, and maturity. The third and final evaluation phase, deploying the final Dem@Care prototype, evaluated the overall efficacy and impact of the Dem@Care system, including clinical considerations and impact on daily life on people with dementia and their caregivers.

This deliverable will report on technical (e.g. number and types of detected activities) and clinical (e.g. health status and/or health evolution of the observed people) assessment of the Dem@Care approach based on the feedback and observation acquired in the evaluation of the final pilot.

A separate section describes the technical evaluation of the final Dem@Care system which is followed by an in-depth description of the results of the evaluation for the @Lab, @Nursing home and @Home studies. The original evaluation strategies were first detailed in D8.2 and they have been further developed in the evaluation process in all test sites with updated protocols. In all there has been five deliverables that describe different stages of evaluation process, D8.1, D8.2, D8.3, D8.4 and this final deliverable, D8.5. Delays in the delivery of the technical system during the different phases of the project have been addressed with longer and more continuous evaluation activities than originally planned.

The piloting and testing of the Dem@Care system has been carried out in three from each other very different contexts, the @Lab context which focuses on how the system in a lab environment can enhance conventional assessment methods for the diagnosis of cognitive and neuropsychiatric symptoms and the ability to perform activities of daily living of people with dementia. The tests involved collaboration and comparison of test results between CHUN in Nice, France and CERTH in Thessaloniki, Greece, who both performed the tests.

In the @Nursing home context, the Dem@Care system is tested in a natural setting of a dementia care unit with a focus on how information from the system aids the staff in their clinical assessments of people with behavioural and psychological symptoms in dementia, BPSD, and in evaluating care interventions aiming at reducing the BPSD problems. These tests have been performed by LTU in Luleå, Sweden. A minor test of using the CAR video sensor was performed by CHUN with five enrolled residents in Nice, France.

Finally the @Home context aims to explore how Dem@Care technology can enhance clinical support and enable and maintain the independence of older adults with early stage dementia in their own homes, and also assist informal family caregivers. These tests have been performed by DCU in Dublin, Ireland and by CERTH in Thessaloniki, Greece.

Since the settings are diverse in many ways, with different patient groups who have different problems and priorities, the clinical challenges also vary. These differences in site-specific goals, clinical challenges and contexts lead to necessary differences in evaluation strategies

and protocols. While the @Lab study performs mostly quantitative and controlled evaluation protocols, the @Nursing home and @Home sites have used a qualitative design to maximize the rich information that can be obtained from a small sample size. Furthermore, the approach employed for @Nursing home and @Home sites collected contextual, longitudinal and ethnographic data that is not possible to observe in a laboratory setting. The stage of dementia for individuals in the three test contexts also varies; the @Home and @Lab settings have concentrated on people with a mild stage of dementia while the @Nursing home setting have worked with individuals with severe dementia.

The strategy of choosing three diverse contexts with very different aims and methods to test and evaluate the Dem@Care system was based on an approach where the results from each setting informed the others in a cyclical process. Experiences and test results of the use of the system from the most controlled setting, the @Lab, was transferred to the @Nursing home as the second most controlled context, and finally to the @Home settings being the least controlled context. In this way the @Lab setting could make initial evaluations of sensors and functions in a highly controllable laboratory setting, and validate the sensor information with a large number of users. Resulting information and analysis was then transferred to the @Nursing home and the @Home settings. Equally the contextual information and analysis from the @Nursing home and @Home informed the more controlled procedures in the lab to help create a more naturalistic setting and enhance the diagnostic procedures.

In all settings performing the tests of the Dem@Care system it was possible to evaluate the acceptability and usability of the system including the use of each of the individual sensors and the user interfaces employed, from the perspective of the person with dementia and clinical staff.

This deliverable presents an integrated analysis and discussion of the impact of using the Dem@Care system based on the test of the final pilot system. The results of tests in each context are described to inform evaluations of the overall personal and clinical impact, together with a likely societal impact of the Dem@Care system as a whole.

In the following table, an overview of the components-sensors and the total participants for each site is presented.

Table 1. Pilots Overview

Site	**Sensors**	**Number of participants**
@Lab - Nice	DTI-2, CAR + HAR (RGB-D camera), Microphone, Motion PlugASUS/KINECT, DTI-2, GoPro	132 (MCI, AD, healthy)
@Lab – Thessaloniki	DTI-2, CAR + HAR (RGB-D camera),Microphone Motion, PlugASUS/KINECT/HD Camera, DTI-2	158 (MCI, AD, healthy)

@Nursing Home – Lulea	DTI-2, CAR , Gear4	8
@Nursing Home – Nice	DTI-2, CAR	5
@Home – Dublin	DTI-2, CAR, GoPro, iTalk iPhone app (audio)	12
@Home - Thessaloniki	DTI-2, UP24, CAR + HAR (RGB-D camera), Microphone, Motion Plug, Presence, Aura + Beddit (Sleep sensors)	4

1.1 Progress in relation to the DoW

The DoW of the project states that the objective of Dem@Care is the development of a complete system providing personal health services to people with dementia, as well as medical professionals and caregivers, by using a multitude of sensors, for context-aware, multi-parametric monitoring of lifestyle, ambient environment, and health parameters. Dem@Care developed a closed-loop management solution for people with mild or mid-stage dementia through multi-parametric remote monitoring and individual-tailored analysis of physiological, behavioural and lifestyle measurements.

1.1.1 Progress towards Objectives

The Dem@Care project has developed, tested and evaluated a system for the holistic management of dementia that integrate medical and care knowledge with advance information and communication knowledge.

An important uniqueness of the system is that it both supports the clinical assessment of the individual problems of people with dementia in different stages of the disease, from people with mild to severe dementia. The system also enables and maintains the independence of older adults with early stage dementia in their own homes, and assistance to their informal family caregiver. The technical support system includes in this way two loops, one for the individuals with early stage dementia and their informal caregivers, and one loop for professionals that provide clinical data of psychological, behavioural and lifestyle measurements that can support clinical assessments and interventions.

The Dem@Care system is designed to be flexible and possible to adjust to individual needs of people with dementia, which means that the same system can be used in such different contexts as a lab environment which is setup to facilitate diagnosis of dementia, in the home environment to facilitate clinical assessments and support of the person with dementia in everyday activities, and in a dementia care unit to support the clinical assessment of professionals of people in a severe stage of dementia suffering from BPSD. The system is collecting data from a toolbox of different sensors, both wearable and stationary, that can be adjusted to the different contexts and the individual needs of the person with dementia.

Considering the number of people suffering from dementia in Europe, the use of the system in the tested contexts has the potential to have a considerable societal impact since it respond to major challenges in the care of people with dementia. The diagnosis of dementia is a challenge in itself since it is a symptom diagnosis and there is room for considerable improvements in existing strategies for making the diagnosis. Early, timely and accurate diagnosis is regarded as an important way to improve the support of people with dementia. Improvement of clinical support and support of people with dementia and their informal caregivers living in their private homes is regarded as very important for enhancing community based support. Community based support systems that can provide high quality support is regarded as the most important way to improve quality of life of the individual and is also a cost effective support system for people with dementia who still are able to live in their private homes. The management of people with BPSD is one of the major challenges in the care of people in severe stage of dementia. An improvement of clinical assessments strategies and a consequently improvement of care interventions has the potential to support the wellbeing of the individual and reduce cost of care in an area of care which involves the major cost of care for people with dementia in Europe.

The developed, tested and evaluated Dem@Care system has proved to meet the goals and objectives of the project. Delays in the technical development of the system introduced difficulties in evaluation of the impact of the system for people with dementia, their informal carers, and for clinical assessments of professionals in the three different contexts where it has been tested. This is specifically true for the @Nursing home and @Home contexts. To address this, additional pilots were introduced in Thessaloniki, with four complete @Home installations running for several months and a high number of additional @Lab experiments. The conducted evaluation indicates that the use of the system has potential to have a considerable impact on the support of people of dementia and their informal carers in all tested contexts.

1.1.2 @Lab Pilot – Nice, France

The main goal of the test in the @Lab sites was to assess whether the Dem@Care system can contribute to conventional assessment methods for the diagnosis of cognitive and neuropsychiatric symptoms and the ability to perform activities of daily living of people with dementia. The DoW stated that the first initial pilot will involve short-term tests (between 1 to 1 1/2 hours) during regular consultation in a memory clinic in a Geriatric hospital. The tests should involve monitoring of people with dementia in early stages of the disease using the Dem@Care system to provide a brief overview of their health status with regard to cognition, behaviours and functions and to correlate the Dem@Care system data with the typical assessment tools. The @Lab site aimed to assess the usability and effectiveness of the Dem@Care system in the lab context and to explore if the system can add reliable diagnostic information to existing standardized diagnostic procedures.

The evaluation protocols of the Dem@Care project were detailed in D8.2 in terms of protocols and methodology to be used for evaluating the quality of the project's methods for assessing health status and dementia progression, as well as for investigating acceptability and usability of the Dem@Care system. In D8.3, the @Lab setting presents interim results for the first prototype of the Dem@Care system focusing on the usability and aspects of the acceptability of the system and the test protocols.

The tests performed in the hospital in Nice included three groups of participants, healthy controls, individuals with MCI, and individuals with AD. The study protocol began in the memory clinic in Nice in June 2012 and inclusion of participants continued throughout the three pilot phases targeting the total number described in the DoW. In total 132 participants were included in the tests.

In D8.4, the @Lab evaluation describes analyses and results of data collected through video, audio and accelerometer sensors. A shorter version of the @Lab protocol was then designed in order to shorten the evaluation time and increase the number of enrolled participants until the end of the trial. 89 participants underwent the long version and 43 the short version in Nice.

Both the long and the short protocol were successfully implemented in another clinical site, the Alzheimer Day care centre in Thessaloniki in Greece. Although the protocols remained the same, in the Thessaloniki @Lab pilots, additional plug and motion sensors were installed and used.

This deliverable presents findings from @Lab protocol and includes analysis of several sensor data (DTI-2, Speech analyses), as well as a cross-pilot comparison of the collected video data, and outcomes of an informal expert evaluation of the exploitation potential of the Dem@Care system in the @Lab context.

1.1.3 @Lab Pilot – Thessaloniki, Greece

In Thessaloniki @Lab pilots, both long and short protocols that were used in Nice pilots, were applied. The pilots were implemented in Alzheimer Day Care Center in Thessaloniki Greece and involved 158 participants. The main goal was to assess whether the Dem@Care system supports conventional clinical assessment methods for the diagnosis of cognitive and neuropsychiatric symptoms and the ability to perform activities of daily living of people with dementia. Moreover, we would like to examine if a successful experimental setting (clinical protocol and the Dem@Care system) is able to perform efficiently in two different sites in different countries. In D8.4 an expert evaluation of the system with 14 clinicians was presented with rather positive outcomes. Moreover, D8.4 included an analysis of the clinician interface.

The long protocol pilot included 98 participants divided into two groups: individuals with MCI, and individuals with AD. The short protocol included 60 participants divided into three groups: healthy, individuals with MCI, and individuals with AD. The protocols were the same with the ones in Nice in terms of duration and tasks. However, in Thessaloniki pilots, additional motion and plug sensors were installed and used. Moreover, in the short protocol two mobile apps were introduced. The first one simulated a phone operation and it was used in a mobile phone for a specific task in order to record the number of attempts, error operations etc. The second app simulates a web bank transfer and it was used through a tablet. The data from both these applications revealed statistically significant difference between the three groups (Healthy, MCI and AD).

This deliverable presents the results from both pilot phases. These results indicate that the Dem@Care system is able to support clinical assessment and provide the base for objective assessment. More specifically, the data analysis showed statistical significant differences in between the groups in multiple activities of, both clinical protocols. Moreover, the analysis revealed strong correlations between specific lab activities and neuropsychological tests. Fi-

nally, the results emphasize that the Dem@Care system and the relevant @Lab protocol can have the same positive results in different sites that are in different countries.

1.1.4 @Nursing Home Pilot – Luleå, Sweden

In an early stage of the project there was a deviation of the initial plans described in the DoW for test to be carried out in Sweden by LTU, which initially were planned to focus on people with mild dementia living in their homes. Instead a test of the Dem@Care system with people who had severe dementia residing in a nursing home and also suffering from behavioural and psychological symptoms of dementia, BPSD, was introduced. This was decided on with the rationale that a stronger focus in the test of the system among people with dementia cared for in a nursing home setting would add important information on the performance of the Dem@Care system. The revised evaluations plans and protocols were presented in the deliverable D8.2 which stated that the first test of the Dem@Care pilot should involve five people with dementia and after that more participants will be included consecutively. The total number of people with dementia involved in the nursing home tests became less than planned, 19 in total, mostly due to delays in the technical development of the system. Most of the test activities of the different pilot systems in the nursing home context were conducted in Luleå, Sweden by LTU. In addition a minor test of using the CAR video sensor was performed by CHUN in a test with two enrolled residents in Nice, France.

Pilot testing and evaluation were performed in all areas outlined in the DOW and previous deliverables. The tests were performed with the protocols outlined in the D8.2, which detailed protocols and methodology to be used in the evaluation of the system in the nursing home setting. These protocols were later slightly revised in the evaluation process based on the gained experiences. As outlined in the DOW, the test of the first pilot prototype in the nursing home setting focused on usability, functionality and reliability in order to further refine the functional requirements. The second evaluation phase, focused mainly on the Dem@Care system's external qualities, and the formative evaluation of suitability, accuracy, security, and maturity. The third and final evaluation phase described in this deliverable focused on the effectiveness of the system to support clinical staff in the care of people with BPSD. The final pilot system could among other things produce aggregated reports on patterns of sleep and patterns of stress, which were used as important tools in the clinical assessment process.

1.1.5 @Home Pilot – Dublin, Ireland

For the task 8.5, 'Pilot for Assisted Living in Ireland (DCU)', the DOW states that the first pilot would involve deployment of the Dem@Care system to the DCU community flat setting, which has a typical apartment layout and facilities (kitchen, bathroom, living room, and balcony). The intention was for a short pilot of one month with actors/students who would replicate the activities carried out in the @Lab and @Nursing Home settings. The second pilot would then involve five participants in real homes in Dublin for one to two months, and the third pilot an additional five participants for six months. These real deployments would be selected from contacts within the Memory Works clinic in DCU, which supports people with dementia in living more independently.

As described in the First Pilot Evaluation Report (D8.3), the first @Home pilot was more extensive than originally planned, and Dem@Care sensors were deployed to a real lead user dyad in their own home, based on an assessment of clinical need. A full installation was also available for system testing in DCU. Early sensor deployment enabled data collection to begin

for a real lead user dyad that in turn has led to the creation of a substantial longitudinal dataset for this dyad. It also facilitated ongoing co-design and evaluation activities. The second pilot commenced from this baseline and included additional data collection with this lead user and the recruitment of a second lead user dyad. The Second Pilot Evaluation Report (D8.4) presents the results of this pilot along with the rationale for the prioritisation of development that included moving the focus for developing new @Home functionality to the final phase of system development in year three. A protocol was also developed and presented in that report for the shorter and more focused system testing that was scheduled to take place as part of the final @Home pilot. This involved the use of the Dem@Care system to support a cognitive intervention study.

This deliverable presents the findings from the third pilot these include an analysis of the lead user case studies and the cognitive intervention studies, and an expert review of the final Dem@Care system by clinicians, researchers, informal caregiver, and people with dementia. It also comments on the ethical issues encountered during the pilot, presents guidelines for using Dem@Care in the home environment, and suggestions for future development.

1.1.6 @Home Pilot – Thessaloniki, Greece

In Thessaloniki @Home pilots 4 participants were recruited (3 MCI and 1 AD). Before the installation of the system in the first participant's home there has been a 5 month extensive testing of the system in real home conditions. This testing procedure has been described in D8.4.

In all 4 homes a full set of sensors and components were installed including: CAR, HAR, Sleep sensor, Activity sensor, Plug sensors, Motion sensors, and Presence sensors. Based on the Dem@Care data analysis the clinician was able to introduce specific and personalized interventions to each of the four participants. Moreover, these interventions were adapted or even substituted by others based on the information that the Dem@Care system provided to the clinician during the period of each home protocol.

Furthermore, in all 4 pilots the user (patient or caregiver) interface was used. The first and the third participants were able to receive in their tablet device messages, either automatically generated by the system or from the clinician, regarding various daily activities aspects. With respect to the other two participants (who were not able to use a tablet), the user interface was used by their caregivers. The positive results from a usefulness and usability assessment are also presented in this deliverable. It is important to note that the assessment of the first participant provided new ideas and fixes for the UI. The updated version based on these thoughts was used by the third participant and the two caregivers.

The data analysis of the 4 @Home pilots indicated the following important results:

- the system provided valuable information to the clinician in order to objectively assess activities and conditions of everyday life, decide and adapt interventions and monitor compliance and participants progress.
- the recorded and analysed data from Dem@Care system provided evidence of improved sleep quality, activity and daily schedule.
- all of the participants improved in several neuropsychological measures
- the three MCI participants reported improved feeling and goal achievement

- the caregivers of the second and fourth participant provided positive feedback regarding the system and the richness of the information that were able to see.

This deliverable presents the positive results from all the four pilots as well as an expert evaluation of clinician @Home UI with 10 domain experts. These experts are professionally active psychologists working at Alzheimer day care centres.

2. Technical System and Interfaces

The collection of sensors considered in Dem@Care enables the capturing of a variety of data about the individuals being monitored. Dedicated analysis components that have been developed in WP3 and WP4 process these data to extract observations about locomotive, physiological and voice-based attributes (e.g. number of steps, skin conductance, verbal reaction time), about objects within the field of attention (e.g. kettle, watering can) and their location (e.g. near the TV), as well as about elementary activities of the person (e.g. eating). These observations are then analysed in WP5 to derive complex activities and high-level interpretations, as well as to detect clinically relevant situations and problems that need to be highlighted to the clinical experts and caregivers, and provide personalised feedback to the PwD through WP6's feedback services and intelligent GUIs.

The clinical objectives maintained at each pilot setting (i.e. lab, home and nursing home) with respect to the aforementioned purposes, designate the desired functionality of the framework. In the following, we present an overview of the interpretation capabilities of the final Dem@Care prototype regarding the detection of activities and problems in each pilot site.

2.1 Functionality in the Lab setting

The primary aim of the Dem@Care system in the lab environment is to assist clinicians to diagnose early stage Alzheimer's disease in an objective manner, via the use of an ecological experimentation protocol that considers standardised scenarios of daily living oriented activities. During the protocol steps and their constituent tasks, a predefined set of measurements that are of clinical relevance are monitored. These measurements serve clinicians as indicators to assess cognitive, behavioural and psychological traits (e.g. gait, functional abilities, and affective state) that are related to the diagnosis of mild cognitive impairment (MCI) and of dementia.

Table 2 lists the information that the framework extracts in the lab setting (both for the long and short protocols) based on the sensor observations collected (Table 2). This translates to recognising the behaviour of the participant with respect to the protocol specifications, i.e. recognising the activities performed, the time required for each activity, the number of repetitions of a certain activity, etc. These parameters are used to perform automated clinical assessment, classifying individuals as cognitively healthy, MCI, or dementia.

Table 2. Sensors and modalities in the lab setting

Sensor	Modality
Depth Camera	Posture, Location, Primitive Event
IP Camera	Posture, Location, Primitive Event
GoPro Camera	Objects, Location, Primitive Event
DTI-2, UP24	Moving Intensity

Plugs	Objects
Tags	Objects
Microphone	Voice
Phone simulator	Mobile Phone
Bank transfer simulator	Tablet

Table 3. Supported measurements, activities and problems in the lab setting

Protocol Measurements and Activities	Problems
• Walking attempts • Moving intensity monitoring • Speech-related parameters • Semi-directed activities: dial phone number; establish the account balance; leave the room; prepare drink; prepare the drug box; read an article; turn on the radio; water the plant; • Mobile apps (phone and bank transfer simulator)	• activities with long duration • repeated activities • missed activities • high moving intensity • various statistical values regarding deviations from norms, such as mean total duration of each activity, mean successful attempts, and so forth

2.1.1 System Usage

Dem@Lab, an asset of Dem@Care, is a system for dementia assessment clinical trials, following an Ambient Assisted Living methodology. Dem@Lab is comprised of the interconnected system infrastructure of Dem@Care, along with the tailored back-end of device manipulation and front-end for tailored user interfaces for the lab trials. This way, Dem@Lab addresses all requirements for the orchestration of interconnected devices in a @Lab context, visual, audio and semantic analysis and tailored presentation of assessment support.

Regarding technical implementation, each device is connected to a central system with a universal interface developed for Dem@Care using the WSDL[1] web service standard for remote access and interoperability. Consequently, a WSDL-client backend implements the automatic orchestration of devices as guided by user interactions on a @Lab front-end application. Sensor data are stored in Dem@Care in a semantically-enriched format in an RDF Knowledge Base, enabling their temporal fusion for activity recognition and their aggregation for statistic comparisons. Such results are also presented in the front-end.

The usage of the system is mostly linear, automated and user-friendly. The initial lab deployment is still done by Dem@Care technicians, installing the necessary wireless and wired sen-

[1] WSDL W3C Recommendation: http://www.w3.org/TR/wsdl

sor networks and configuring the communication infrastructure. Yet, after this setup the lab can autonomously continue for months, if only for monthly sensor calibration technician visits.

First of all the system enables user management, adding and editing participants and their demographics at any point. Assessment can be initiated with existing or new participants, which takes the user to the screen shown in Figure 1. The top view shows current information of the protocol step (what instructions to give, which picture to show etc.). The midline shows current protocol progress and the bottom view shows sensor status and activity detection at any point both from online and offline sensors. Pressing next guides the conductor through the trial, automatically manipulating the equipment. For instance, the appropriate cameras are switched on for walking in the corridor (steps P1.1 and P1.3) or performing daily tasks in the room (step P3.1) as does the microphone for the interview (P2.1-9).

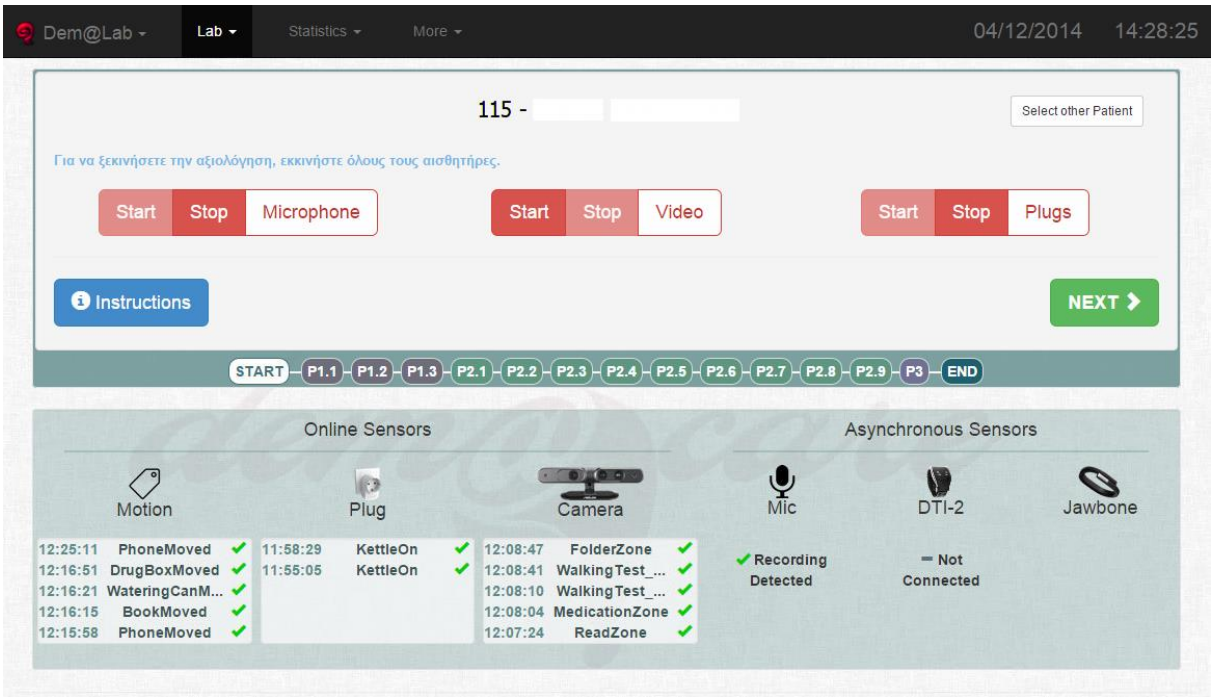


Figure 1. Dem@Lab Assessment view, orchestrating sensor manipulation through the protocol

Reaching the final step prompts the clinician to re-attach wearable sensors and begin processing and analysis, which takes a few seconds. The individual's detailed performance in all steps is displayed in the view shown in Figure 2, where the clinician can see in-depth information such as the order and duration of each performed task. The final assessment, however, is mostly supported by the summary view, shown on Figure 3, where the participant's performance is contrasted to all norms of healthy, MCI and Alzheimer's disease individuals.

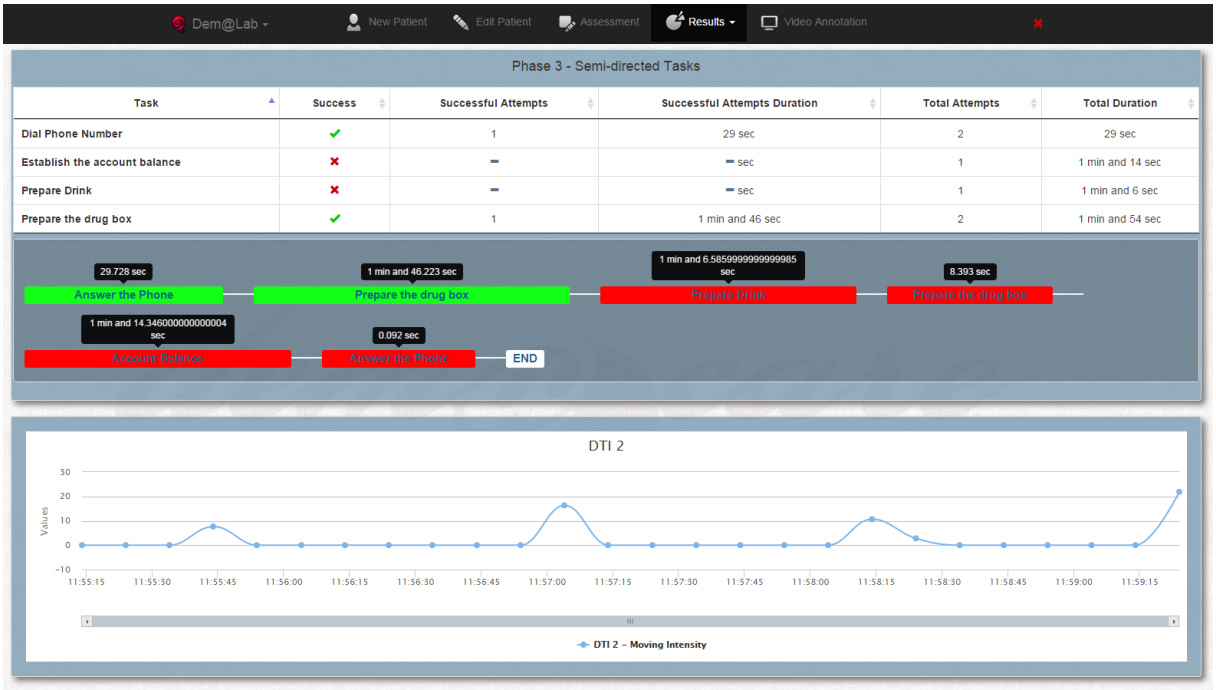


Figure 2. Dem@Lab visualization of a participant's Phase 3 results

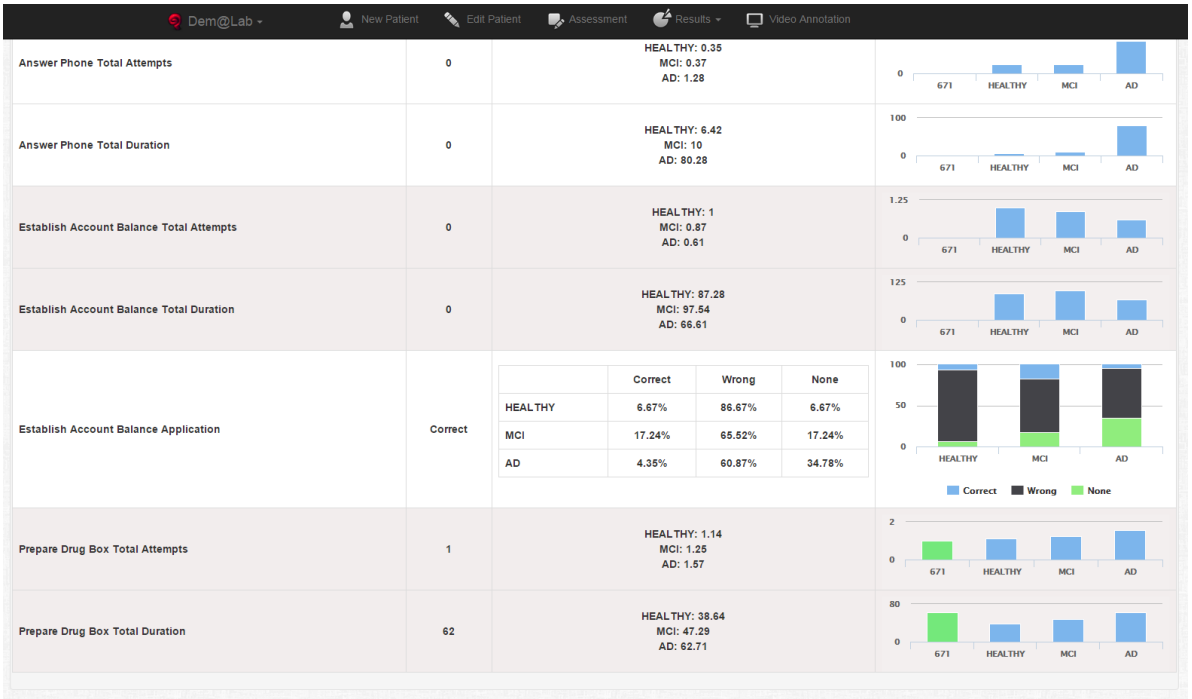


Figure 3. Dem@Lab summary visualization of a participant's results across norms

2.2 Functionality in the Nursing Home setting

The nursing home a natural clinical setting, which is less controlled environment than the lab but more controlled than the private home and deployment of sensors was determined by the clinical needs of the nursing home staff. The focus is primary given on monitoring the PwD

sleep, activities and stress levels in order to inform the staff members about changes in the behaviour patterns which were information used in the clinical assessments and evaluation of interventions.

Table 4. Sensors and modalities in the nursing home setting

Sensor	Modality
DTI-2, UP24	Moving Intensity, Stress levels
Gear4/Aura	Sleep Monitoring
Microphone	Voice
Depth Camera	Posture, Location, Primitive Event

Table 5. Supported measurements, activities and problems in the nursing home setting

Measurements and Activities	Problems
• Moving intensity monitoring • Stress/anxiety monitoring • Sleep monitoring: sleep related activities (sleep episode, nap, etc.); sleep-related parameters (sleep duration, number of awakenings, etc.); sleep quality • Events and activities: bathroom visit, in bed, out of bed, standing, walk, lying, fall, sitting, moving in bed, etc. • Correlations between sleep-related problems and physical activity, e.g. when low physical activity affects the quality of sleep • Speech-related parameters (mood assessment) • Extraction of high-level person-tailored norms/patterns, e.g. duration/frequency of certain activities	• high moving intensity • various statistical values regarding deviations from norms, such as mean total duration of each activity, mean number of repetitions, etc. • sleep-related problems, e.g. large number of sleep interruptions, short sleep duration, etc. • Reoccurring problems, e.g. problems that occur more than three days within a week • High stress/anxiety levels

2.2.1 System Usage

Regarding its usage, the system is largely based on web technologies to centrally accumulate data from deployed sensors. The Dem@Nursing application is always accessible from the web allowing the clinician:

i. To upload and process patient data remotely e.g. during on-site visits or his home and office, using the Dashboard view

ii. To monitor and review detailed and aggregated observations and their emerging patterns, via the Trends view

As the selected sensors in the nursing home framework, accumulate files offline, those files have to be collected and uploaded to the system for processing. This can be done through the Dashboard view, which is shown on Figure 4, either by technical staff or the clinician or the carer himself, e.g. while visiting the patient at a nursing home. Alternatively, the files can be transferred in any medium to a place with web access e.g. the clinician's office, and uploaded from there.

After uploading files, the user has accumulated a repository of files to processing, at his disposal. Using the Dashboard, any number of files can be chosen, regardless of sensor type, to be then added to a Processing Queue and analyzed in a serial manner. Through this process, internal processing components, as integrated in the Dem@Care system (WP7), retrieve sensor data, translate them in an interoperable format and store them in the system's Knowledge Base (WP5). The Dashboard provides feedback throughout this process, e.g. in cases where one or more files contain errors, keeping the clinician informed and endorsing his confidence to use the system without the help of technical experts.

Similar to processing sensor data, the user may also invoke semantic interpretation from the Dashboard for the automatic detection of problems according to patient profile. This is done by selecting a target period for semantic analysis and the desired thresholds for Problem detection, which may be tailored to each patient, time interval or simply free to experiment with. Currently, those thresholds include:

- "Stress value" threshold (ranging from 0 to 6)
- "Stress in a row" threshold (number of consecutive minutes)
- "Short sleep duration" threshold (in seconds)
- "Number of sleep awakenings" threshold
- "Long sleep latency" threshold (in seconds)
- Days for recurring sleep problems threshold (in days)

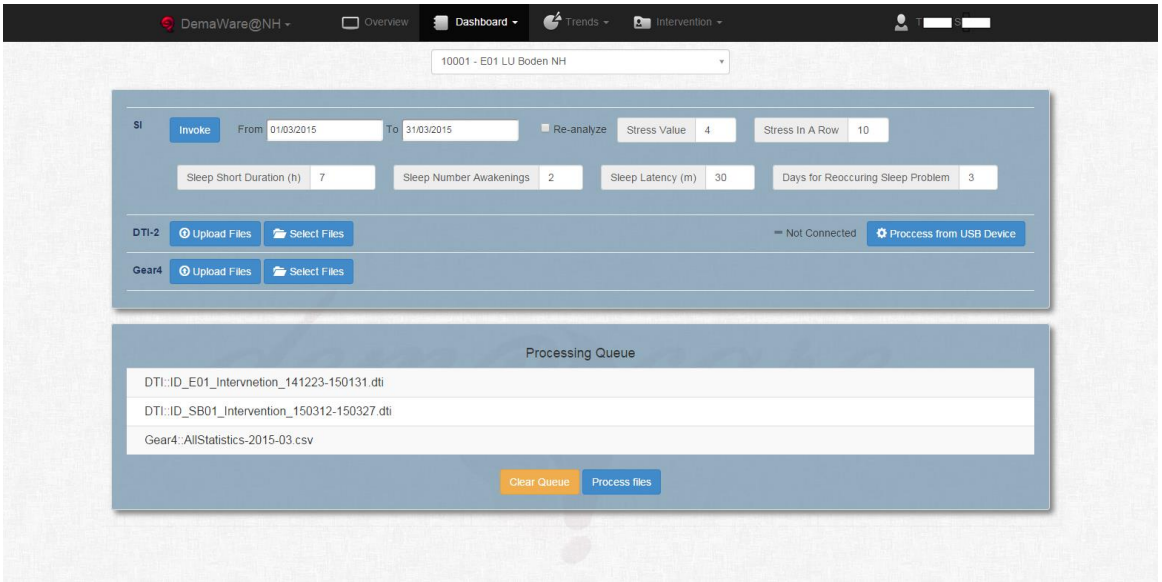


Figure 4. The Dem@Nursing Dashboard, allowing sensor data processing and configurable semantic interpretation.

At any point between or after sensor data processing and semantic analysis, the user may monitor patient conditions via the Trends view, which enables both fine-grained monitoring, at sensor level, and aggregated, longer-term monitoring based on semantic analysis. Especially the latter promotes the detection of pattern-forming behavior i.e. trends in time, and thus timely and precise intervention.

Figure 5 shows the Trends Overview page at a Daily scale. The upper part shows a chart for measurements and activities at daily level. The measurements refer to DTI-2 measured sensor values after processing i.e. the daily sum of Stress Levels and Moving Intensity. The activity chart shows daily totals of activity duration which in this case accounts for total sleep detected by Gear4. So far, the visualizations are useful to observe patterns forming, e.g. periods of excess stress or interupted sleep.

In addition, semantic analysis greatly increases the application's clinical value, by automatically detecting and alarming the user of exceptional and alarming events. As seen on the bottom part of the Trends view in Figure 4, Problems inferred during semantic analysis are visualized on a timeline, next to actual sensor events e.g. NightSleep. This view enables clinicians to quickly locate areas of interest at per minute level without having to review all data. E.g. stress levels have exceeded allowed values around noon on Monday 16th of March 2015, while sleep was problematic, either due to short duration or too many interruptions around that day.

As prompted be the automatic detection of problems, the clinician may still want to view detailed sensor data for that particular time. This can be done from the single day (1-Day) mode of the Trends view. The single day view offers a summary view where all sensor data is shown in per-minute resolution and a comparison view. In the comparison view, the user may select one or more measurements and activity durations in order to compare them. This is done by displaying the values on the same chart as seen on Figure 5. Here, skin conductivity and stress level (based on skin conductance, age and gender – D3.4) are selected, showing their correlation. Most importantly, the user may see in detail the cause and the extent of a particular problem. In the case of Figure 5 we can see that indeed, the patient has experienced high stress levels (value above 3) for the greater part of the day 14th March 2015.

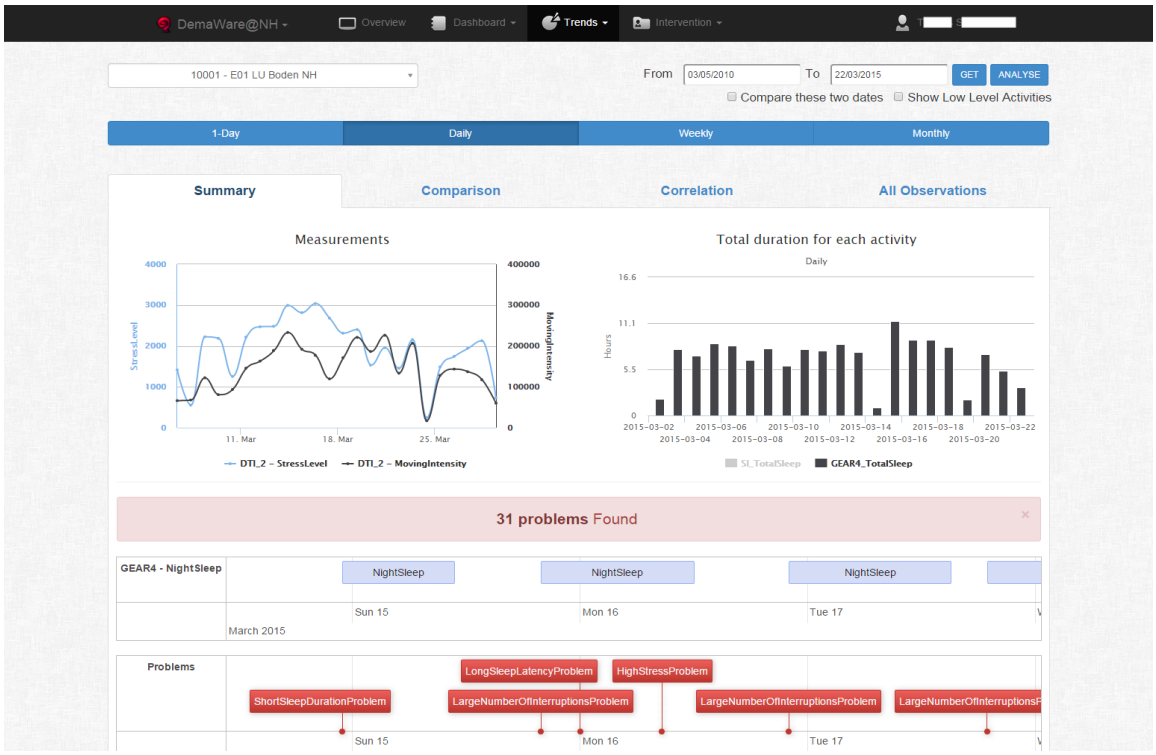


Figure 5. Dem@Nursing Trends Summary view, with showing a digested view of measurements and activities in time, and a timeline of sleep activity, stress and sleep problems.

2.3 Functionality in the Home setting

The primary aim of the Dem@Care system in the home environment is to promote the enablement and the safety of the PwD. This is accomplished via the monitoring of the PwD's daily life and the provision of appropriate feedback to the PwD, the attending clinician and respective carer(s). This requires recognising the PwD behaviour and identifying not just what the PwD is doing but also situations that indicate a problematic behaviour and require feedback support.

Table 7. lists the information that the framework extracts in the home setting based on the sensor observations collected. This translates to recognising the behaviour of the PwD with respect to activities of clinical interest (IADLs) and problems. In addition, the framework supports the calculation of questionnaire scores, the derivation of norms and correlations among different modalities, as well as the visual comparison of behavioural and monitoring parameters.

Table 6. Sensors and modalities in the home setting

Sensor	Modality
GoPro Camera	Objects, Location, Activities
DTI-2, UP24	Moving Intensity
Gear4/Aura	Sleep Monitoring
Microphone	Voice

Plugs	Objects
Tags	Objects
Passive Infra-Red	Location (presence)
IP Camera	Posture, Location, Primitive Event

Table 7. Supported measurements, activities and problems in the home setting

Measurements and Activities	Problems
• Moving intensity monitoring • Sleep monitoring: sleep related activities (sleep episode, bed exit, night bathroom visit, nap, etc.); sleep-related parameters (sleep duration, number of awakenings, etc.); sleep quality • ADLs: prepare the drug box; talk on phone; prepare meal; have breakfast; washing hands, cleaning, ironing, watch TV (TV open). • Correlations between sleep-related problems and physical activity, e.g. when low physical activity affects the quality of sleep • Speech-related parameters (mood assessment) • Extraction of high-level person-tailored norms/patterns, e.g. duration/frequency of certain activities • Questionnaires	• activities with long duration • repeated activities • high moving intensity • various statistical values regarding deviations from norms, such as mean total duration of each activity, mean number of repetitions, etc. • sleep-related problems, e.g. large number of sleep interruptions, short sleep duration, etc. • Reoccurring problems, e.g. problems that occur more than three days within a week

2.3.1 System Usage

Regarding usage, sensor measurements are always uploaded to and accessible from a central repository, either in Dublin or in Thessaloniki. In Dublin, the process is quite similar to nursing home, due to the use of offline sensors, as it uses the Dashboard for remote or local upload. In Thessaloniki, this step is eliminated, as sensors continuously (at most with an hour delay in some cases) stream sensor data into the system. The Dashboard also presents the option to analyse sleep and stress measurements for problems according to personalized configurations per individual and per time interval.

Both pilots are able to access the web interface at all times via the Trends view. This view is available at a daily, weekly, monthly and single day scale. While the former allows long-term pattern observation for problem detection, improvement or deterioration according to intervention logs, the latter allows clinicians to go into further details to pinpoint the causes of certain events. The Trends view is further discriminated into Summary and Comparison. The Summary view shows a digested view of the most critical information, physical activity, sleep, ADLs and problems, which is the same implementation as in Dem@Nursing only with different content. The Comparison view allows dynamically selecting any type of the availa-

ble activities, physical measurements and problems to investigate their correlation for the given time interval.

As the system collects a great deal of information, the clinician is given a few options to either go in-depth or get a long-term overview. Initially the Summary view shows only some measurements either at daily, weekly or monthly scale. The timeline below shows the result of definitive activities after semantic fusion has been performed. Ticking a check-box to "Show low-level activities" takes the user to a higher level of detail by bringing up all activity detection results from visual methods and atomic sensor readings from lifestyle sensors, which were originally composed to form fused activities. This detailed view has many times aided clinicians in Thessaloniki, keeping a detailed log and tailoring interventions according to sleep observations (interruptions, duration, sleep depth), electrical devices (TV, lights), presence in rooms (bathroom visits) and usage of daily objects (medication, vacuum, iron etc). An example is displayed in Figure 7, where low-level activities are displayed along with their combination into fused, complex activities. In this example, switching on the TV and moving the remote (TvOn and TvRemoteMoved) constitute a TV Watching activity. The analysis takes into account interleaving this activity for bathroom visits and preparing the drug box (BathroomPresence, KitchenPresence and DrugCabinetMoved).

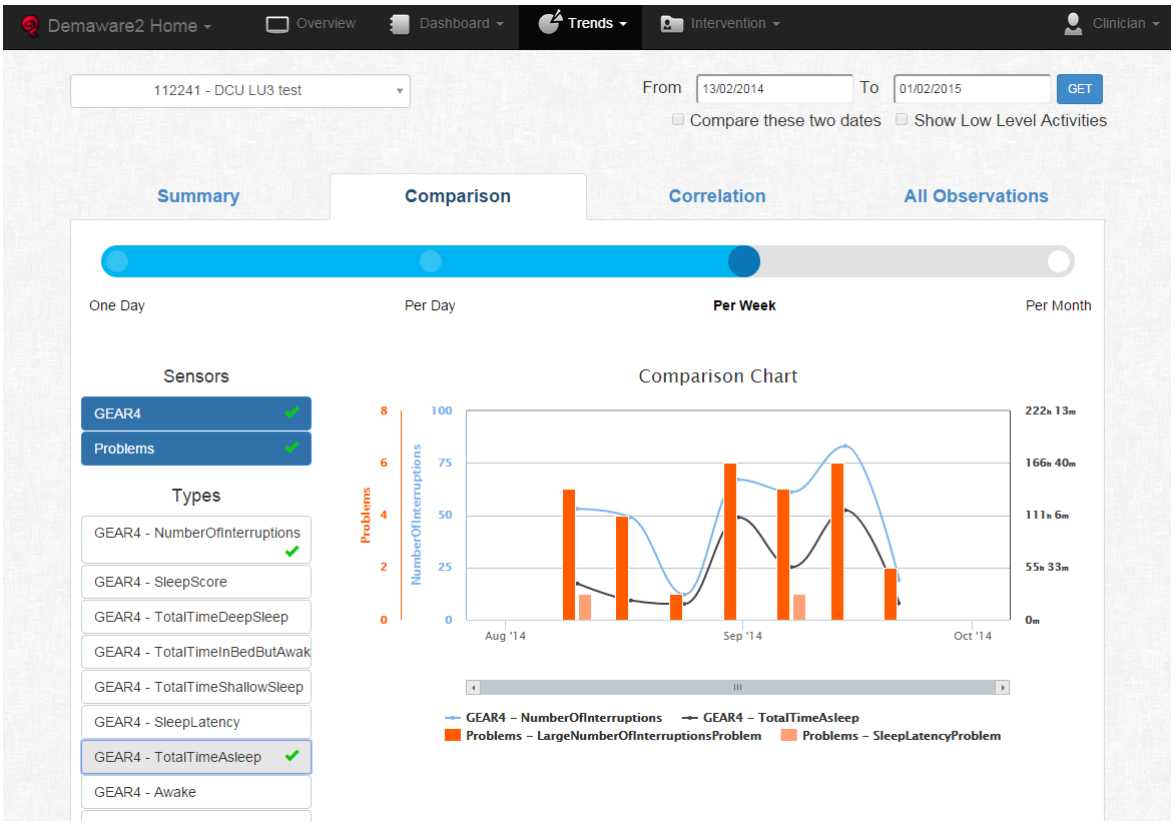


Figure 6. Dem@Home Trends Comparison view, showing a selection of aggregated weekly sleep patterns and problems.

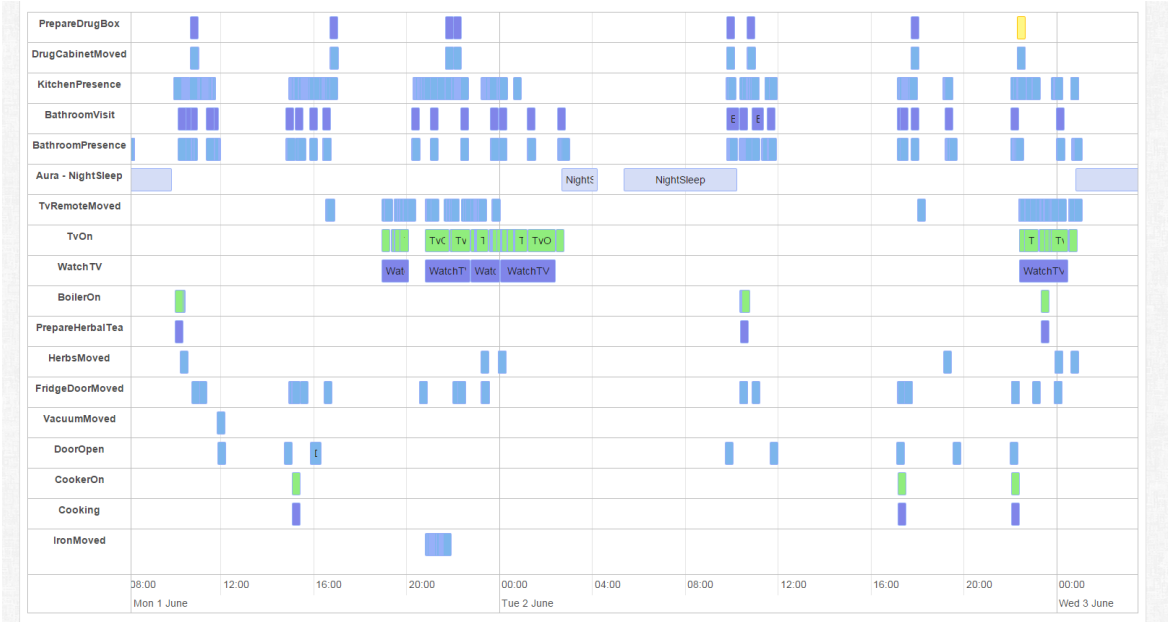


Figure 7. Dem@Home Trends Summary view, showing detailed timeline of all low-level activities (blue and green) together with their fusion into high-level ones (deep purple)

The patient interface is given to participants and their relatives (informal carers) to monitor their life and interact with clinicians in an alternative way. In many cases, participants were not only able but also akin to technology and have enjoyed reviewing their daily measurements. Naturally, only a limited view of the measurements is displayed to avoid overwhelming the users or even stressing them out in case of small irregularities. Educational material such as recipes, nightly routines etc. are included to help guide them step-by-step or even as a pastime. Finally, messages and reminders are exchanged between end-users and clinicians to endorse their daily routine without missing out activities. Figure 8 shows a combined view of message inbox (top) and sensor readings (bottom). Overall, the application has not only helped end-users and carers feel more confident and secure with the system they are using, but also encouraged social interactions between end-users, carers, clinicians and even technicians during installation or calibration visits.

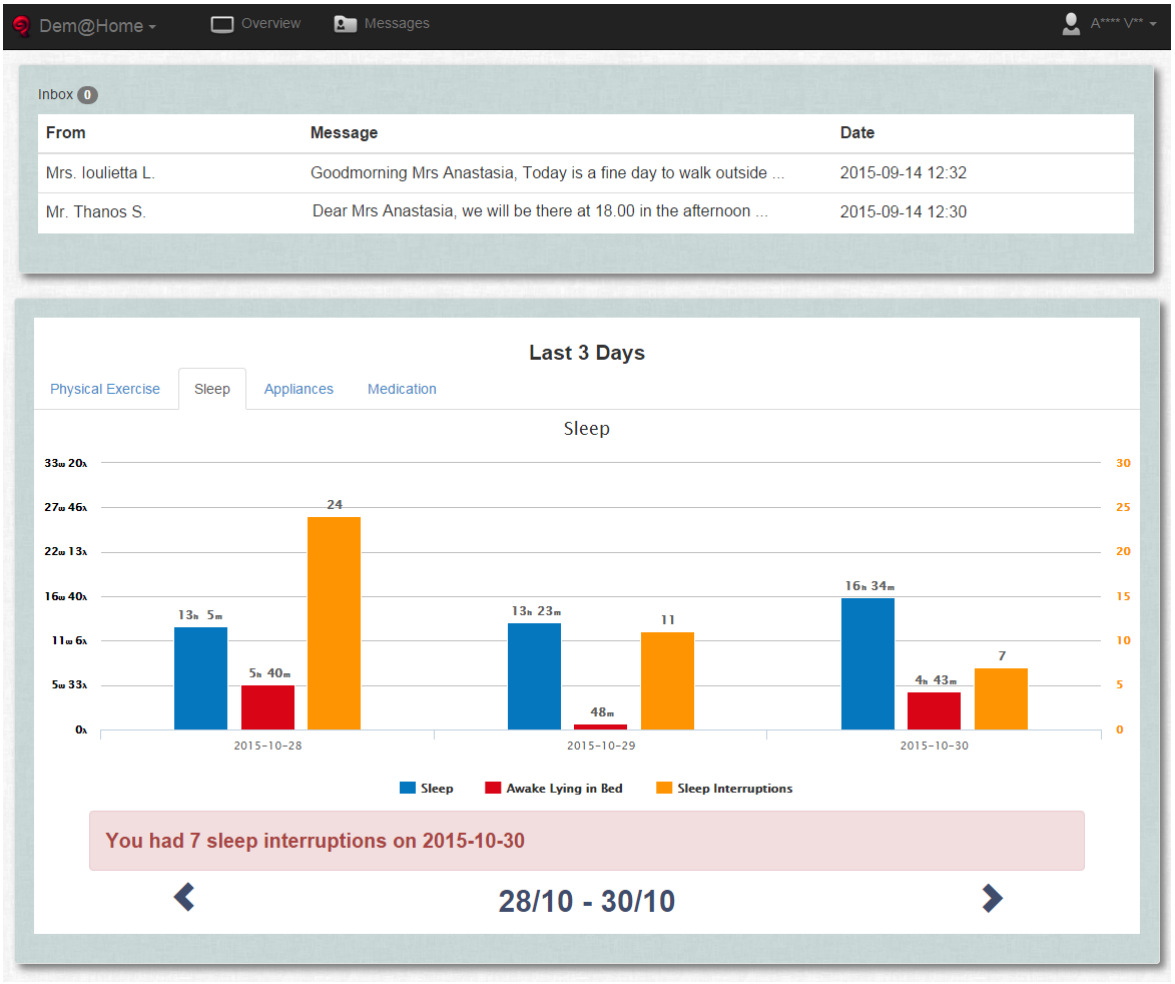


Figure 8. Dem@Home End-User view, showing message exchange (top) and monitoring of selected sleep metrics for the last three days.

3. Main findings of clinical evaluation

This chapter presents the main integrated findings for the three different test contexts, the lab, the nursing home and the home.

3.1 The @Lab evaluation

The described main findings of the @Lab evaluation is an integration of findings from the evaluation conducted in Nice by CHUN and the evaluation conducted in Thessaloniki by CERTH.

3.1.1 Importance for the person with dementia

The results of the @Lab site data analyses are relevant to various stakeholders who are involved in dealing with dementia and related disorders as well as its consequences. First, the outcome of the different studies are of high interest for clinicians working in memory clinics since we tried to demonstrate the additional value of ICT use in clinical practice for routine assessments and this without necessarily increasing the workload. The automatically detected events may serve as clinical decision support for diagnosis and could even further guide the appropriate selection of intervention. Patient's behavioural, cognitive and functional status can be assessed objectively without the presence of the typical observer's biases. The results of this @Lab studies will aid clinicians improving the accuracy of diagnosis and thus, prognosis by increasing knowledge about early indicators of developing progressing towards dementia pathology. As a result, they can better inform patients and their families about risks and what specific actions need to be taken.

Moreover, based on the participants' statements, the simple fact that they use additional, new and innovative methods to help improving assessment and the detection of early dementia-related marker, is very much appreciated by them and perceived as useful and increase the feeling of security/safety in terms of 'what the clinician might not see or hear, the sensors will detect". The patients often state that they feel well taken care of since we use modern technology to improve the work of a clinician.

Moreover, the caregivers who accompanied the participants were open and interested in installing sensors in the room in order to monitor sleep quality but particularly the risk of falling. It was perceived as a relief having the system installed in the room of the resident, so that events may be detected before the patients suffers from significant accidents in their room.

3.1.2 Clinical importance

Currently, the inadequacy of existing methods combined with biased evaluations, points to a need for objective and systematic assessment tools and researchers aim to provide novel solutions. Clinical expertise and literature review indicates that ICT are not yet able to provide a direct diagnosis of AD and related disorders, but can supply additional information for the assessment of specific domains (behaviour, cognition, activity of daily living). This information can contribute with other clinical and biological data to earlier diagnosis of AD and related disorders.

Based on the @Lab data analyses we could show that Dem@Care serves as an additional assessment tool improving the early detection of dementia, thus able to detect fine subtle behavioral changes in the different patient groups. We demonstrated with several sensor analyses studies that it is possible to obtain just based on the sensor-extracted data relatively high accuracy rates to differentiate between healthy, MCI and AD subjects.

In very short time (20') the examination at Lab can discriminate 3 groups with very high accuracy (e.g. in Thessaloniki short protocol, the performance of the groups in each protocol's task was statistically different based on ANOVA analysis). Moreover, people with AD can be easily detected by the system even in early stages of dementia (mild dementia), which is very difficult in other neuropsychological assessments. Furthermore, even though that healthy and MCI people are very close to cognitive scores and functionality (both can live alone) we can see differences also in those 2 groups too. In addition, if we take into account data from lab and neuropsychological assessment we can see that many subscales and tests from the battery are totally correlated with results at Lab (e.g FUCAS, FRSSD, MMSE etc.)

The different studies using the same protocols in both Thessaloniki and Nice, performed were highly innovative and among the first ones that tried to demonstrate the use of ICT-based tools for clinical assessment purposes of dementia patients. The aim was to validate the sensor measurements by associations with classical assessment instruments and accordingly promote a holistic solution for the remote management of people with dementia. From the early beginning on of the project, patients were involved in the co-design process of the multiple sensor-based system, from example by taking into account acceptability of various sensors.

Physiological sensors were deployed to provide measurements that are pertinent to chronic health issues related with dementia, and to activity characteristics that can be indicative of its progression, augmenting the data currently used to evaluate a person's condition.

Audio sensing for cognitive state detection was investigated, focusing on the investigation of new lines of research with regards to the correlation between vocal characteristics and stages of dementia. Speaker identification and audio segmentation strategies were improved, to deal with the challenging problem of recognizing the voice of the person of interest in the presence of background noise or in the midst of other speakers.

Several advances in challenging problems in visual sensing were made to serve the goals and purposes of the Dem@Care system. Video data collected from wearable and static sensors were calibrated and fused to take advantage of their complementary nature. This lead to improved activity recognition performance, thanks to additional localisation information that provides context to the other camera data. Person detection and tracking methods were developed that make use of contextual scene information for accurate person localisation and tracking.

A comprehensive view of the patient's lifestyle, behavioural patterns and daily activities was studied for accurate diagnosis, and for correlating observed behaviours with the different stages of dementia. This will significantly advance the typical clinical workflow for dealing with dementia, which currently involves very subjective and incomplete means of recording, such as questionnaires and diaries.

3.1.3 Assets for future exploitation

The test and evaluation of the Dem@Care system represent a first step in a new innovative approach for diagnosing people with dementia. The exploitation of the findings of the evaluation into regular clinical practice is depended on additional research efforts. In order to receive recognition in the clinical scientific and medical community further tests and validation of the technologies could eventually lead to a change of attitude among general practitioners in using a Dem@Care type of technical solution in routine clinical assessment procedures of diagnosing dementia. Actually the Nice clinical team is partnering with IMB, towards this exact objective focusing on the voice-assisted diagnosis through mobile devices[2]. This includes a 'de-mystification' of ICT usage by showing that it is actually easy and simple to use could increase acceptability. Some important technical progress was achieved with a system, which to a large extend is able to manage, collect, process and visualize the procedure without the presence of a technical expert.

The goal of such a potent ICT system for dementia assessment is to fuse multi-sensory information, to reliably orchestrate the collection process and to analyse and present meaningful assessment information. Initially, data fusion from different sensors and their automatized interpretation towards behaviour recognition is necessary for the complete assessment of a participant's cognitive and functional status. The great deal of hardware (e.g. sensors) and software (e.g. the annotation of the process) involved in a lab trial needs to be manipulated as automatically as possible, relieving the burden of interacting both with the system and a participant. It would also help to speed up the process. Immediate and accurate visualization of the system's results is naturally of great importance in order to support the clinician towards future steps and reassure the participant with feedback and the importance of taking part in such trials.

Dem@Lab, which is presented in section 2.1.1, is a valuable asset emerging from Dem@Care for future exploitation. The system has indeed demonstrated that it's easy-to-use, reliable and accelerates lab trials. @Lab in Thessaloniki has included 158 participants in the course of few months, having only one psychologist handling the system without technical support. Similarly, Nice has accumulated 132 participants in a bit more complex setup (two rooms), handled by a clinician and technician at the same time. Together with performance achievements as an integrated system, its assessment capabilities are also high, as reported in the present and past WP8 deliverables.

Future exploitation of the results of the Dem@Care system is focused on integration, assessment and marketing directions. As piloting continues in clinics, the system evolves to become more adaptable and modular towards an even easier setup, which still involves technical work on-site. As more individuals are included both the models and visualizations are becoming more suitable and meaningful to clinical staff. Finally, the asset will be marketed to match demands and present appealing profit to international clinics. The effort is described in D9.12.

[2] See more in D9.12 exploitation deliverable

3.2 The @Nursing Home evaluation

An important finding of the evaluation of the @Nursing home test of the Dem@Care system with the selected sensors is that there are indications of a potential to contribute to facilitate the process of assessing the situation of the person suffering from BPSD and evaluating care interventions. The Dem@Care system has in the test of the final pilot been integrated with a systematic clinical system used in Sweden for assessing the level of BPSD and evaluating care interventions. The evaluation indicate that the information on behavioural patterns of individuals with BPSD regarding sleep patterns and patterns of stress/anxiety produced by the Dem@Care system can have an added value in this clinical assessment process.

3.2.1 Importance for the person with dementia

An improved system for clinical assessment of BPSD and evaluation of care interventions has the potential of improving the wellbeing of the person suffering from BPSD. This is directly related to the potential of the system to contribute to an improved clinical assessment and evaluation process of care interventions targeting the specific BPSD problems of each person with dementia suffering from BPSD. The evaluation indicate that with the added information from the Dem@Care system more specific care interventions can be introduced that can contribute to minimise the level of BPSD and the duration of the problems. There is much evidence that level of BPSD and duration of the problems is directly related to the wellbeing of the person suffering from it.

3.2.2 Clinical importance

The problem of BPSD is one of the major challenges in the care of people with severe dementia that consumes major resources of the care system. The assessment of the situation of people with BPSD is complex and dependent on many factors as the skills and knowledge of staff and their access to accurate and reliable clinical information. The evaluation indicate that the main contribution of the Dem@Care system in the clinical assessment process is in area of access to reliable and specific clinical information of patterns of sleep and patterns of stress/anxiety. The evaluation indicated that this information contributed to introducing more specific care interventions adjusted to the specific needs of each individual. There is much evidence that relevant and specific care interventions can improve the situation of the person suffering from BPSD considerable. An improved system for assessment and evaluation of care interventions has therefore the potential to have a huge clinical importance.

3.2.3 Assets for future exploitation

The Dem@Nursing asset (presented in section 2.2.1) has emerged through the adaptation of the Dem@Care system to the @NH pilot. This asset holds not only unique modules to handle sensors specific to this scenario, but also targeted interpretation and clinical user interfaces that meet its requirements. Namely, nursing home is a stressful and intense residential environment for long-term monitoring and interventions, while interesting modalities include sleep, stress and physical activity. With the early editions of Dem@Care we noticed how much time it took a clinician to go through all system observations in order to forge a calendar and detect and flag problematic behavior and deterioration. The Dem@Nursing asset has fulfilled these requirements, mainly with tailored interpretation to highlight problems accord-

ing to a clinical patient profile, largely facilitating and boosting a clinician's productivity and effectiveness.

The evaluation of Dem@Nursing indicate that it can provide added clinical value in addressing one of the core problems in the care of people with severe dementia, making it an important assets for future exploitation. The tested approach of using the system in combination with sensors, has proved to work well in the evaluation tests conducted in the nursing home context with people with BPSD. However, the evaluation, so far, has involved a limited number of participants, in a specific nursing home. Therefore, its results are hardly suitable to generalize to the any situation of dementia care in other nursing homes and especially in other European countries. Many factors can influence the use of a multi-sensor system in this clinical context, one of which is that the level of experience of using technologies as sensors in this context may vary as the general maturity of using ICT devices.

As expected, more and larger evaluation studies are needed to show the effectiveness of the system in order to convince potential customers, among caregiving organisations, to invest in an ICT system such as Dem@Nursing. Fortunately, this effort will continue through additional funding, obtained by relevant partners and initiatives, to continue the evaluation of the effectiveness of using the system in this clinical context, which, in turn, will endorse its value for further exploitation. As described in D9.12 exploitation deliverable, LTU in collaboration in CERTH are applying for seed funding in order to continue development and clinical studies in the Nursing Home environment.

3.3 The @Home evaluation

3.3.1 Importance for the person with dementia

For all participants, both PwD and carers, involvement in the Dem@Care project had a positive impact. The Dem@Care system deployed at home allowed an objective assessment of activities of daily living leading to personalised interventions. Daily and detailed monitoring contributed to adapted and even more targeted interventions. In addition, the increased levels of human and social interaction provided to the PwD and carer by the researcher or therapist was an important reason for their enjoyment and perceived benefit of being involved with the project. The idea that they were contributing to future developments in dementia research by being involved was also important to them.

For the main lead user in Dublin pilots (LU2 - Sean), measuring sleep was of particular importance and benefit. Sean experienced difficulty with his sleep and reported poor perceptions of overall sleep quality. The Dem@Care system revealed that this perception was largely driven by his experience of the hours just prior to getting up for the day; this portion of his sleep was often disrupted by his wife Catriona as she got ready to go to work, but that he was sleeping well earlier in the night. The daily feedback of objective sleep data challenged Sean's perceptions and enabled him to build a more accurate picture of his real sleep patterns. It also informed a change in the household routine that had positive benefits for his morning sleep. Many of the participants who took part in the CR intervention felt that overall they had increased their autonomy and they felt more confident in their ability to take care of themselves. These participants also felt that they had learned ways of coping with aspects of life which had been distressing them or had improved their performance on certain everyday activities which had been causing them difficulty (e.g. ability to use a mobile phone or iPad).

With respect to the Thessaloniki pilots, every participant has increased their autonomy and the ability of taking care of themselves. Specifically, our 2 MCI patients after clinician's interventions they became more independent and active. We found improvement in specific ADLs, which had been identified as problematic in the initial assessment from psychometric measures and Dem@Care interface (e.g. less usage of washing machine, vacuum, low scores in FRSSD, FUCAS, IADL and interviews). The evidences from the Dem@Care data are also supported by the participants' statements. More specifically they have mentioned to the clinician that they have been more socially active, optimistic and confident. Also carers have been noticed improvement of their patient as they have been stated to the clinician. Based on their statements, every participant has increased their autonomy and the ability of taking care of themselves. Also carers have been noticed improvement of their patient as they have been stated to the clinician. One of the caregivers mentioned: "I see that my father is getting better! He is more active and walking a lot". The second participant has sleep problems, cognitive functions, such as memory, and gait issues. His caregivers were very anxious about their father's condition. After clinician's interventions carers could see improvements in participant condition, for example, stating to the clinician that he is not forgetting words. The carers used the system (carer interface) twice a day for 5 to 10 minutes each time. They mentioned that the system helped them to identify issues that it would be impossible to know otherwise (e.g TV usage or proper medication routine).

3.3.2 Clinical importance

Clinicians are interested in understanding everyday functioning of individuals to gain insights into difficulties that affect quality of life, and to assist individuals in completing daily activities and maintaining independence. Everyday functioning encompasses a range of daily functional abilities that individuals must complete to live competently and independently such as cooking, managing financial issues, and driving. In addition, deficits and changes in everyday functioning are considered precursors to more serious cognitive problems. Evaluation of the Dem@Care system in private homes indicates that it can provide additional clinical value in the provision of dementia care as it provides an ecosystem of connected devices, systems and services that provides a comprehensive view of the person with dementia's lifestyle, behavioural patterns and daily activities. It identifies potentially problematic areas using individualised problem-detection parameters, and examines these patterns to identify improvement, stasis, and deterioration over time. Dem@Care also provides people with dementia and their families with relevant information about their health, including health education and lifestyle management material. They in turn become more knowledgeable and aware of their health condition, and better equipped to safely assume responsibility for their own self-care. As would be expected different combinations of sensors are most useful depending on the care setting and the clinical needs of the person with dementia, which validates the Dem@Care Toolbox approach to sensor deployment. The expansion of the @Home pilots from Ireland to Greece supports the mobility of @Home protocols to other European countries, albeit on a small scale.

Many factors can influence the use of a multi-sensor system in these clinical contexts. Important issues for future exploitation will be technical performance, robustness, and ease of use of the system. Although general levels of acceptance were good, a number of usability issues were identified that will require technical development before this can be achieved. Improvements are also needed with regard to sensor integration, fusion of data from different

sensors, and presentation of key clinical indicators in clear, accurate, and easily understandable reports. Ease of use will be especially important to the deployment of Dem@Care in a person's home if the use of the sensors and interfaces are to become commonplace, particularly with those who have limited previous experience with technology. Ease of use is also vital to the deployment of Dem@Care in clinical practice as the use of multi-sensor technologies is not as yet fully accepted, nor is it common practice. It is anticipated that more and larger evaluation studies are needed to show the ease of use and effectiveness of the system in order to convince clinicians in caregiving settings to invest in a technical system such as Dem@Care.

By using the relevant interface a clinician can detect early changes in patient's life. He/she knows exactly when the patient did the suggested intervention and can make correlation with other activities at such as sleep or activities of daily living (clean up the house etc). Also based on the semi-structure interviews which are programmed once in a week the patient reveal to the clinician if he/she feels better emotionally, physically or if he/she had noticed any difference in their lives. For instance, regarding the 2 participants from Thessaloniki pilots (1st and 2nd) we can see that after specific interventions their sleep made great improvement. This was detected by the interface but also from clinical interviews too.

Moreover, the participants in Thessaloniki pilots were living alone. They have been examined neurologically and neuropsychological with specific measures in order to see the exact cognitive and emotional condition before and after the specific interventions. After the installation of the system and the specific interventions the clinician discovered that participants improved their cognitive functions, activities of daily living and emotion. They became more aware about their personal issues and problems. There has been noticed improvement in their cognitive functions and sleep. These positive results are mainly based on the Dem@Care system for the following reasons: a) objective and detailed detection of problems or issues that could not be identified through clinical only assessment, b) constant measurements, c) successful personalized interventions based on the a and b and d) direct guidelines from the system to the patient.

3.3.3 Assets for future exploitation

The Dem@Home asset (presented in section 2.3.1) has emerged from the use of Dem@Care at two distinct pilot locations, @Home Dublin and Thessaloniki. As with the previous assets, the system has adapted its analysis modules, analysis and graphical user interfaces to suit clinical needs. The @Home pilot is much alike Nursing Home, gathering data from offline devices for sleep (Gear4) and actigraphy (DTI-2) but with the addition of recognition of daily activities coming from the wearable camera (WCPU). This addition offers much more room for clinical observations at the expense of increased complexity and modules to handle.

On the other hand, the Thessaloniki pilots use an entirely different set of online, proprietary sensors to substitute all modules and even increase the number of modalities. Therefore, it also implements secure authentication protocols for online retrieval (D7.6, D7.7). Still, both setups are utterly endorsed by an interoperable platform with a unified presentation and visualization for clinicians. Dem@Home also supports a simple patient interface and clinician-patient interactions.

Within the Dem@Care system, DCU have developed analytics for identifying recurring patterns of behaviour from sensors, both wearable and ambient, which can track the strength and degradation of these patterns over time. This will help to identify pivotal points where decline in cognitive abilities may occur. By synchronising these pivots points with life-logging data, we will then investigate the possible triggers for this decline with the ultimate aim of understanding lifestyle influences decline and initiating preventative measures where possible. These analytical techniques can also be generalised for use on a wide variety of datasets across many domains; for example, fitness, personal growth, and education.

Regarding future exploitation Dem@Home there are plans for academic exploitation and there are several potential future research paths. DCU plans to focus on fewer vital aspects of daily living that can promote wellness in order to increase benefits to cognitive health and to provide a simpler solution better suited to the home environments encountered in this study. Similarly, CERTH has developed HealthMon, a mobile health sleep and physical activity monitoring application using wearables, in an effort to maximize the system's ease-of-use, deployability and market profit. It also addresses the aspect of real-time feedback in cases of emergencies; a topic that was not addressed yet in the context of long-term monitoring in Dem@Home. Pilots and acceptance studies in people of different ages have been carried out.

The objective measurement of sleep was one of the most successful outcomes from the Dem@Care @Home pilot evaluations. Sleep disturbance is very common in a wide cross section of the community, particularly the elderly and those with mood problems, and it has a notable negative impact on quality of life and cognitive performance. We plan to use three sensors, actigraphy, sleep sensors and light sensors, in order to examine sleep patterns in early dementia. We will investigate how ambient technology retrofitted into the homes of PwD, and recommender decision support systems, may be used to modify the light exposure an individual receives with the overall goal of synchronising the internal body clock with their bio-psycho-social norms. The PwD will be supported throughout by a cloud-based platform and a customised tablet application that informs them of current sleep and activity habits, the lighting profiles instantiated in their home (through a recommender system), and sleep hygiene advice thus ensuring that they develop a sense of ownership of their own sleep health.

4. @Lab evaluation

4.1 Aims and Objectives

The main goal of the @Lab evaluation was to assess whether the Dem@Care system can contribute to conventional assessment methods and procedures for the diagnosis of cognitive and neuropsychiatric symptoms. In addition the ability of people with dementia to perform activities of daily living was also assessed.

The Lab-based pilot was going to be used as a reference site to test Dem@Care technologies and to acquire clinical knowledge about the behaviour of dementia patients and interaction with Information Communication Technologies (ICT). The acquired expertise was used to drive deployment of ICT solutions in terms of usability, functionality and reliability in the Nursing-Home and Home pilots. The lab-based test and evaluation and the research connected to it is primarily concerned with assessment and diagnoses of people with dementia. It was conducted in both Nice by CHUN and Thessaloniki by CERTH and was carried out in specially designed lab environments placed in a clinical context of memory clinics with the same standardised evaluation protocols in both sites.

In order to assess the usability and effectiveness of the Dem@Care system in adding reliable diagnostic information to the existing standardized diagnostic procedure, we compared data from individuals with early stage AD, individuals with MCI, and individuals from a healthy control group. The evaluation was based on gathering data from different sensors, in combination with audio and video data, while participants were performing our clinical protocol. The main focus was on the assessment of the functioning in instrumental activities of daily living and data from conventional clinical assessments. Furthermore, physical and vocal tasks were administered (part 1 of @Lab protocol) providing additional information about the patient's' cognitive state. The evaluation methodologies are selected to answer the specific research questions of each test setting.

Acceptability and usability of the system and related sensor equipment has been tested along the evaluation process with technician, clinicians and patients and part of those results have been published in earlier deliverables as D8.3. Throughout the evaluation process, the system was tested with 280 participants (132 in Nice and 148 in Thessaloniki pilots) and sensor data has been extensively analysed. The process of testing and evaluating in the @Lab sites was a continuous process throughout the project, including enrolling new participants in both Nice and Thessaloniki, resulting in a large collection of sensor data. CHUN and CERTH worked closely with other clinical partners and WP2 to provide feedback from functional requirement, acceptability, and usability testing. Close collaboration also continued with each of the technical partners as part of system installation, testing and deployment.

4.1.1 Specific evaluation questions

- Can the Dem@Care system be used to differentiate between early stage AD and related disorders from patients with mild to moderate stages of the disease and healthy elderly?
- Can the Dem@Care system assess the impact of behavioural disturbances, in particular apathy, and the completion of instrumental activities of daily living?

- Can the Dem@Care system assess the impact of cognitive decline based on speech and vocal characteristics?
- Can the Dem@Care system obtain data using actigraphy coupled with an audio-video setting that is comparable to data obtained with a conventional examination in the assessment of cognitive and neuropsychiatric symptoms of dementia?
- What is the acceptability among participants of using the Dem@Care system during standard consultation in a memory centre?
- What is the acceptability of introducing a follow-up monitoring system based on the use of ICT within participants' own homes?

4.1.2 Objectives of the final evaluation

After the successful testing of several sensors for assessment support in @Lab in Nice setting, for the final evaluation the objective was to verify if the Dem@Care system tested in one site with the same protocol be successfully transferred and implemented into another clinical site and obtain similar results? For this, the in Nice by the CHUN developed @Lab protocol (first the long version of 10 activities and later the shorter version of only four activities of daily living) was introduced in a clinical setting in Thessaloniki in Greece. The positive obtained results will be presented in the next paragraphs.

4.2 Thessaloniki long protocol

The Thessaloniki @Lab scenario was the same as the Nice scenario with minor changes in each task (e.g. position of the items) and additional sensors. The goals of the protocol are a) to support clinicians in the assessment of autonomy and functionality in daily activities of dementia patients, b) to investigate the accuracy and the effectiveness of the system.

The lab assessment is divided into two steps:

(a) The first step called "Directed Activities" is conducted by a clinician, who details step by step the different activities the participant has to do. This step is divided into two parts. The objectives of the first part are to characterize participants' gait in mono and dual tasks, and to assess the impact of cognitive activity on gait (e.g., walking speed during the walking exercise done in dual task). The second part is based on vocally-directed tasks (e.g. repeating a sentence after the clinician).

(b) The second step called "Semi-directed Activities" consists of assessing the autonomy of the participant. The participant has to correctly perform a list of daily tasks (e.g., using phone, preparing tea) within a timeframe of 15minutes. For this step, the participant is alone in the experimental setting and can refer to the instruction sheet at any time.

The activities for the long protocol are:

- Boil water to Prepare tea
- Make a phone call
- Establish account balance
- Read a magazine

- Turn on the radio
- Water the plant
- Exit the room
- Check the pill box

4.2.1 Installation

In order to evaluate both the protocol and the system, we extended the project's initial set of sensors by integrating Plug and Tag sensors. The Plug sensors monitor the energy usage of each connected device, even in standby mode. Tag sensors monitor and record motion events like door/window open/close events.

In CERTH @Lab scenario, an ambient depth camera is placed to survey the whole room, collecting both image and depth data. The Plug sensors are attached to electronic devices, i.e. the tea kettle and the Radio in this intervention, to collect power consumption data. Tags are attached to each object in the intervention, i.e. the tea cup, kettle, drug-box, watering can, folder of bills and the phone. Consequently, they are able to motion of the objects in space, based on accelerometer values. Plug and Tag sensors are used to detect semi-directed activities, while the camera is used during directed activities as well. Regarding wearable sensors, the intervention employs the DTI-2 sensor which measures moving intensity during directed and semi-directed activities, and a wearable wireless microphone to record the participant's voice during directed activities and vocal tasks.

The activities and the relevant sensors are:

- Boil water to Prepare tea (CAR, motion sensor on the mug, motion sensor on the kettle, plug sensor for the boiler)
- Make a phone call (CAR, motion sensor on the phone and on the paper with the number)
- Establish account balance (CAR, motion sensor on the calculator, on the paper with the amounts and on the paper with the answer)
- Read a magazine (CAR motion sensor on the magazine)
- Turn on the radio (CAR, plug sensor for the radio)
- Water the plant (CAR, motion sensor on the watering can)
- Exit the room (CAR, motion sensor on the door)
- Check the pill box

For the tasks that involve more than one sensor (e.g. prepare tea: motion, plug and CAR) the recorded data is semantically interpreted by the SI component (WP5). The SI provides a possibility regarding the task attempt success.

Therefore the following statistical analysis was based on:

- Tasks with one sensor: sensor data
- Tasks with more than one sensors: SI possibility

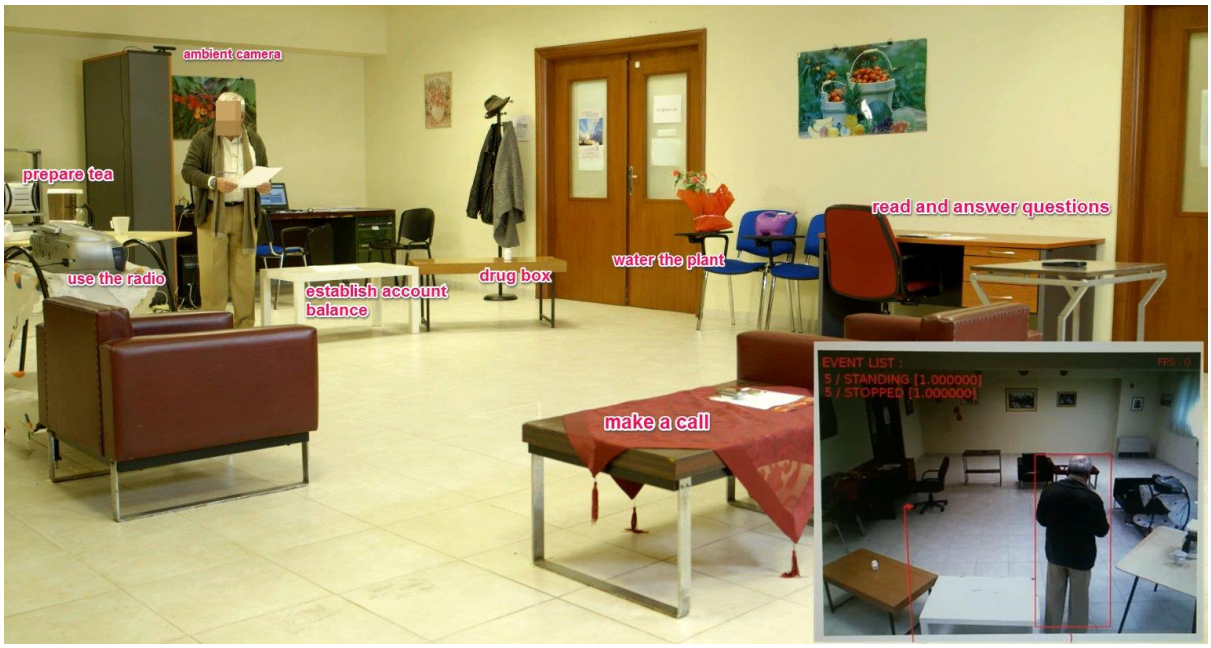


Figure 9. The Thessaloniki long protocol installation

Figure 10. The DTI-2 bracelet and the motion sensor on the mug

4.2.2 Participants

The long protocol experiment in Thessaloniki included 60 participants (28 AD and 32 MCI) aged 60-90. The majority of participants were female (women 42 and men 18) while mean level of education was 7.4 years for AD group and 9.45 for MCI (Table 8). All participants were recruited at the Day Care Center "Agia Eleni" of Greek Alzheimer Association in Thessaloniki, Greece. The diagnosis was given by the neurologist of the day centre. The number of patients who had been diagnosed with dementia was 28 and the number of patients with a

MCI diagnosis was 32. The neuropsychological assessments were conducted by psychologists working in the centre. The diagnosis of AD followed the criteria of the NINCDS-ADRDA and the DSM-IV [1] and the criteria of diagnosing MCI the criteria of Petersen et al. [2]. Each participant gave informed consent before the assessment. The procedure has the approval of the Ethical Committee of the Greek Association of Alzheimer's Disease and Related Disorders.

Table 8. Comparison between patient with MCI and patients with AD

Tests	**MCI (n=28) M(SD)**	**AD (n=32) M(SD)**	**p**
MMSE	27.36 (2.32)	22.93 (4.00)	p<0.001
FRSSD total score	3.49 (2.28)	9.19 (4.28)	p<0.001
FUCAS total score	44.36 (2.41)	53.85 (8.59)	p<0.001
FUCAS understanding	6.00 (0.00)	6.56 (0.75)	p<0.001
FUCAS Memory	6.73 (0.88)	8.63 (1.71)	p<0.001
FUCAS Competence	7.03 (0.98)	9.30 (2.06)	p<0.001
FUCAS Medication	7.39 (0.79)	9.56 (2.06)	p<0.001
FUCAS Communication	8.33 (1.22)	10.26 (2.97)	p<0.001
FUCAS Shopping	7.52 (0.94)	10.22 (3.07)	p<0.001

Cognitive assessment was performed by means of a neuropsychological test battery designed to comprehensively evaluate attention, working memory, memory, executive functioning, and language. In addition to the cognitive assessment, all groups were also assessed for depression with the geriatric depression scale (GDS) [3], which consists of 15 yes or no questions. Moreover, the instruments used to test the cognitive functions of patients on the onset of the program and one year after included the Greek version of Mini Mental State Examination (MMSE) [4], which is a globally used test for general assessment of cognitive functions, The Functional Rating Scale for Dementia (FRSSD) was used to assess the activities of daily living (ADL) (14 activities). The FRSSD collects data from caregivers, and high scores represent severe difficulties in daily functioning. The Functional Cognitive Assessment [5] (FUCAS), was used as a screening tool for dementia, since it examines executive function in instrumental ADL. Data is collected from the patient, and is considered to play a critical role in the diagnosis of dementia.

Table 9. Demographic characteristics of participants

Variables participants	MCI (n=28) M(SD)	AD (n=32) M(SD)	p
Sex	Women 26 Men 6	Women 16 Men 12	p=0.16
Age	72.15 (6.82)	77.15 (6.51)	p=0.12
Education	9.45 (3.50)	7.44 (4.79)	p=0.07

4.2.3 Results

We conducted a Mann–Whitney test to compare the means of the groups' (AD, MCI) performance in lab activities (duration and succeed). We used Mann–Whitney because of the uneven distribution of the sample into the two conditions. Tests of normality (Shapiro–Wilk) showed that the conditions were not normally distributed, while Levene test of homogeneity of variance showed that the assumption of homogeneity has been met. The test examined the possible significant difference of performance between the AD and MCI group, with respect to the total scores of the lab ADL activities. The results showed that performance by the individuals who had been diagnosed with AD had lower number of successful attempts than MCI group in all tests performed.

The results and the differences between the groups are shown in Table 10. The comparison between groups about the duration in every activity was statistical significant with MCI group spending more time to every activity than AD group did.

The results showed that the successful attempts of the individuals who had been diagnosed with AD was worse than MCI group to all tasks: *Total successful attempts* (M^1= 3.4, (SD)=2.41, M^2=6.2 (SD)=1.93), *Make a phone call* (M^1= 0.44 (SD)= 0.58, M^2=0.94, (SD)=0.67), *Water a plant* (M^1= 0.48 (SD)= 0.51, M^2=0.85, (SD)=0.36), *Boil water to prepare tea* (M^1= 0.18 (SD)= 0.40, M^2=0.42, (SD)=0.50), *Turn on the radio* (M^1= 0.03 (SD)= 0.19, M^2=0.33, (SD)=0.69), *Read a magazine and write some answers* (M^1= 0.59 (SD)= 0.93, M^2=0.91, (SD)=0.72), *Establish account balance* (M^1= 0.30 (SD)= 0.67, M^2=0.91, (SD)=0.72*), Check the pill box* (M^1= 0.37 (SD)= 0.69, M^2=0.61, (SD)=0.56). However, for *Exit the room* (M^1= 1.04 (SD) = 0.76, M^2=1.24, (SD)=0.83) there were no statistical significant difference.

The comparison between groups about the duration in every activity was statistical significant with MCI group spending more time to every activity than AD group did*: Total successful attempts duration* (M^1= 160.93 (SD) = 187.21, M^2=287.85, (SD)= 180.40), *Boil water to prepare tea attempts duration* (M^1= 7.85 (SD) = 19.50, M^2=18.27, (SD)= 28.64*), Make a phone call duration* (M^1= 24.78 (SD) = 47.30, M^2=33.60, (SD)= 30.62), *Establish account balance duration* (M^1= 32.07 (SD) = 77.11, M^2=58.27, (SD)= 56.47), *Read a magazine Duration* (M^1= 61.33 (SD) = 140.59, M^2=99.18, (SD)= 140.79), *Turn on the radio duration* (M^1= 6.52 (SD) = 33.87, M^2=36.33, (SD)= 116.51), *Water the plant duration* (M^1= 12.33 (SD) = 25.73, M^2=18.45, (SD)= 41.37), *Check the pill box duration* (M^1= 5.74 (SD) = 10.52 , M^2=9.46,

(SD)= 9.93). Only in the duration of the *Exit room* task was no statistical significant difference (M^1= 10.30 (SD) = 8.21, M^2=14.27, (SD) = 10.86).

Table 10. Overview of comparison between AD and MCI in performing instrumental activities.

	Activities (successful attempts)	**AD n=28**	**MCI n=32**	**Mann-Whitney**
1	Total successful attempts	M 3.4 /SD 2.41	M 6.21/SD 1.93	**p<0.001**
2	Total successful attempts duration	M 160.93/SD 187.21	M 287.85/SD 180.40	**p=0.03**
3	Boil water to prepare tea attempts	M 185/SD .40	M .42/SD .50	**p=0.05**
4	Boil water to prepare tea attempts duration	M 7.852/SD19.49	M 18.27/SD 28.64	**p=0.05**
5	Make a phone call	M .444/SD .58	M .94/SD .66	**p<0.001**
6	Make a phone call Duration	M 24.778/SD 47.30	M 33.60/SD 30.62	**p=0.029**
7	Establish account balance	M .30/SD .67	M .91/SD .72	**p<0.001**
8	Establish account balance Duration	M 32.07/SD 77.10	M 58.27/SD 56.47	**p=0.02**
9	Read a magazine	M .593/SD .93	M .91/SD .72	**p=0.04**
10	Read a magazine Duration	M 61.333/SD 140.59	M 99.18/SD 140.79	**p=0.04**
11	Turn on the radio	M .037/SD .193	M .33/SD .69	**p=0.03**
12	Turn on the radio duration	M 6.52/SD 33.87	M 36.33/SD 116.51	**p=0.03**
13	Water the plant	M .48/SD .509	M .85/SD .36	**p=0.03**
14	Water the plant duration	M 12.33/SD 25.73	M 18.45/SD 41.37	**p=0.01**
15	Exit the room	M 1.04/SD .76	M 1.24/SD .83	**p=0.32**
16	Exit the room duration	M 10.30/SD 8.21	M 14.27/SD 10.86	**p=0.14**
17	Check the pill box	M .37/SD .688	M .60/SD .55	**p=0.04**
18	Check the pill box duration	M 5.741/SD 10.52	M 9.45/SD 9.93	**p=0.03**

In addition, we also tested the correlation between the successful activities attempts with a Pearson correlation test. There was a correlation between the two variables: make a phone call and establish of account balance [r=0.33, p=0.01], make a phone call and read a magazine and write some answer [r=0.30, p=0.05] make a phone call and turn on the radio [r=0.298,

p=0.05], establish bill account and water the plant [r=0.29, p=0.05], prepare the pill box and exit the room [r=0.26, p=0.05] (Table 11).

Table 11. Correlation between the activities among MCI and AD (N=60)

Activities (successful attempts)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1. Boil water to Prepare tea	-							
2. Make a phone call	-0.33	-						
3. Establish account balance	-0.02	**0.33****	-					
4. Read a magazine	0.193	**0.307***	0.212	-				
5. Turn on the radio	0.079	**0.298***	-0.11	0.11	-			
6. Water the plant	0.078	0.25	**0.29***	0.11	.12	-		
7. Exit the room	-0.84	0.18	0.18	-0.50	0.09	0.17	-	
8. Check the pill box	0.15	0.06	0.00	0.19	0.05	0.09	**0.26***	-

** Correlation is significant at the 0.05 level (2-tailed).*

***Correlation is significant at the 0.01 level (2-tailed).*

The correlation between the performance of participants in the specific activities in the lab and the neuropsychological tests was also examined. The correlations are shown in

Table 12. We used Pearson correlation to examine our hypothesis. We found that there are strong correlations in several of the examined instrumental activities: *Total score of successful attempts* and MMSE (r= 0.38, p= 0.003), fucas total score (r=- 0.48, p<0.001), frssd total score (-0.37, p=0.003), subscales of fucas test memory (r=-0.43, p=0.001), competence (r=-0.47, p<0.001), medication (r=-0.64, p<0.001), communication (r=-0.29, p= 0.02), shopping (r=-0.35, p=0.007). *Answer Phone* and fucas total score (r=-0.35, p=0.006), frssd total score (r=-0.29, p=0.02), subscales of fucas competence (r=-0.38, p=0.003), medication (r=-0.43, p=0.001), communication (r=-0.29, p=0.02). *Establish Account balance* and MMSE (r=0.34, p=0.008), fucas total score (r=-0.41, p=0.001), frssd total score(r=-0.30, p=0.02), subscales of fucas understanding (r=-0.25, p=0.05), memory (r=-0.43, p=0.001), competence (r=-0.44, p<0.001), medication (r=-0.50, p<0.001), communication (r=-0.35, p =0.007), shopping (r=-0.28, p =0.03). *Read an Article* and ability of taking care of his medication fucas test (r=-0.35, p =0.006). *Water plant* and MMSE (r=0.37, p =0.003), fucas total score (r=-0.39, p=0.002), frssd total score (r=-0.26, p=0.04), subscales of fucas memory (r=-0.36, p =0.005), competence (r=-0.39, p=0.002), medication (r=-0.45, p <0.001), communication (r=-0.28, p=0.03), shopping (r=-0.27, p =0.03).

Table 12. Correlation between the performance in activities among MCI and AD and neuro-psychological tests (N=60)

Activities	**MMSE**	**Subscales of Fucas**						**Fucas total score**	**Frssd total score**
		Understand	Memory	Competence	Medication	Communication	Shopping		
Total successful attempts	**.376****	-.192	**-.434****	**-.474****	**-.640****	**-.288***	**-.346****	**-.483****	**-.373****
1. Boil water to prepare tea	.159	-.174	-.136	-.063	-.176	-.027	-.098	-.109	-.066
2. Make a phone call	.107	.011	-.253	**-.381****	**-.425****	**-.285***	-.235	**-.351****	**-.292***
3.Establish account balance	**.342****	**-.254***	**-.430****	**-.437****	**-.497****	**-.345****	**-.280***	**-.410****	**-.296***
4. Read a magazine	.175	-.054	-.200	-.222	**-.353****	-.131	-.174	-.225	-.188
5. Turn on the radio	.077	-.163	-.173	-.233	-.209	-.110	-.193	-.206	-.097
6. Water the plant	**.374****	-.142	**-.355****	**-.388****	**-.452****	**-.277***	**-.271***	**-.388****	**-.257***
7. Exit the room	.174	-.046	-.095	-.056	-.199	.038	-.047	-.121	-.138
8. Check the pill box	.084	.024	-.075	-.089	-.177	0.000	-.085	-.092	-.096

** Correlation is significant at the 0.05 level (2-tailed).*

***Correlation is significant at the 0.01 level (2-tailed).*

Finally, supervised machine learning was used to separate the MCI from AD participants, based on the sensors' attributes. Sensors' attributes include the number of the activities that the patient performed and how many of them were completed successfully, the duration of each attempt and their averages, leading to a unique multi-dimensional feature vector for each patient. The goal of this experiment was to study if an autonomous system could be build that will be able to predict accurately new patients by using only the sensor's attributes. On this basis, we collected data from 60 patients (i.e. 30 MCI and 30 AD) and split them by 2/3 in order to collect training and test sets. The multi-dimensional vectors and the labels of the training data were used to train a SVM classifier [6] (i.e. a multi-dimensional hyperplane in

the feature vector dimension space) to discriminate the MCI from AD patients. The distance between the test feature vectors and the hyperplane was then computed for each test patient in order to predict the patient belongs to the MCI or AD category and eventually evaluate the overall system. The test was initialized 100 times with random split data, while a 10-fold cross validation was run in order to measure the accuracy of the SVM model.

A multi-dimensional feature vector of 16 attributes was used (time duration and successful attempts of each activity) and resulted in a highly accurate SVM model that achieved 89.15±0.20% mean average accuracy on itself, while test data were predicted with 65.22±0.66% accuracy rate.

4.2.4 Conclusions for the Thessaloniki long protocol

The results of the long protocol pilot study revealed that in general the MCI participants carried out successfully more activities than the AD patients. However, there is one activity with no significant difference between the two groups (activity: exit the room). This can be explained because this activity was the easiest and the most common one and almost every participant was able to accomplish. Also, it is a fact that only a patient in very severe dementia could not find the exit (these patients were excluded from our sample).

Based on the Mann-Whitney analysis and the means of the initial clinical assessment, our research revealed that the sensor-based framework is able to detect and discriminate mild dementia from mild cognitive impairment, which is a very active and interesting research topic. Although it has been proved that the memory deficits observed in individuals with mild dementia, previous studies have also found that individuals with very mild dementia have relatively poor performance in tasks with high attentional demands [7].

Furthermore, our results indicated that there are strong correlations between participant's neuropsychological measurements and their successful attempts during the lab protocol. More specifically, the participants' total successful attempts have strong correlation with their general cognitive function based on their performance in MMSE test, the total scores of FRSSD, the total score of FUCAS and subscales of FUCAS test (such as understanding of the demand, memory, competence, remembering of taking pills, use the phone, make successful shopping). Besides, the participants who couldn't make successfully a phone call have very low scores in total score of FUCAS and in the following subscales: communication, competence and ability of taking and organizing medication. Regarding the establish account balance task, all tests scores indicate that a person who has low cognitive scores in MMSE and worse performance in functionality scales cannot manage to establish successfully an account balance. This result is in line with the financial management issue that is very crucial not only to people suffering from dementia but also for their caregivers too. The assessment of financial capacity may be carried out by professionals, but ideally it should be undertaken using both interview strategies and objective assessment data [8]. Clinical judgment and subjective measurements may prove unreliable if there is no support by objective data [9]. Discrepancies in the clinical judgments of healthcare professionals with respect to patient capacity are also well documented [10]. In our case this is avoided because we measure financial capability objectively via tests such as MMSE, FUCAS, FRSSD and sensor-based system and has been proved that there is strong correlation between these (*Establish Account balance* and MMSE (r=0.34, p=0.008), fucas total score (r=-0.41, p=0.001), frssd total score(r=-0.30, p=0.02), subscales of fucas understanding (r=-0.25, p=0.05), memory (r=-0.43, p=0.001), competence (r=-0.44, p<0.001), medication (r=-0.50, p<0.001), communication (r=-0.35, p =0.007), shopping (r=-

0.28, p =0.03)). Also the fact that people who have low scores in the understanding and memory as is proved from FUCAS and MMSE test is a sign that they cannot remember of understand the instructions of the establishment of account balance.

Our results also show that a person diagnosed with AD cannot establish successfully an account balance, take care of a plant, or prepare a complex activity such as turning on the radio and find the accurate frequency or prepare a tea and make a phone call. These results are close to a recent study [11] which has found the most notable early functional difficulties for the MCI group were evident in the domain of money and self-management.

Our study has shown that the sensors-based system is suitable for assessing functional performance in patients with these conditions. As MCI and AD strongly influence daily activities, this instrument, which helps to recognize functional decline related to motor dysfunction and cognitive impairment, could identify patients' suffering and caregivers' burden. Functional disability has a major impact on quality of life of patients with AD and their caregivers.

The results prove that if the patient is able to prepare a tea then he can be responsible to prepare his own pills too. Also, the ability to answer the phone shows that a patient who cannot manage to make a phone call cannot also establish an account balance read a magazine or an article and write some answers and turn on the radio. Complex activities which include more than one steps overcome activities with executive functions. These outcomes showed that our system is a strong functionality measurement tool and it can be used not only as a screening tool but also as a measurement to determine and predict what a PwD is capable to do.

Another important evidence of our research was that the duration of every activity was higher in MCI patients more than in AD group. This can be explained if we take into account that patient with Alzheimer disease gave up most of the activities and as a result the wasted less time in each of them in contrast with MCI who were trying to complete and remember the instructions during the test.

Finally, based on the SVM analysis, the Dem@Care system is able to predict with more than 89% possibility if a patient is MCI or AD. This experiment showed us that an autonomous system based on machine learning techniques can be built so that we can predict the category of new patients if they have an adequate size of attribute data. This result provides the base for a dementia prediction system that will be able to support efficiently the clinicians during their assessment.

The above positive results indicate that the transfer of the long protocol from Nice to Thessaloniki was not only possible but also very effective both for clinical and research perspective.

4.3 Nice short protocol

In the following, two analyses studies from the @Lab data performed in the last year, as well as a cross-site comparison study of the video data are presented.

4.3.1 DTI-2 data analyses in @Lab setting

This section describes objective measurements of gait parameters in healthy and cognitively impaired elderly using the dual task paradigm.

Alzheimer's Disease (AD) is the most common neurodegenerative disorder and one of the leading causes of death at old age. AD affects different domains of functioning, including

cognitive and motor functioning. Motor functioning involves the integration of various cognitive functions including visuospatial perception, attention, and planning. Deficits in these cognitive functions can therefore affect motor functioning. Subtle changes in motor functioning could be an early indicator of cognitive decline, which suggests that a "motor signature" can be detected in predementia states such as Mild Cognitive Impairment (MCI). The early detection and treatment of MCI represents a major challenge for clinicians resulting in the emerging area of research for useful biomarkers, including motor markers.

The relation between motor activity and dementia has received some research attention over the past years. Studies have shown that compared to healthy elderly, AD patients walk more slowly and have an increased fall risk. More recently, it has been demonstrated that particularly impairments of gait are not only evident early in AD and non-Alzheimer dementias but also predict progression from MCI to dementia. Therefore, it has been proposed that gait analysis, particularly while dual tasking, may represent a new track for the assessment of MCI. The dual task paradigm can be used to study the allocation of attentional resources during a motor task. Dual tasking relies on dividing attention between two distinct tasks, often a motor task such as walking and a cognitively demanding task such as reciting words or calculations. Performing a dual task can reveal latent gait disturbances which are only evident under cognitive stress. Measuring gait under dual task conditions helps to isolate the cognitive control component of locomotion and provides insights into the mechanisms of motor control and possible links to the progression of cognitive impairment. MCI and AD patients typically show more pronounced decrements in gait when performing two tasks simultaneously compared to healthy elderly. In a study including MCI patients, mild AD patients and healthy control subjects, participants were asked to walk 45 meters along a straight corridor. Several parameters such as stride frequency, stride length, symmetry and regularity, and speed of walking were measured during single and dual tasks by means of two accelerometers placed around the participants' waist. During the dual task, AD patients were found to be slower than MCI patients who were found to be slower than healthy controls. Additionally, MCI and mild AD patients showed alterations in other aspects of gait during the dual task compared to the single task which were not found in healthy controls. Other studies that have only included MCI patients and not AD patients have found similar results. Similarly, Beauchet et al. [12] investigated the increase in stride velocity and stride-to-stride variability of stride length in 12 elderly by means of sensors attached to the participants' lower extremities finding that stride velocity and stride-to-stride variability of stride length increased during a dual task condition compared to a single task condition. These findings could be explained by early changes in the motor cortex area that occur early in the course of dementia. Annweiler et al. [13] found that the neurochemistry and volume of the primary motor cortex were associated with gait performance while single and dual tasking in a sample of MCI patients. Stride time variability was mainly sensitive to neuronal function whereas gait velocity was more affected by inflammatory damage and volumetric changes. Together, these findings indicate that changes in walking parameters are specific to MCI and, hence could be used as a specific biomarker of MCI.

Research has only recently started to look into ways to measure the link between cognitive and motor function and to more objectively detect subtle changes that could indicate MCI or progression from MCI to mild AD. The findings described above and other real-time measures of function may offer novel ways of detecting transition phases leading to dementia.

Most studies on gait in MCI and AD patients have employed pressure-point systems, such as GAITRite® System or passive infrared sensors which are not always accessible for all clinical sites. A more practical and low-cost solution for gait analysis is ambulatory actigraphy, which consists of a piezoelectric accelerometer designed to record body locomotor activity. Actigraphy has previously been used in the assessment of various disorders including sleep-wake disorders, hyperactivity disorders and dementia. The present study aims at exploring the relation between gait parameters, measured by means of ambulatory actigraphy during a single and dual task, and cognitive impairment in order to obtain more insights into the utility of such a paradigm as an additional indicator for the diagnosis of MCI and early AD.

Materials and Methods

Participants and Procedure

Participants aged 65 or older were recruited within the Dem@Care protocol at the Nice Memory Research Center located at the Geriatric department of the University Hospital. The sample consisted of 24 individuals diagnosed with MCI, 23 individuals diagnosed with AD and 22 healthy controls (HC). For the AD group, the diagnosis was determined using the proposed diagnostic criteria from Dubois et al. requiring the presence of a progressive episodic memory impairment and biomarker evidence. For the MCI group, patients were diagnosed using the Petersen clinical criteria. In addition, subjects were required to have a mini-mental state examination (MMSE) [4] score higher than 24. Subjects were not included if they had a history of head trauma with loss of consciousness, history of lower limb surgery, arthritis, obesity (BMI higher than 30), concomitant medication including benzodiazepines or antipsychotics, psychotic or aberrant motor activity (tremor, rigidity, Parkinsonism) as defined by the Movement Disorder Society Unified Parkinson Disease Rating Scale in order to control for any possible motor disorders influencing the ability to carry out a walking task. The study was approved by the local ethics committee of the geriatric hospital in Nice and only participants with the capacity to consent to the study were included. Each participant gave informed consent prior to the study.

Assessments and clinical protocol

All participants performed a single walking task (ST) that consisted of walking 10 meters, turning around and walking 10 meters back. Subsequently, all participants performed a dual task (DT) that involved walking the same distance while counting backwards from 305 in steps of 1. During both tasks, participants wore a wrist-worn accelerometer (DTI-2) from which objective measures for walking speed, cadence (i.e. number of steps per minute) and step variance (i.e. variance in time between two consecutive steps) were derived. The accelerometer data were analyzed by determining segments of walking data from the raw signal, and by applying step detection using a step detection algorithm that selects steps based on peaks in the accelerometer magnitude signal using a set of heuristics related to the time between consecutive steps and the amplitudes of the signal peaks.

Neuropsychological measures included the MMSE, Frontal Assessment Battery (FAB), and Trail Making Test (TMT) A and B.

Motion data acquisition and analysis

Gait was measured using DTI-2 containing a 3D-accelerometer and data storage capabilities. The accelerometer was worn by the participants for the duration of the trial, after which the actigraphy data was retrieved from the device by the experimenter. During the trial, the exper-

imenter indicated the start and end of both the single task and dual task condition by pressing an event button on the accelerometer, creating an annotation on the device such that actigraphy data from both tasks could be easily extracted from the recording.

After extracting the actigraphy data, each recording was linked to the participants through a participant ID, and the actigraphy data for the individual single and dual tasks was extracted using the event markers recorded by the device. The actigraphy data for the tasks was then further cleaned by removing any initial and trailing periods of inactivity, caused by e.g. the delay between the creation of the event marker and the commencement of the actual task.

Gait features were then determined algorithmically, using a heuristics-based step detection algorithm. The algorithm involves cleaning the accelerometer signal with a bandpass filter, finding a number of peaks in the filtered signal as potential steps, and creating a selection of the detected peaks which optimizes a set of heuristic rules regarding the peak amplitude and distance to other peaks. From the detected steps, cadence was derived as the number of steps per minute, and step variance as the variance of the time between successive steps. Walking speed was derived as the distance travelled, divided by the time between the first and last step.

Statistical analysis

Statistical analysis was performed using SPSS 23. Analyses included chi-square test, oneway analysis of variance (ANOVA), mixed between-within subjects ANOVA and correlation analyses. Posthoc tests were performed with Bonferroni correction.

Results

Demographics and clinical assessments

The study included a total of 69 participants of which 23 individuals were diagnosed with AD (mean age = 77 years (± 9, MMSE = 17 ± 4.6), 24 individuals were diagnosed with MCI (mean age = 75 ± 9, MMSE = 24.8 ± 3.2) and 22 were healthy controls (mean age = 73 ± 7, MMSE = 28.4 ± 1.5). Demographic information and neuropsychological test results for the three groups are presented in Table 13.

There was no significant difference between the three groups in gender ($X^2(2,67)=3.63$, p=.163) or age (F(2,66)=1.63, p=.204). Information about the MMSE was available for 67 participants. As expected, individuals diagnosed with AD had a lower MMSE (N = 23, mean = 17 (± 4.62)) than individuals diagnosed with MCI and HC, and individuals diagnosed with MCI (N = 24, mean = 24.75 (± 3.18)) had a lower MMSE than HC (N = 20, mean = 28.35 (± 1.5)). All differences were statistically significant (F(2,66)=63.23, p=.000). Information about subscales of the MMSE was available for 47 participants[3]. As can be seen in Table 14, the differences between the HC and MCI are rather small and the differences between the HC and AD seem to be particularly pronounced in the temporal, attention and calculation, and recall sub-scores. A one way ANOVA revealed significant differences for all subscales (orientation in time: F(2,46)=24.47, p=.000; orientation in place: F(2,46)=22.1, p=.000; registration: F(2,46)=4.17, p=.022; attention and calculation: F(2,46)=11.56, p=.000; recall: F(2,46)=23.52, p=.000; language: F(2,46)=9.24, p=.000; complex commands: F(2,45)=7.25, p=.002). Posthoc tests revealed a significant difference between HC and AD (p=.000) and

[3] Information about the MMSE complex commands subscale was only available for 46 participants.

MCI and AD (p=.000) for the orientation in time subtest, between the HC and AD (p=.000) and MCI and AD (p=.000) for the orientation in place subtest, between MCI and AD (p=.033) for the registration subtest, between HC and AD (p=.000) and MCI and AD (p=.008) for the attention and calculation subtest, between HC and MCI (p=.001), between HC and AD (p=.000) and between MCI and AD (p=.003) for the recall subtest, between HC and AD (p=.002) and MCI and AD (p=.002) for the language subtest, and between HC and AD (p=.013) and MCI and AD (p=.003) for the complex commands subtest.

Information about the FAB was available for 55 participants. Post-hoc tests showed that participants diagnosed with AD (N=18, mean=10.89 (± 3.94)) had significantly lower scores on the FAB than individuals diagnosed with MCI (N=20, mean=15.1 (± 1.74), F(2,54)=18.32, p=.000) and HC (N=17, mean=15.94 (± 1.78), F(2,54)=18.32, p=.000).

Table 13. Demographic information and neuropsychological tests for three groups

	Gender (male/female)	**Age**	**MMSE**	**FAB**	**TMT A (in sec)**	**TMT B (in sec)**
HC	5/15	73 (SD=7)	28.35 (SD=1.5)	15.94 (SD=1.78)	45.38 (SD=15.2)	118 (SD=45.7)
MCI	8/16	75 (SD=9)	24.75 (SD=3.18)	15.1 (SD=1.74)	56.4 (SD=19.1)	171.73 (SD=94.78)
AD	12/11	77 (SD=9)	17 (SD=4.62)	10.89 (SD=3.94)	66.58 (SD=37.67)	279.29 (SD=64.05)

Information about the TMT was available for 46 participants for version A and for 39 participants for version B. Information about the TMT A was available for 15 AD patients of whom three took so long that they were not asked to perform version B and who were therefore excluded from the analyses. When excluding these three patients, there was no difference between the three groups in time needed to perform version A of the TMT (F(2,42)=2.58, p=.088). A oneway ANOVA did however find a difference between groups for the TMT B (F(2,37)=12.22, p=.000). Post-hoc tests revealed that AD patients (N=7, mean=279.29 seconds, (± 64.05 second)) needed significantly longer to complete the TMT B than both MCI patients (N=15, mean=171.73 seconds, (± 94.78 seconds), p=.007) and HC (N=16, mean=118 seconds, (± 45.7 seconds), p=.000).

Table 14. Scores on MMSE subscales for three groups

	Orientation in time	**Orientation in place**	**Registration**	**Attention and calculation**	**Recall**	**Language**	**Complex commands**
HC	5 (SD=0)	5 (SD=0)	3 (SD=0)	4.55 (SD=.82)	2.91 (SD=.3)	7.64 (SD=.67)	1 (SD=0)
MCI	4.25 (SD=1.48)	4.25 (SD=.91)	3 (SD=0)	3.35 (SD=1.6)	1.6 (SD=1)	7.45 (SD=.61)	1 (SD=0)
AD	1.94 (SD=1.29)	2.75 (SD=1.18)	2.69 (SD=.6)	1.69 (SD=1.85)	.56 (SD=.96)	6.56 (SD=.89)	.67 (SD=.49)

All participants were slower during the DT than during the ST. Interestingly, there seems to be a steeper increase in walking speed from healthy to MCI than from MCI to AD for both the ST and the DT. A mixed between-within ANOVA found a significant main effect for walking speed (Wilks Lambda=.76, F(1,66)=20.89, p=.000, partial eta squared=.24) with all groups showing a difference in walking speed between the ST and the DT. The difference between groups was significant (F(1,66)=4.24, p=.019, partial eta squared=.114). Posthoc tests revealed that the difference in walking speed between the ST and DT differed between the HC (22.62 (± 3.03) vs. 26.46 (± 6.42)) and the AD group (26.34 (± 5.74) vs. 31.91 (± 7.79), p=.026) with the increase in walking speed from the ST to the DT being greater for the AD patients. Although the increase in walking speed from ST to DT was also greater for MCI (25.88 (± 7.7) vs. 30.95 (± 10)) patients than for HC, the difference between these two groups failed to reach significance (p=.072). No correlations were found between DT duration and neuropsychological measures of aspects of attention such as the MMSE subscale attention and calculation (r = -.19) and the TMT B (r = .294) or measures of motor performance such as the MMSE subscale complex commands (r = -.029).

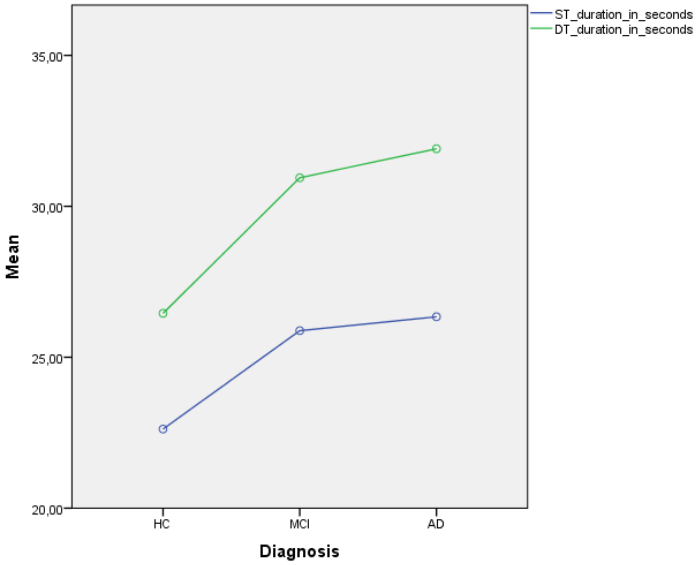


Figure 11. Walking speed during the single walking task (blue) and the dual task walking while counting backwards (green)

All participants had a lower cadence during the DT than the ST. The difference in cadence between the ST and the DT is more pronounced for the MCI and AD patients than for the HC. A mixed between-within ANOVA found a significant main effect for cadence (Wilks Lambda = .57, F(1,66)=50.28, p=.000, partial eta squared = .432) with all groups showing a difference in cadence between the ST and the DT. The difference between groups did not reach statistical significance (F(1,66)=2.89, p=.062, partial eta squared = .081). No or low correlations were found between DT cadence and neuropsychological measures of aspects of attention such as the MMSE subscale attention and calculation (r = .125) and the TMT B (r = -.326) or measures of motor performance such as the MMSE subscale complex commands (r = .037).

HC seem to have a smaller step variance and difference in step variance between ST and DT than MCI and AD patients (see Figure 12). A mixed between-within ANOVA did however not find a significant main effect for step variance (Wilks Lambda = .97, F(1,65)=1.73, p=.193, partial eta squared = .026). There was a significant difference between groups

(F(1,65)=4.2, p=.019, partial eta squared = .115). Posthoc tests revealed that the difference in step variance between the ST and DT differed between the HC (.044 (± .05) vs. .039 (± .054)) and the AD group (.067 (± .07) vs. .102 (± .099), p=.015) with the increase in step variance from the ST to the DT being greater for the AD patients. No or low correlations were found between DT step variance and neuropsychological measures of aspects of attention such as the MMSE subscale attention and calculation (r = -.211) and the TMT B (r = .348) or measures of motor performance such as the MMSE subscale complex commands (r = -.061).

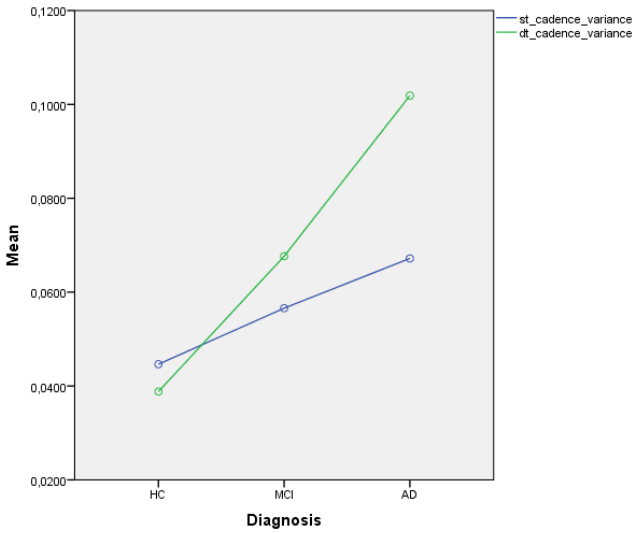


Figure 12. Cadence during the single walking task (blue) and the dual task walking while counting backwards (green)

Table 15. Walking speed, cadence and step variance for three groups

	Walking speed ST (in sec)	**Walking speed DT (in sec)**	**Cadence ST (steps/minute)**	**Cadence DT (steps/minute)**	**Step variance ST**	**Step variance DT**
HC	22.62 (SD=3.03)	26.46 (SD=6.4)	101.57 (SD=12.69)	95.98 (SD=14.03)	.045 (SD=.049)	.039 (SD=.054)
MCI	25.88 (SD=7.7)	30.95 (SD=10)	99.95 (SD=8.99)	87.28 (SD=14.18)	.057 (SD=.045)	.068 (SD=.053)
AD	26.34 (SD=5.75)	31.91 (SD=7.79)	97.19 (SD=11.06)	84.84 (SD=13.44)	.067 (SD=.071)	.102 (SD=.099)

Discussion

The findings of this study add to the growing body of research on the interaction between cognitive function and motor performance and show that there are changes in gait parameters that may help distinguish healthy elderly from elderly with cognitive impairment. These changes were detectable with an actigraph, which seems to be a useful tool combined with the dual task paradigm for gait assessment in clinical practice. As mentioned previously, actigra-

phy has already been proven to be of interest for the evaluation of behavioral symptoms in dementia patients such as apathy or agitation. For example, recently, Valembois et al. [14] assessed the value of wrist actigraphy as a measure of disorder in motor behavior in 183 elderly with dementia with the result that it can be used to record motor activity especially in those with apathy and aberrant motor behaviour. We were interested in the effect of performing a dual task on gait parameters given that dual tasking represents a cognitive challenge since it requests the allocation of attentional resources to concomitant tasks. Although we found differences between the single and dual tasks as well as between healthy elderly and AD patients, it seems that changes in gait induced by simultaneously performing a cognitive task between healthy elderly and individuals with MCI are so subtle that they are difficult to measure at least with actigraphy. The changes may become more salient and, thus easier to detect when patients progress to more severe stages of the disease. This is in line with previous findings. Although significant dual task detriments have been demonstrated in AD, studies on the effects of dual tasking in MCI have not yield conclusive results. For instance, while Maquet et al. [15] found reduced stride frequency and walking speed in MCI patients compared to healthy control subjects, Muir et al. [16] did not find any gait differences between MCI patients and healthy control subject. These inconclusive results may be caused by several factors. First, the distance participants are asked to walk and the cognitive task they are asked to perform during dual tasking differ between studies. Second, the measure used to assess gait parameters as well as the algorithms used to analyze these parameters differ between studies. When it comes to actigraphy, the position of the placed accelerometer can have an important impact on reliability and quality of the measurement. It is known that gait parameters can best be measured by an accelerometer that is attached to the participant's waist, which was the case for the study of Maquet et al. [15]. Consequently, it is possible that the accelerometer on the participants' wrist does not pick up subtle changes in gait parameters and is therefore not sensitive enough for the specific purpose of measuring gait during the performance of a dual task. As mentioned above, research has shown that a wrist-worn accelerometer can reliably distinguish between dementia patients with apathy and aberrant motor behavior and dementia patients who do not show these neuropsychiatric symptoms. An important limitation of our study is therefore the use of a wrist-worn accelerometer. A third explanation is that gait impairments in MCI patients are too small to detect with actigraphy and that the dual task paradigm is not sensitive enough for early MCI screening but rather for more advanced stageS. Even though we did not find significant differences in dual tasking between healthy elderly and MCI patients, we believe that the findings of the present study warrant more research on the interaction between cognitive function and motor performance as an early indicator of cognitive decline. Future research would benefit from using a waits-worn rather than a wrist-worn accelerometer.

In addition, interesting topics for further research on the link between motor function and cognitive function in elderly with cognitive impairment include the relation between dual task performance and an individual's ability to carry out activities of daily living as a measure with higher ecologic validity. Moreover, it would be interesting to further explore the value of using wrist-worn accelerometers in a non-controlled environment to provide continuous information about subtle changes in walking parameters that could be useful to monitor progression of cognitive decline. In non-controlled environments, wrist-worn accelerometers may be preferred as they are more practical and less stigmatizing.

4.3.2 Automatic Speech Analysis for the Assessment of cognitive status

This section describes how a mobile application was used for supporting assessment of cognitive status @Lab.

Constraints on elderly mobility and human resources for elder care have spawned an active area of research in technology to enable remote, automated monitoring. Existing tests to assess cognition in elderly can be administered over the phone and based on previous findings we can state that the non-linguistic features in the speech signal provide important inside as well about a patients cognitive state.

Various types of dementia affect human speech and language and disorders or irregularities in the language domain may be a strong predictor for disease progression. Considering this association, there is reason to explore speech analysis as a mean for early dementia diagnosis. One avenue this article investigates is the analysis of speech by software that takes as input the audio recording from a clinical consultation. In combination with other methodologies such as video monitoring and actigraphy the speech analysis tool has the potential to become a useful non-invasive and simple method for early dementia diagnosis. These technologies enable rapid, accurate and cheap monitoring over time. Non-invasive diagnosis methods also reduce burden on the health care system and improve the possibility of early dementia detection. Therefore, automatic speech analysis provided by a mobile application may be a useful tool in providing additional indicators for assessment and detection of early stage dementia and MCI.

The main goal is to develop an accurate and cost-effective method supporting clinicians in dementia assessment. Based on our previous study results, a mobile application was developed and provided by IBM to standardize the administration of the different vocal tasks and improve the recordings of the patient's voice. The mobile device presents the spoken tasks and records afterwards the patient's voice.

This device allows an easy assessment during a regular clinical consultations for early diagnosis of dementia and its progression monitoring. Furthermore, it may allow in the future self-assessment from home with assistance of family member.

Methods

Healthy elderly subjects (HC), MCI patients and AD patients were recorded with a mobile application while performing several short vocal cognitive tasks during a regular consultation. These tasks included verbal fluency, picture description and counting down. The voice recordings were processed in two steps: in the first step, vocal markers were extracted using speech signal processing techniques; in the second, the vocal markers were tested to assess their 'power' to distinguish between HC, MCI and AD. The second step included training automatic classifiers for detecting MCI and AD, based on machine learning methods, and testing the detection accuracy. Based on previous data collection, the automatic voice analysis software produces a cognitive vocal score ranging from 0-1

Table 16. List of tasks

Name	Characteristics	Origin	Consultation
Sentences repetition	I am going to read you a sentence. Repeat it after me, exactly as I say it	2 from MOCA 1 from MMSE 2 from the present collection	X
Denomination	Step 1: Tell me the name of this animal? (Picture with 3 animals) Step 2: Can you describe me this picture (photography of one of the animal in it natural environment)	MOCA	X
Verbal fluency phonemic	Words beginning with the letter F / In 1 mn The voice analysis will only use the first 30s	MOCA. Also exist with other letters in different batteries	X
Verbal fluency semantic	Names of animal / In 1 mn The voice analysis will only use the first 30s	Classical task used in different batteries	X
Counting backward	From 304 to 285 Possible to change for repeated assessment (eg 405, 605)	Classical executive task used in different batteries	X
Story telling positive	In 1 mn can you tell me something about the first pleasant event coming to your mind (if no response prompt with an example)	Adapted from CERAD and IA interview	X

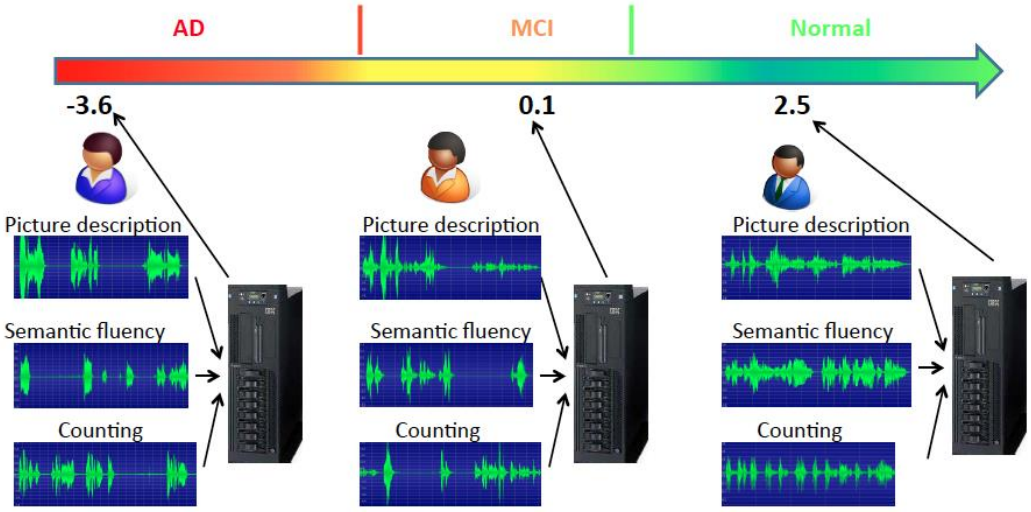


Figure 13. Voice-related protocol tasks @Lab

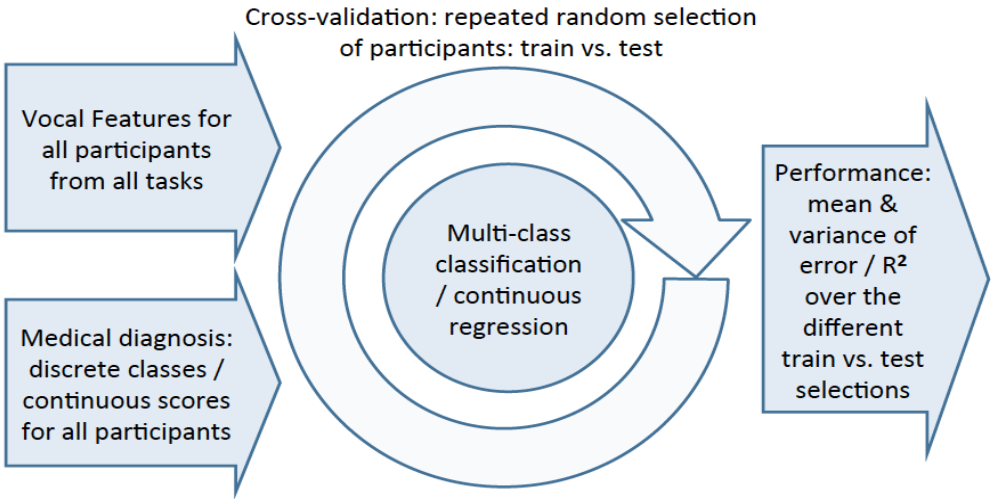


Figure 14. Cross-validation of machine learning results vs diagnosis

Results

Preliminary results show high accuracy rates for the continuous 'cognitive vocal score' which was calculated for each participant within the range of 0 - 1. The fluency and free speech tasks obtain the highest accuracy rates of classifying AD vs. MCI vs. HC. Using the data, we demonstrated classification accuracy as follows: between HC and MCI: 84 ± 4%, between HC and AD: 90 ± 3%, and between MCI and AD: 83 ± 4%.

Insights about the different vocal tasks

Countdown

- Should be continuous with minimal pauses
- The best indicator relates to statistic of silence & non-voiced

Listing (animals and words beginning with F)

- Isolated words, typically in clusters
- The best indicator relates to timing of individual words
- Filtering out irrelevant words (manually) does not improve significantly

Guided speech (describing pictures)

- Should be quite continuous, with a lot of voice
- The best indicator relates to statistic of non-silence & voiced

Free speech (telling a story, recalling what happened)

- Long silence periods are typical, but also a lot of voice
- The best indicator relates to statistic of non-silence & voiced

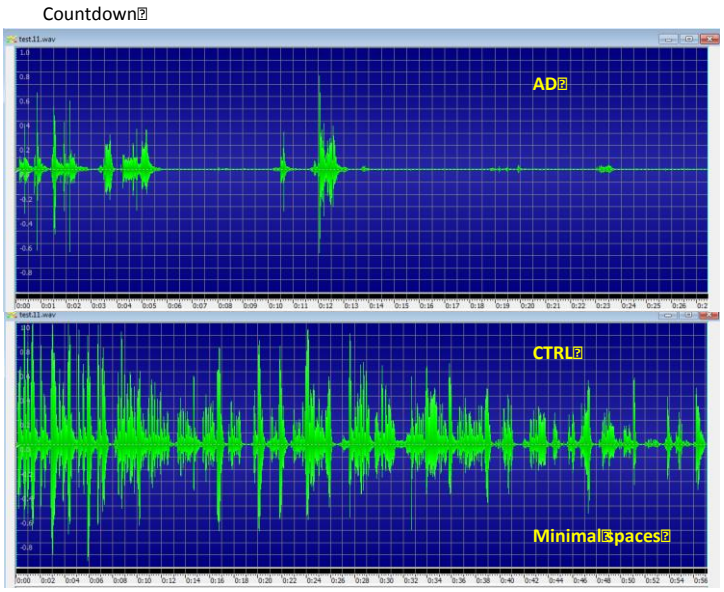


Figure 15. Visualization of countdown task performance - Alzheimer patient vs a healthy control subject

Discussion

Decline in cognitive functioning affects speech production in different ways. Preliminary analysis indicates the potential value of vocal cognitive tasks recorded and analyzed by a mobile application for accurate automatic differentiation between HC, MCI and AD. This can provide the clinician with meaningful information for assessment and early diagnosis purposes, based on non-invasive, simple and low-cost method.

Currently, the inadequacy of existing methods combined with biased evaluations, points to a need for objective and systematic assessment tools and researchers aim to provide novel solutions. Clinical expertise and literature review indicates that ICT are not yet able to provide a direct diagnosis of AD and related disorders, but can supply additional information for the assessment of specific domains (behavior, cognition, activity of daily living). This information can contribute with other clinical and biological data to earlier diagnosis of AD and related disorders. Several studies using ICT in the assessment of different domains show potential benefits of using ICT in clinical practice. It could help identifying earlier individuals that are more likely to develop dementia, clinicians can provide earlier timely care, treatment (pharmacological as non-pharmacological) and support, which will in turn reduce health care costs. Namely, drug research focuses at the moment to target patients at the very early stages of the disease when memory functions are still preserved. This means that the use of ICT could have a direct beneficial effect on the selection of people for the enrolment in clinical trials in the broader population, leading ultimately to a reduction of the total burden for society.

As soon as evaluation tools are available the results should be connected to assessment tools that will determine if the patient requires an assistance system that can provide help and coaching in a personalized way. ICT may be a solution in addressing these challenges by first providing evaluation and monitoring tools, with more objective and more frequent measurements that furthermore can be obtained in almost all contexts. Especially the use of assistance devices in the care of people with dementia may combine the assessment and the assistance dimensions and offers intriguing possibilities to address some of the care needs.

4.3.3 The short protocol

Based on our previously described analyses studies, the @Lab protocol in Nice has been reduced to a shorter version in order to improve its usability in daily clinical practice. The main parts remain the 1. directed tasks (Single and Dual task and a set of vocal tasks recorded for automatic speech analyses) and 2. semi-directed tasks (4 activities of daily living).

Emphasis was further placed in the last year on the improvement of the design of the @Lab interface and the summary report in order to facilitate the regular use of the Dem@Care system in the Memory Clinic in Nice. The idea was to visualise and highlight in a summary report for the clinician in red deviating sensor measurements. In this way, the clinician can immediately detect which behaviour seems abnormal or changed over time. In green, the measurements are visualized that are situated within normal ranges according to either the AD, MCI or healthy subjects group.

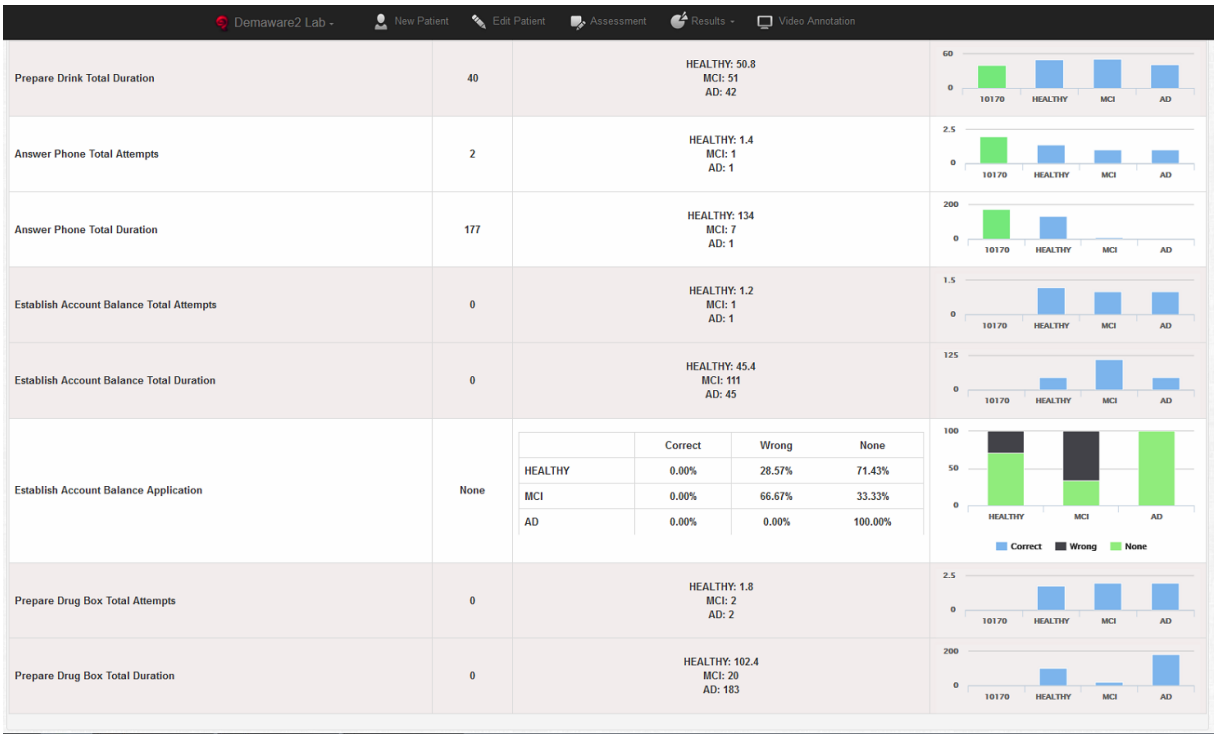


Figure 16. @Lab summary report example

Figure 17. CAR sensor visualization of activities of daily living.

4.4 Thessaloniki short protocol

The Thessaloniki short @Lab protocol settings were the same as the Nice one. In the short protocol the tasks, the distances and the position of the items were identical. As in long protocol, additionally, in Thessaloniki pilots, we used motion and plug sensors.

The lab assessment is divided into two steps:

(a) The first step called "Directed Activities" is conducted by a clinician, who details step by step the different activities the participant has to do. This step is divided into two parts. The objectives of the first part are to characterize participants' gait in mono and dual tasks, and to assess the impact of cognitive activity on gait (e.g., walking speed during the walking exercise done in dual task). The second part is based on vocally-directed tasks (e.g. repeating a sentence after the clinician)

(b) The second step called "Semi-directed Activities" consists of assessing the autonomy of the participant. The participant has to correctly perform a list of daily tasks within a timeframe of 5minutes. For this step, the participant is alone in the experimental setting and can refer to the instruction sheet at any time.

The activities for the long protocol are:

- Prepare tea
- Make a phone call to a specific number
- Establish account balance and transfer money through a tablet device to a specific account
- Prepare drug box following a prescription

4.4.1 Installation

The installation followed the same principles as the long one. The major difference is that in two tasks (Establish account balance and Make a phone call) the participants used two prototype apps. The first one simulated a phone operation and it was used through a smart phone in order to record various elements of the Make a phone call task (e.g. correct number) (Figure 19). The second app simulated a bank transfer account and it was used through a tablet (Figure 20).

The sensors for every activity were:

- Prepare tea (CAR, motion sensors on the kettle, mug, tea box, plug sensor)
- Make a phone call to a specific number (CAR, motion sensor on the phone, phone app)
- Establish account balance and transfer money through a tablet device to a specific account (CAR, motion sensor on the paper, motion sensor on the tablet, bank transfer app)
- Prepare drug box following a prescription (CAR, motion sensor on the three pill box, motion sensor on the drug box)

The following statistical analysis for the short protocol was based on:

- Tasks with one sensor: sensor data
- Tasks with more than one sensors: SI possibility
- Apps data

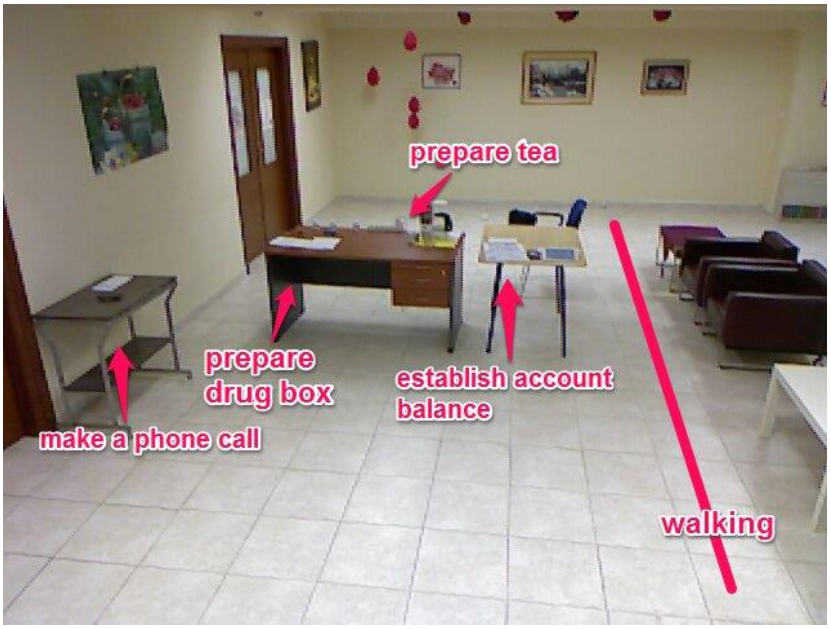


Figure 18. Thessaloniki short protocol installation

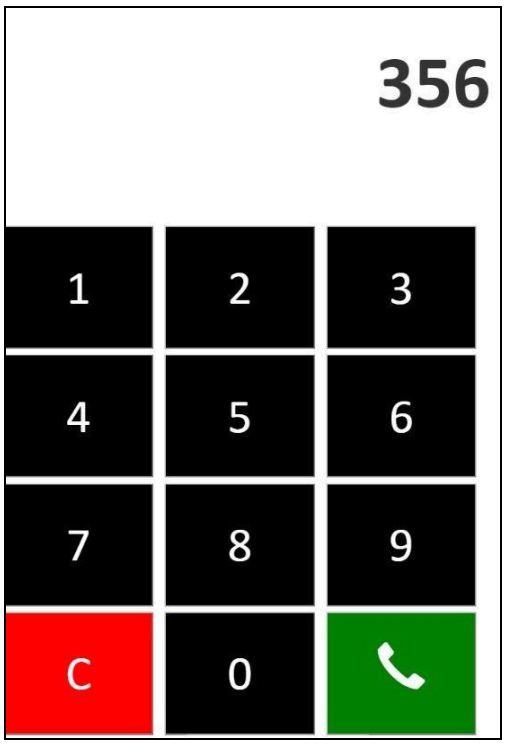


Figure 19. Phone app

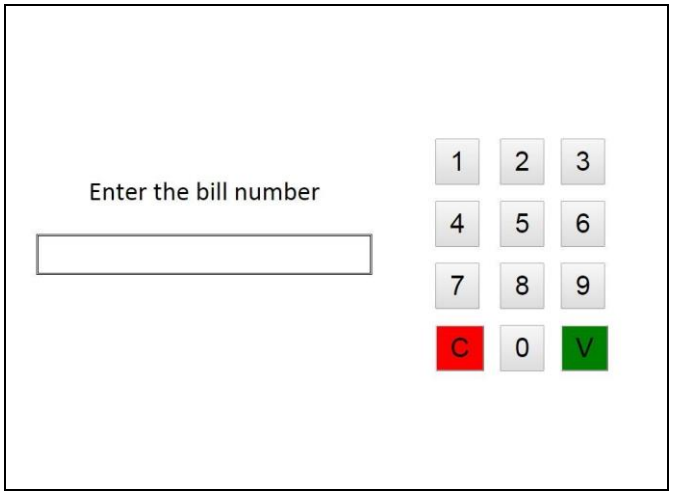


Figure 20. Money transfer app

4.4.2 Participants

The long protocol experiment in Thessaloniki included 98 participants (27 AD, 38 MCI, 33 Healthy) aged 60-90. All participants were recruited at the Day Care Center "Agia Eleni" of Greek Alzheimer Association in Thessaloniki, Greece. The diagnosis was given by the neurologist of the day centre. The neuropsychological assessments were conducted by psychologists working in the centre. The diagnosis of AD followed the criteria of the NINCDS-ADRDA and the DSM-IV [1] and the criteria of diagnosing MCI the criteria of Petersen et al. [17]. Each participant gave informed consent before the assessment. The procedure has the approval of the Ethical Committee of the Greek Association of Alzheimer's Disease and Related Disorders.

Table 17. Comparison between patient with MCI, patients with AD and healthy

	AD		MCI		Healthy		p
	Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation	
MMSE	21.074	4.4021	27.703	1.8539	28.968	1.0796	p<0.001
FRSSD total score	9.815	4.1606	3.919	1.8315	2.323	1.7774	p<0.001
FUCAS total score	57.815	12.9557	44.270	2.0636	42.118	.4777	p<0.001
FUCAS Medication	10.038	2.5057	7.324	.7474	7.065	.3592	p<0.001
FUCAS Telephone	11.962	2.5843	8.027	1.0926	7.065	.3592	p<0.001
FUCAS Shopping	9.654	2.5914	7.486	.9609	7.000	0.0000	p<0.001
FUCAS Transport	10.154	2.8940	7.432	.8347	7.065	.3592	p<0.001
FUCAS Memory	8.923	1.5472	6.595	.7623	6.032	.1796	p<0.001
FUCAS Planning	7.846	1.9533	6.081	.2767	6.000	0.0000	p<0.001
FUCAS Time	7.115	1.5831	6.000	0.0000	6.000	0.0000	p<0.001

Cognitive assessment was performed by means of a neuropsychological test battery which was the same with the long protocol.

The study included a total of 98 participants of which 27 individuals were diagnosed with AD (mean age = 73 years ± 5.8), MMSE = 21 ± 4.4), 38 individuals were diagnosed with MCI (mean age = 70 ± 5.8, MMSE = 27.7 ± 1.85) and 33 were healthy controls (mean age = 65.8 ± 4, MMSE = 28.9 ± 1).

There was no significant difference between the three groups in gender ($X^2(2,67)=3.63$, p=.163), education or age (F(2,66)=1.63, p=.204). Information about the MMSE was available for 98 participants. As expected, individuals diagnosed with AD had a lower MMSE but not in severe stages of dementia (N = 27, mean = 21 (± 4.4)) than individuals diagnosed with MCI and HC, and individuals diagnosed with MCI (N = 38, mean = 27.7 (± 1.85)) had a lower MMSE than HC (N = 33, mean = 28.96 (± 1.07)). All differences were statistically significant (F(2,66)=63.23, p=.000). The differences between the HC and MCI are rather small and the differences between the HC and MCI seem to be only in cognition and memory and not in functionality and activities of everyday living.

Table 18. Demographic characteristics of participants

Variables participants	MCI (n=38) M(SD)	AD (n=27) M(SD)	Healthy (n=33) M(SD)	p
Sex	Women 28 Men 10	Women 22 Men 5	Women 21 Men 12	p=0.16
Age	69.811 (5.8634)	73.333 (6.8219)	65.800 (3.9397)	p=0.00
Education	11.919 (3.9397)	9.926 (4.4021)	12.300 (3.8788)	p=0.07

4.4.3 Results

We conducted an ANOVA test to compare the means of the groups' (AD, MCI, Healthy) performance in lab activities (duration and succeed). The test examined the possible significant difference of performance between the three groups, with respect to the total scores of the lab ADL activities. The analysis revealed statistical significant differences between three groups in all the parameters tested (attempts successful attempts, duration).The level of significance set in a=0.05. We can see that AD group has less total successful attempts in contrast with other groups of HC and MCI (F(7.86)=1.37, p=0.001), the mean duration of attempts is higher than others (F(3.02)=73.7, p=0.05). Also successful attempts in specific activities such as preparation of Hot tea (F(5.41)= 0.22 ,p=0.006), preparation of drug box (F(8.51)= 0.55, p=0.001), make a phone call (F(9.7)= 0.55, p=0.001), successful use of bank application (F(8.9)=0.14, p=0.001), correct insert of the PIN (F(12.6)= 0.74, p=0.001), successful bank amount (F(8.6)=0.74, p=0.001) was worse in AD group in contrast with HC and MCI group. Also HC outperformed MCI group in mean attempts duration (F(3.02)=52.48, p=0.05) , prepare hot tea successful attempts (F(5.41)=0.51, p=0.001), answer phone total duration (F(7.6)=33.3 p=0.001) , Answer phone total successful duration, (F(5.05)=20.93, p=0.008) , bank confirmed successful attempts (F(8.95)=0.75, p=0.001) Bank Amount successful attempts (F(8.6)=0.85, p=0.001), Bank PIN total duration (F(6.8)=9.6, p=0.001), Bank Amount

total successful duration (F(8.6)=4.63, p=0.001) .In other activities no significant changes detected. The results of the ANOVA are shown in Table 19.

Table 19. Overview of comparison between AD, MCI and Healthy in performance

	Activities (successful attempts)	AD n=27 M / SD		MCI n=38 M / SD		Healthy n=33 M / SD		ANOVA
1	Total Suc. Attempts	1.370	1.0057	2.316	.9036	1.970	.9515	**.001**
2	Mean Attempt's Duration	73.7044	56.17061	56.6839	21.75390	52.4858	22.28860	**.053**
3	Mean Suc. Attempt's Duration	111.1352	120.64651	67.1963	24.64532	69.7985	29.66243	**.022**
4	PrepareHotTea Suc. Attemps	.222	.4237	.632	.4889	.515	.5658	**.006**
5	PrepareHotTea Mean Suc. Percentage	.1400	.26691	.4011	.31403	.3018	.31628	**.004**
6	AnswerPhone Total Duration	114.333	141.9651	62.421	39.2873	33.303	31.8546	**.001**
7	AnswerPhone Total Suc. Duration	84.222	131.9269	45.684	44.4541	20.939	33.4915	**.008**
8	EstablishAccountBalance Total Duration	50.074	83.1666	84.921	82.8187	108.394	79.8079	**.026**
9	PrepareDrugBox Total Attemps	2.815	2.0946	1.895	1.1807	2.000	1.0308	**.032**
10	PrepareDrugBox Suc. Attemps	.556	.5774	.921	.2733	.939	.3482	**.000**
11	PrepareDrugBox Total Duration	101.333	80.9544	74.316	32.6754	75.667	29.8304	**.071**
12	PrepareDrugBox Mean Suc. Percentage	.3381	.34099	.6608	.21399	.6670	.22667	**.000**
13	PhoneApp Suc. Attempts	.556	.6980	.763	.6339	1.242	.5607	**.000**
14	PhoneApp Suc. Duration	33.556	64.6977	84.289	105.6542	79.424	90.8065	**.066**
15	BankApp BankConfirmed Suc. Attempts	.148	.4560	.579	.6423	.848	.7550	**.000**
16	BankApp BankCancelled Total Attempts	.148	.4560	.553	.7604	.485	.8337	**.071**
17	BankApp BankAccount Suc. Attempts	.444	.6980	1.132	.9349	1.545	1.0335	**.000**

18	BankApp BankAccount Suc. Dur	4.074	7.4778	27.053	37.9658	28.121	38.0171	**.008**
19	BankApp BankPIN Total Attempts	.741	.9443	1.921	1.1942	2.364	1.4322	**.000**
20	BankApp BankPIN Suc. Attempts	.741	.9443	1.895	1.2256	2.333	1.4720	**.000**
21	BankApp BankPIN Total Dur	2.741	5.5233	11.421	13.0169	9.667	7.2313	**.002**
22	BankApp BankPIN Suc. Dur	2.741	5.5233	11.368	13.0600	9.636	7.2707	**.002**
23	BankApp BankAmount Total Attempts	1.148	1.0635	1.474	.8925	1.636	1.0252	**.004**
24	BankApp BankAmount Suc. Attempts	.741	.9443	1.395	.7181	1.364	.8594	**.000**
25	BankApp BankAmount Suc. Dur	1.000	2.3697	7.474	15.0956	4.636	4.8077	**.038**

In addition we also tested the correlation between the successful activities attempts with a Pearson correlation test. There was a significant positive correlation between the two variables: prepare drug box and prepare tea (r=0.373, p=0.01).

Table 20. Correlation between the activities among MCI and AD (N=60)

Activities (successful attempts)	**1**	**2**	**3**	**4**
1. Prepare Tea	-			
2. Make a phone call	-0.54	-		
3. Establish account balance	0.06	.197	-	
4. Prepare Drug Box	**0.373****	-0.95	0.212	-

** Correlation is significant at the 0.05 level (2-tailed).*

***Correlation is significant at the 0.01 level (2-tailed).*

The correlation between the performance of participants in the specific activities in the lab and the neuropsychological tests was also examined. The correlations are shown in Table 21. We used Pearson correlation to examine our hypothesis.

Table 21. Correlation between the performance in activities among MCI, AD and healthy and neuropsychological tests (N=60)

Activities	**MMSE**	**Subscales of Fucas**							**Fucas total score**	**Frssd total score**
		FUCAS Medication	**FUCAS Telephone**	**FUCAS Shopping**	**FUCAS Transport**	**FUCAS Memory**	**FUCAS Planning**	**FUCAS Time**		
Total successful attempts	.187	-.164	-.117	**-.293****	-.176	-.155	**-.253***	**-.216***	**-.223***	-.143
1. Prepare Tea	.065	-.131	-.012	-.090	-.095	-.021	-.138	-.164	-.108	-.060
2. Make a phone call	.047	.043	-.010	-.155	.007	-.055	-.053	.021	-.002	.047
3. Establish account balance	.080	-.078	-.107	-.076	-.076	-.103	-.062	-.048	-.081	-.131
4. Prepare Drug Box	**.259***	**-.270****	**-.210***	**-.320****	**-.286****	**-.222***	**-.327****	**-.326****	**-.360****	**-.289****

** Correlation is significant at the 0.05 level (2-tailed).*

***Correlation is significant at the 0.01 level (2-tailed).*

After statistical analysis, correlation found between specific neuropsychological tests and specific activities. Moreover, Prepare drug box activity is highly correlated with MMSE total score (r=0.259, p=0.05), FUCAS total score (r= -0.360, p=0.01), Frssd total score (r=-0.289, p=0.01), and subscales of FUCAS [medication (r=-0.270, p=0.01), Telephone (r=-0.210, p=0.01), Shopping (r=-0.320, p=0.01), Transport r=-0.286, p=0.01), Planning (r=-0.327, p=0.01), Time r=-0.326, p=0.01). Furthermore, Total successful attempts is correlated with subscales of FUCAS shopping- financial management (r=-0.293, p=0.01), planning (r=-0.253, p=0.05), Time (r=-0.216, p=0.05) and FUCAS total score (r=-0.223, p=0.05)

Similar to the long protocol experiment, supervised machine learning was used to separate the groups, based on the sensors' attributes. The results are presented in the following table:

Table 22. SVM Analysis on the short protocol results

Type-Comparison	**Results based on sensors**	**Results based on apps**
AD-MCI-HEALTHY	48.75%	48.41%
AD-MCI	68.31%	69.43%
AD-HEALTHY	71.73%	81.13%
MCI-HEALTHY	60.67%	48.61%

4.4.4 Conclusions for the Thessaloniki short protocol

The results of the short protocol pilot study revealed that the healthy participants outperformed the MCI, who outperform the AD participants. Based on the ANOVA test there are statistically significant results in almost every task characteristic. The performance of each group is not random but it is based on their clinical profile.

Nowadays the majority of clinicians use specific neuropsychological tests in order to provide an accurate diagnosis for the patient but also to discriminate prodromal stages of dementia from mild cognitive impairment stages and elders with no memory and cognitive deficits. However, the majority of clinicians argue about scoring of people and even more there is always the issue of subjective assessment. But in our assessment the objective measurement of these patients is a clue for their diagnosis in correlation with their performance in neuropsychological testing. Moreover we applied three specific measurements MMSE, which measures general cognitive status, FUCAS, which is a test which give us information about everyday functionality and activities of daily living applied to the patient and higher ranks indicate severe problem of functionality and FRSSD, which measures functionality in general via specific questions applied to caregivers and higher scores indicate worse functionality. We found that there were strong correlations between these measurements and performance, which indicates the validation and the ability of discrimination of the patient with AD in mild dementia stage, MCI, healthy while their functionality in three groups was also in a mild impairment level in AD group, in good level in MCI and in healthy. These results indicate that even people with mild dementia can be discriminated from patients with mild cognitive impairment and healthy group via a short-time, objective and accurate assessment.

Furthermore, our results indicated that there is a strong correlation between the tasks of prepare tea and prepare drug box. This was an expected result as these two tasks were the most complex ones including various steps.

The ANOVA analysis also revealed the importance of the mobile apps in clinical assessment. These apps can help and support monitoring in cases and tasks that the sensors are not capable to record. The most interesting result is that there are statistically significant results in various steps of the apps usage (for example the correct pin input).

The SVM analysis revealed especially for the apps that it is very difficult to predict between MCI and Healthy participants because they are both capable to use the apps. On the other hand, the sensors seem more sensitive and efficient in order to predict between MCI and Healthy participants. With respect to the MCI-AD and Healthy-AD combinations the results are very positive.

Finally, the short protocol was successfully transferred and implemented in Thessaloniki with very encouraging and significant outcomes.

4.5 Nice -Thessaloniki comparisons

This evaluation focuses on comparing the performance of Dem@Care system at event recognition during the laboratory pilots of Nice and Thessaloniki. It used as basis the complex event recognition component (CAR). Participant data referred to events related to walk task and the four instrumental activities of daily living of the latest version of the experimental protocol of laboratory pilot. Three main evaluations are realized: the analysis of correlations between parameters extracted from automatically recognized events and events obtained from

manual annotation of patient activities; the analysis of differences between the cognitive status of patients according to automatically extracted events; and finally, the analysis of differences in activity performance across different sites of Dem@Care laboratory pilot.

4.5.1 Validation of automatic event recognition system

The first evaluation conducted validates the measurement of the event recognition system compared to ground-truth data, i.e., events observed and annotated by domain experts (e.g., clinicians) per pilot site. In Nice pilot, events annotated by domain experts and event automatically recognized by an event recognition system are statistically correlated in duration with the duration of events manually annotated (Pearson's r, $p < 0.01$; see Figure 21)

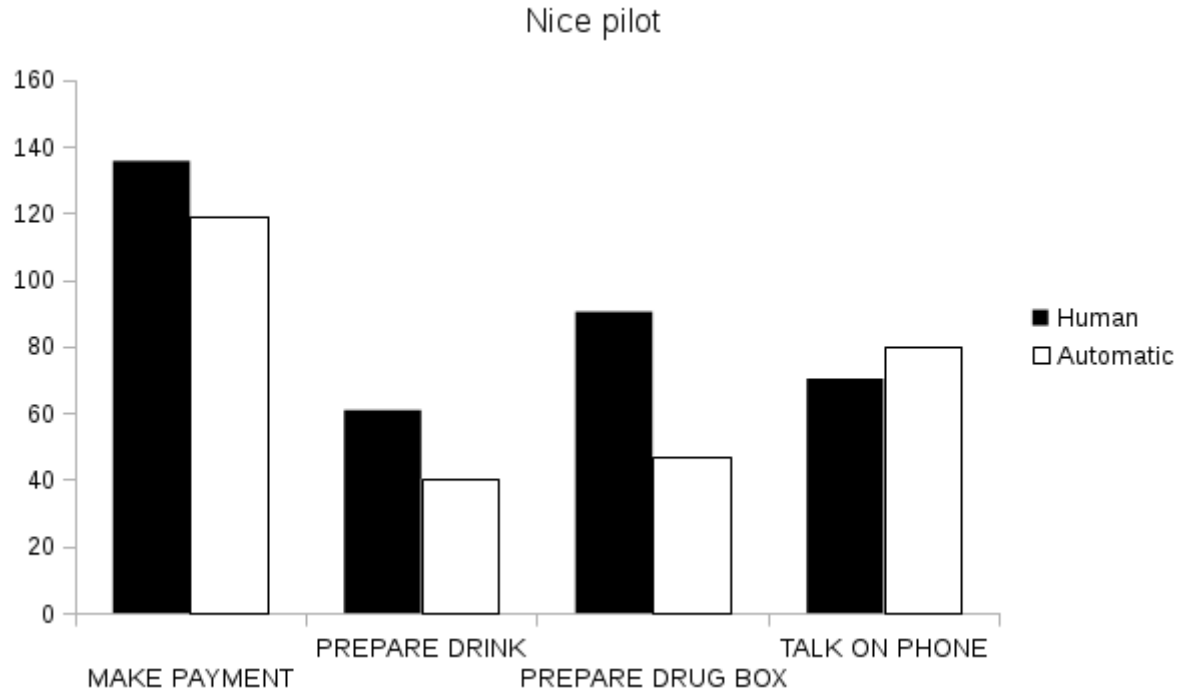


Figure 21.Comparison between the assessed duration (in seconds) of automatically recognized events and ground-truth data in Nice Pilot

In Thessaloniki pilot, automatic event recognition is statistically correlated with annotated events both in frequency and duration for all (Pearson's r, $p<0.01$), with exception for the frequency parameter of prepare drug box and talk on phone events, which are marginally correlated (Figure 22).

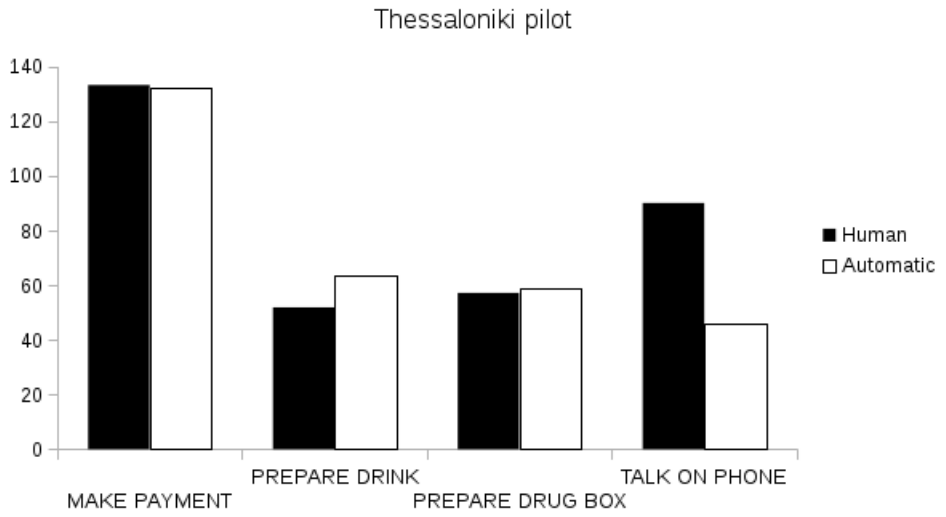


Figure 22. Comparison between the assessed duration (in seconds) of automatically recognized events and ground-truth data in Thessaloniki Pilot

Given these results we may conclude that the automatic event recognition system provides event measurements correlated to events manually annotated by domain experts. We observe that the correlations between manually annotated events and automatically extracted events increase with the number of participants. For instance, the analysis of the short protocol in Nice pilot contains 19 participants and has fewer correlations between extracted event and ground-truth annotations than Thessaloniki event data, which is composed of 74 participants. These differences in correlation number may be seen as human annotator biases that are commonly introduced during event observation and annotation, but become less prominent as the number of participant in the evaluation samples grows larger.

4.5.2 Comparison between cognitive status groups

The second evaluation concentrates on information derived from the activities performed by participants of the laboratory pilots and tests for statistical differences in these activities between different cognitive status classes (Memory Cognitive Impairment – MCI, Alzheimer, and Healthy).

In Nice pilot, no statistically significant differences are found between MCI and healthy participants, neither using human annotations of events (Figure 23) nor automatically recognized events (Figure 24). Since this evaluation focused on the short version of the laboratory protocol, there were not enough participants for a fair comparison between Alzheimer group and the others.

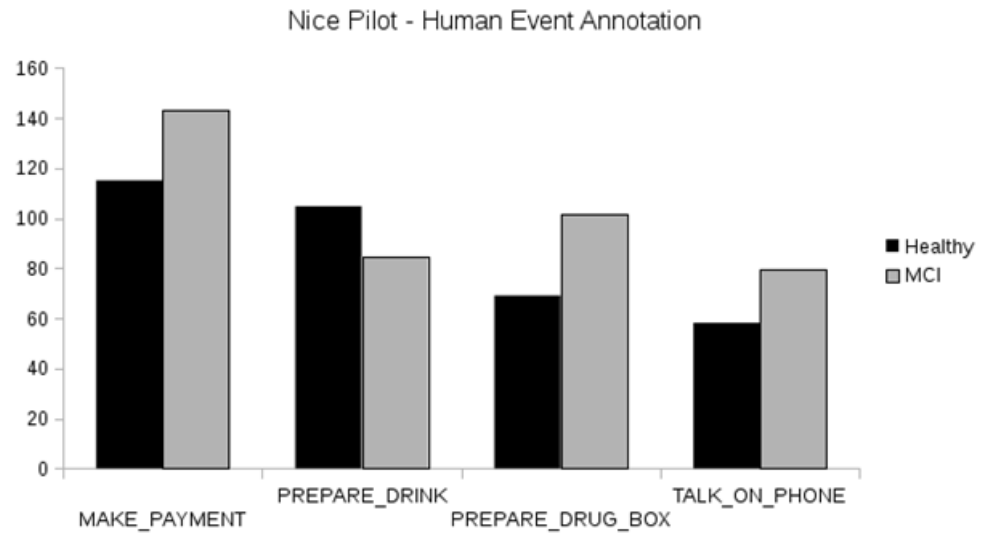


Figure 23. Comparison between the duration of manually annotated events of different cognitive status groups of Nice pilot

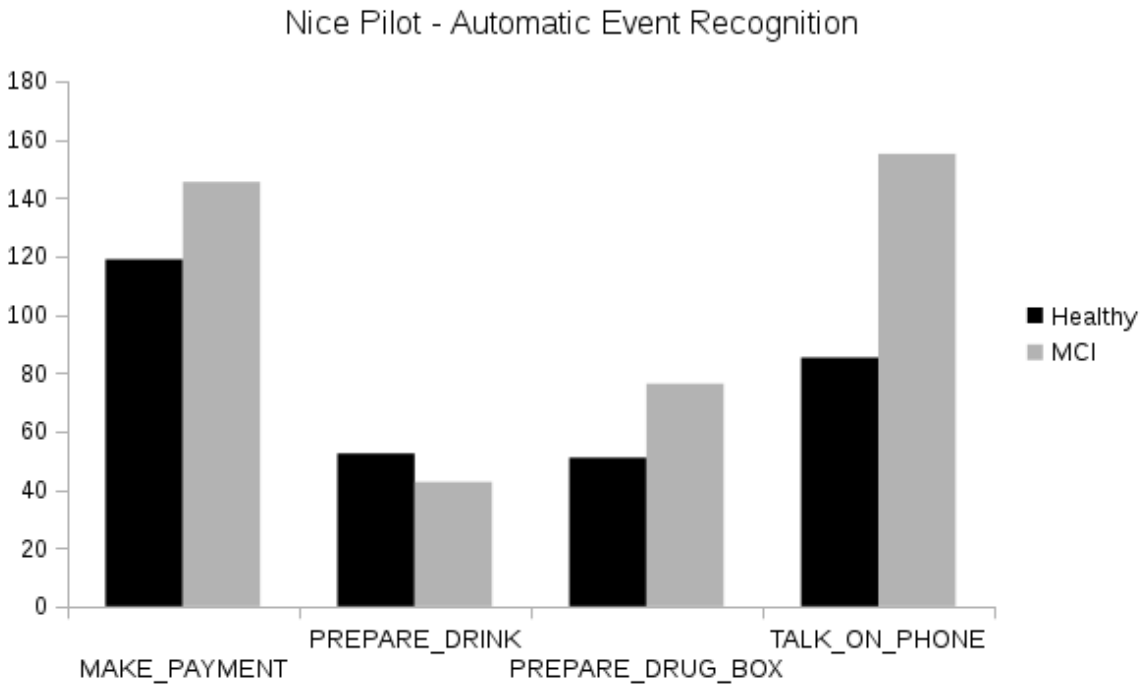


Figure 24. Comparison between the duration (seconds) of automatically recognized events of different cognitive status groups of Nice pilot.

In Thessaloniki pilot, when analyzing events manually annotated by human experts, we observed differences between the duration of activities among cognitive classes for "talk on the telephone" event between healthy and Alzheimer groups, and healthy and MCI groups (one-way ANOVA, $p<0.01$). Differences in the duration of "make payment" events are also ob-

served between healthy and Alzheimer participants, and MCI and Alzheimer participants (one-way ANOVA, $p < 0.01$; see Figure 25).

When using automatically recognized events, we observe statistically significant differences between activities of healthy and MCI groups (frequency of "make payment", duration of "talk on the telephone"; one-way ANOVA, $p<0.05$). Differences in the duration of "make payment" activity are also observed for healthy and Alzheimer participants (ANOVA, $p<0.05$), and MCI and Alzheimer participants ($p< 0.01$). Gait-related events like walk and walking test second attempt also present statistically significant differences between MCI and Alzheimer groups (ANOVA, $p < 0.05$); see Figure 26.

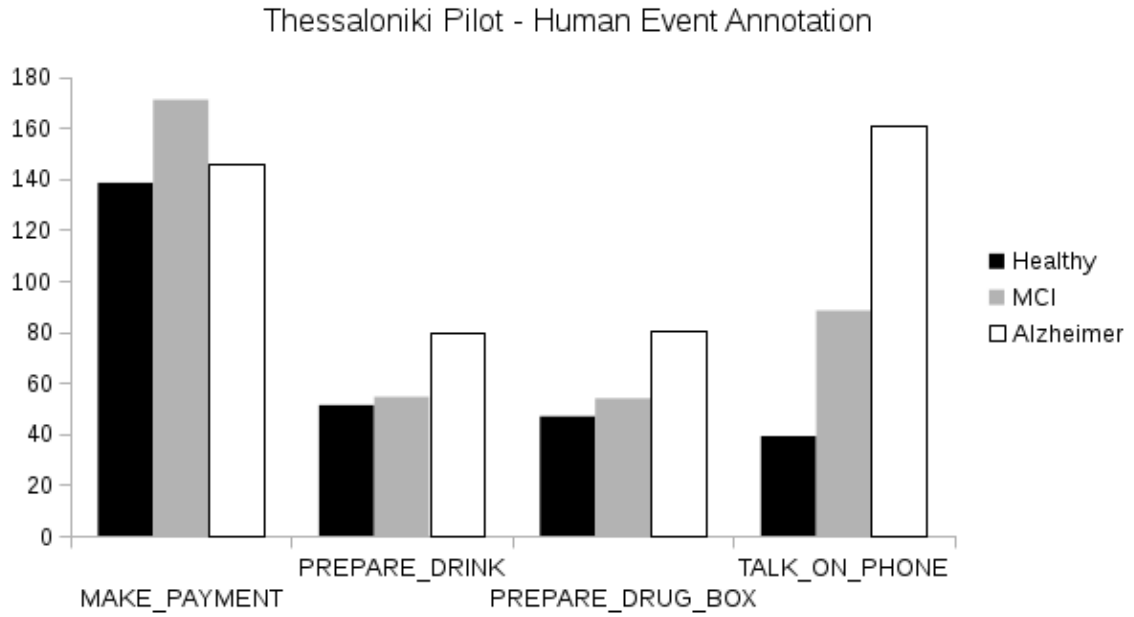


Figure 25. Comparison between the duration of events (seconds) derived from human annotations by cognitive status using Thessaloniki pilot data..

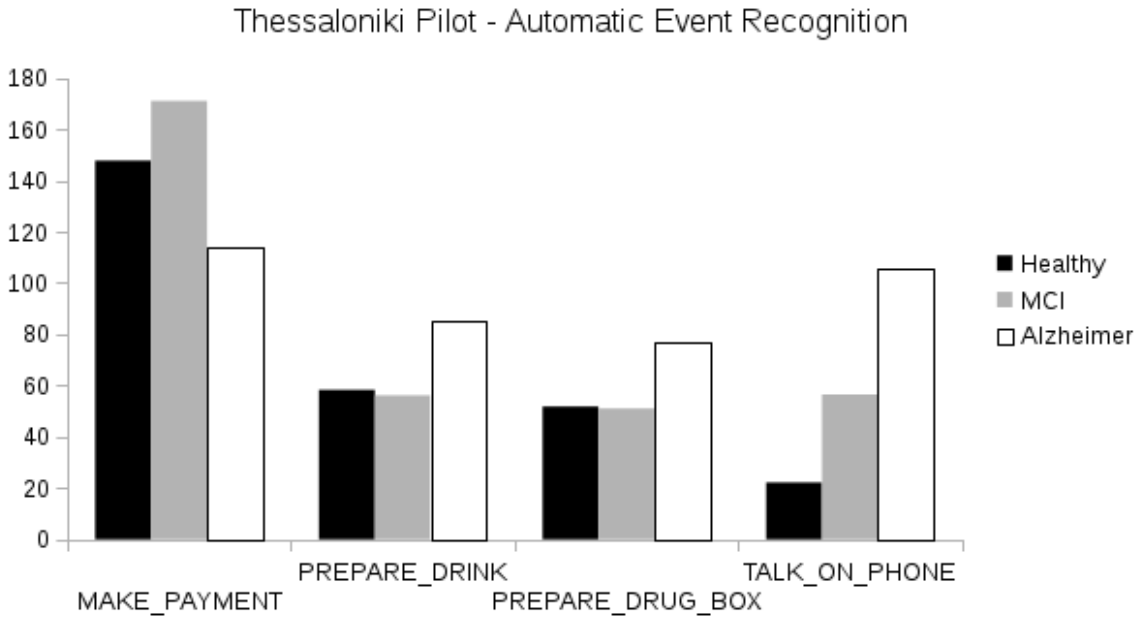


Figure 26. Comparison between the duration (seconds) of activities among cognitive class using automatically recognized events: Thessaloniki pilot.

In summary, we may conclude the event recognition system results are accurate enough to reproduce the trends observed in ground-truth data (*e.g.*, statistical differences in the duration of talk on the telephone and make payment events). Although there are certain events that highlight differences between cognitive classes (*e.g.*, make payment event), there is no single parameter (*e.g., event* frequency) or activity that can discriminate all classes of cognitive status.

4.5.3 Comparison between laboratory pilot sites

In the third evaluation we sought for differences between the activities of patients of different pilot sites (Nice, Thessaloniki) but same cognitive status (Healthy, MCI). For instance, would the healthy groups be different between Nice and Thessaloniki pilot participants? We compare Nice and Thessaloniki participants using the four usual instrumental activities of daily living with manually annotated IADL and the automatic recognition of IADL and gait-related events.

By comparing event information from annotations produced by domain experts, we found statistically significant differences between healthy participants of the two pilots in the frequency of "make payment" event and the duration of "prepare drug box" event (ANOVA, $p< 0.01$ and $p < 0.05$, respectively, Figure 27). Differences in "make payment" events are also observed between MCI groups (ANOVA, $p<0.01$, see Figure 28).

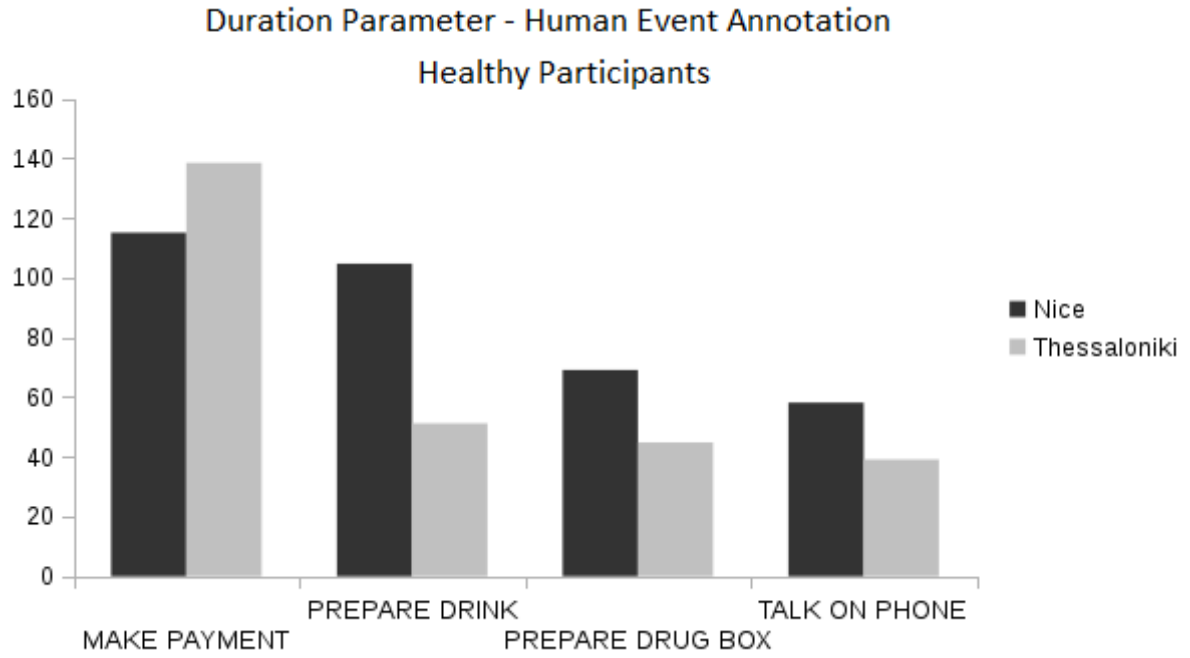


Figure 27. Comparison between Nice and Thessaloniki pilots by the duration (seconds) of events annotated by domain experts from data of healthy participants

When automatic event recognition is used to analyze the performance of pilot participants we found that no statistically significant differences exist between healthy participants of Nice and Thessaloniki pilots (Figure 28) that is also observable in ground-truth data. The differences in event frequency of "make payment" event turned out to be only marginally significant when using automatically extracted information (Figure 29). Nevertheless, there are statistically significant differences between the duration of "talk on the telephone" event (ANOVA, $p<0.01$) both between healthy participant groups and between MCI groups (Figure 30). The latter differences may be a fine pattern not observable before due to the subjective component of manual annotation of events, and will be object of study in further work.

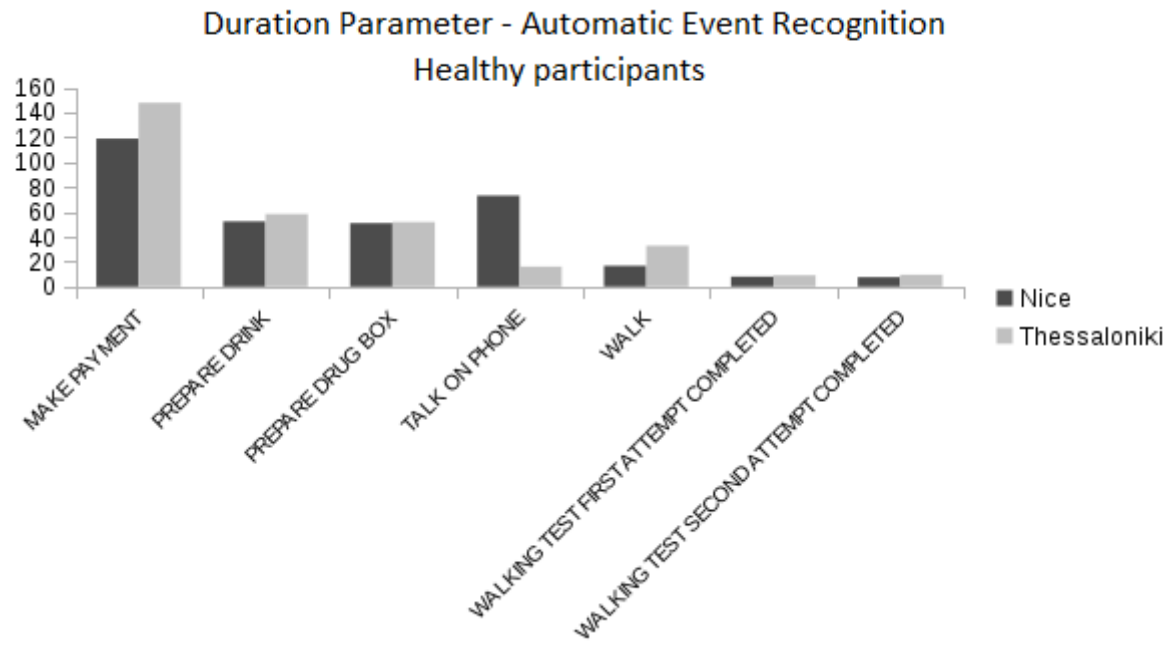


Figure 28. Comparison between Nice and Thessaloniki pilots by the duration (seconds) of events automatically extracted from healthy participant activities

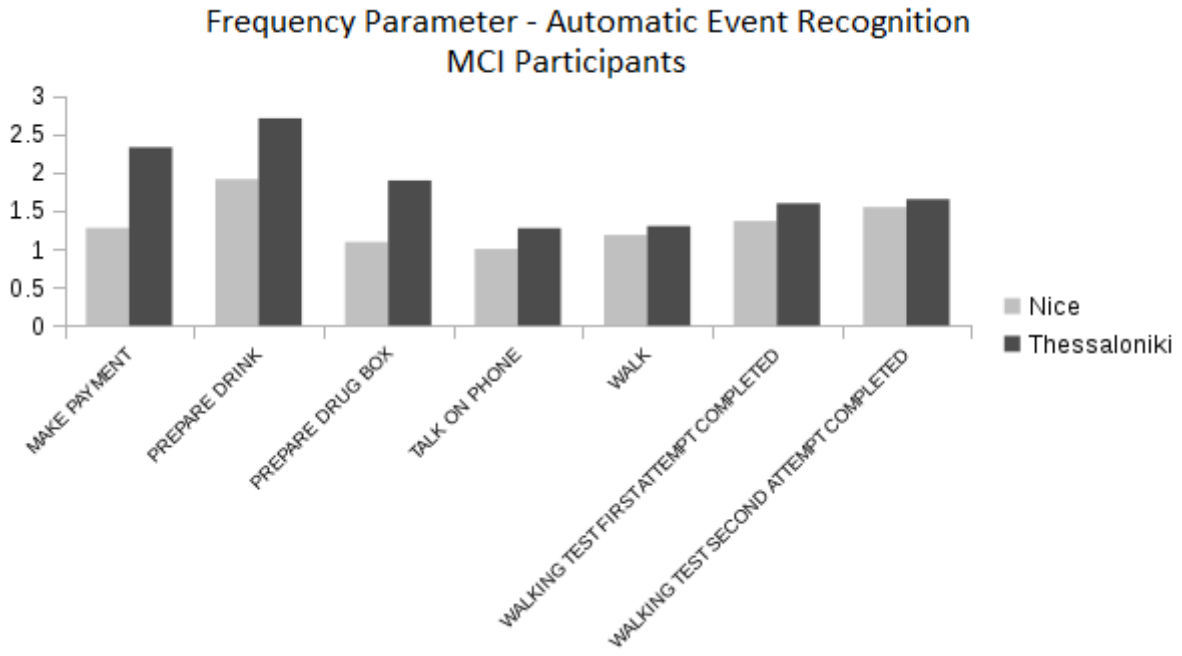


Figure 29. Comparison between Nice and Thessaloniki pilots by the frequency of events automatically extracted MCI participants

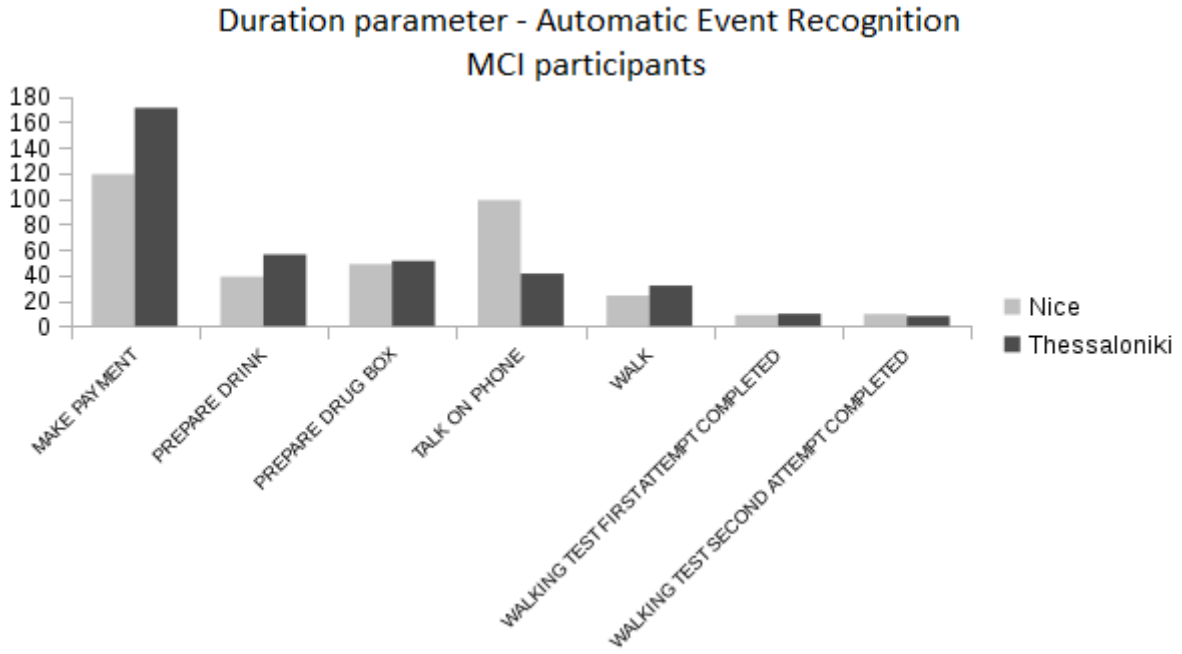


Figure 30. Comparison between Nice and Thessaloniki pilots by the duration (seconds) of events automatically extracted by our event recognition system from MCI participants

4.5.4 Discussion

During this cross-pilot evaluation we firstly demonstrated that the proposed event recognition system provides accurate event recognition data for the analyses of the performance of pilot participants on IADL activities. Therefore, the proposed system permits to obtain objective, patient performance data with relatively less effort than manual annotation of events by human domain experts, and without the common observer biases.

Secondly, we observe that certain activities and derived parameters may discriminate participants from certain groups of cognitive status (make payment event), but no parameter can discriminate all cognitive classes. In this sense, as discussed in Konig et al. [18], more sophisticated models are necessary to model the differences between cognitive status classes (Healthy participants versus MCI; and MCI participants versus Alzheimer's participants) and support clinicians at the objective, assessment of a patient cognitive condition.

Finally, when comparing cognitive status classes between pilots, no statistical differences are found between the profile of activities (duration and frequency) of participants of Thessaloniki and Nice pilots using an objective measurement. The only exception was the duration of "Talk on the telephone" event that emerged as a pattern only visible from automatically extracted data. Further work will investigate these new patterns to verify whether it is a punctual difference on the way this activity is performed or an artefact created by the event recognition system.

5. @Nursing Home evaluation

The @Nursing home evaluation was a continuous process over the time span from the deployment of the first Dem@Care pilot system to the evaluation of the final pilot system. It was carried out in the context of eight nursing homes in Luleå, by LTU and in one nursing home in Nice by CHUN. The evaluation in Luleå had a special focus on the use and function of the system from a clinical perspective of assessing the problems of the residents who suffered from BPSD. The evaluation in Nice had a special focus on testing the CAR sensor for activity recognition. The first part of the evaluation process focused on assessment of usability and usefulness of the system and the tested sensors. It also included validation of the sensor information at the stage when the system could compute and produce accessible reports. The evaluation of the final pilot prototype focused on the assessment of effectiveness of the system to contribute to clinical assessments and evaluation of care interventions for people with dementia suffering from BPSD. The evaluation in all its stages included in Luleå a total of 12 people with dementia, among whom eight had the system deployed. In addition about 46 staff members were at various degrees involved in the different evaluation activities. In Nice, five residents were involved in the testing.

5.1 Aims and objectives

The evaluation of the @Nursing home was designed to assess the usability and effectiveness of the Dem@Care technology in the context of the nursing home, where the targeted user is a person with severe dementia suffering from Behavioural and Psychological Symptoms of Dementia (BPSD). The support of people with dementia who suffers from BPSD is one of the major challenges in the caring of people with dementia who are in a late and severe stage of the disease. An important part of this challenge is to understand and interpret what the person is experiencing and what can be the cause of such a disrupted behaviour, since these individuals have difficulties in expressing themselves. There are clinical requirements of improving the assessment of BPSD and evaluations of care interventions and in many countries in Europe and one common way of doing that is to use the NPI-NH (Neuropsychiatric Inventory – Nursing home version) in a structured way. In Sweden as well as in many other countries the use of sensors is already common in nursing homes in the care of people with BPSD with the purpose of enhancing security. In the Dem@Care system the sensors are used in new and inventive way where they provide behavioural information. The evaluation was therefore designed to evaluate the usefulness, usability, and effectiveness of the Dem@Care system in contributing to improved care of people with severe dementia suffering from BPSD.

5.1.1 Specific research questions

- What is the usefulness of the Dem@Care technology in this context?
- What is the usability of the Dem@Care technology in this context? Can the information from the Dem@Care system support staff members' reasoning when doing assessments and evaluations of the efficacy of intervention strategies among people with BPSD?
- Can support of people with BPSD be more effective with the support of the Dem@Care technology?

5.1.2 The goals of the final evaluation

The goals of the final evaluation phase was to continue the started the evaluation process to answer the specific research questions for the @Nursing home context. Evaluation of the usefulness and usability of the Dem@Care system was to a large extent finalised in earlier evaluation phases. New aspects to evaluate from the perspective of usability were the further refined and developed system itself and the use of voice recordings for assessing stress and anxiety in the participants with BPSD.

Main focus in the evaluation was to recruit and test the Dem@Care system in the clinical assessment of more participants and to compare those data with data from participants who had no access to the system.

In the Nice evaluation the goal was to test the use of 3D-sensor for measuring behavioural patterns.

5.2 Methods

An important aspect of the evaluation strategy of the @Nursing home evaluation carried out in Sweden by LTU is that it was conducted in the natural setting of dementia units and that it was designed to be adjusted to the normal clinical procedures of the included nursing home units. The nursing homes were selected based on the criteria that they in their assessment of the residents suffering from BPSD were trained and used a systematic procedure developed in Sweden for assessing the level of BPSD and evaluating care interventions based on the NPI-NH instrument, called the BPSD registry (www.bpsd.se). The evaluation used standardised forms and evaluation procedures and was a continuous process that was initiated already from the deployment of the first pilot equipment. In early phases of the evaluation the focus was on assessing usefulness and usability while the final evaluation focused more on effectiveness of the system to contribute to the existing clinical assessment procedures.

5.2.1 Participants and Procedure

In the final evaluation process of the effectiveness of the system in total eight participants were recruited, four in an intervention group among whom the Dem@Care system was deployed, and four who followed the same clinical procedure but without the access of the system. The participants were recruited with the criteria that they were diagnosed with dementia and that they by staff were assessed as suffering from BPSD.

In addition three additional participants were recruited based on the same criteria for the testing and evaluation of voice analysis as a way of assessing stress/anxiety.

In Nice, France, five participants were recruited for the evaluation of using the CAR sensor to monitor the behaviour of the participants.

5.2.2 Assessment of usability and usefulness

The protocols for usability and usefulness used to collect information from staff concerning their experience of using the system with its sensors were specially developed for the evaluation and earlier described in D 8.3. It had seven questions related to the usability, wear-ability and acceptability with open answer options. A total of 46 staff members directly involved in

the care of the eight residents suffering from BPSD, who had the Dem@Care system deployed, contributed to the assessment. The involved staffs were interviewed by a trained researcher at the end of the test period of each individual who had the system deployed. In the beginning of the evaluation process the assessment of usability and usefulness related to the use of the deployed sensors, the DTI-2 bracelet, the Gear4 Sleepclock, and the CAR, a three D camera measuring moments in the resident's room. In the final evaluation the focus was more on the use of the system and its produced reports.

5.2.3 Validation of sensor information

Validation on sensor information focused on the sensor information from the DTI-2 regarding stress/anxiety and of information on sleep patterns collected from the Gear4 Sleepclock. This was justified based on clinical experience by staff of being the most useful information in the clinical assessment process of BPSD.

The reports on sleep patterns night time, produced by the Gear 4, were compared with confirmed observations by night staff of sleep pattern. Night staff used a standardised report form for assessing sleep, which was a report form that was used in regular clinical work in the nursing homes.

The reports on stress/anxiety patterns, produced by the DTI-2 skin sensor, were compared with structured observation in day time using a standardised report form for assessing stress and anxiety. This report form was part of the toolbox of structured assessment forms used by the staff in regular clinical work.

The comparison between the information on sleep pattern by the sensors was compared with confirmed observed incidents of sleep and awakening by the staff. The same procedure was used for the comparison of sensor information and observed incidents of stress/anxiety. In this analysis descriptive statistics was used.

5.2.4 Assessment of effectiveness

The assessment of effectiveness of the Dem@Care system followed the structure of an in Sweden established structured system of using the NPI-NH instrument for assessing level of BPSD and evaluating care interventions, the BPSD registry (www.bpsd.se). All participating nursing homes. The assessment process is illustrated in Figure 31.

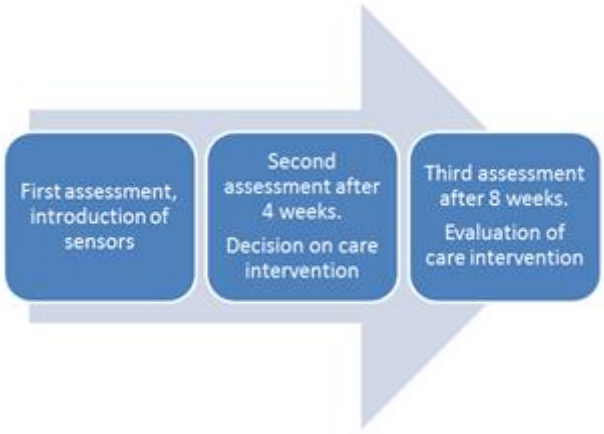


Figure 31. The process of evaluating effectiveness of the system in clinical assessment of the intervention group.

The three steps evaluation process using the NPI-NH instrument [19] was the basis for the evaluation. It was carried out by the staff members of the dementia unit, who were specially trained to do the assessments, as a normal clinical procedure in the natural setting of the nursing home unit. It was supervised by a trained researcher who guaranteed that the same procedures were followed in all assessment sessions. The procedures involved using the NPI-NH instrument to assess the scores for each of the eight dimensions of BPSD and calculate a total score, discuss a possible course of the BPSD problems for each individual, and finally decide on a proper care intervention. For comparison, the same procedure was used for a group of people with dementia suffering from BPSD, with the difference that no sensors were deployed to them. The information was analysed with descriptive statistics.

In addition, all clinical reasoning in the assessment sessions were audio recorded in order to analyse the staff members perception and reasoning of the status of each individual and the effect of the care interventions. The analysis of that data was carried out with a qualitative method of discourse analysis, which involves identifying sequences of communication related to the aims of the evaluation, compare and synthesise the core structures and content of the discourse [20].

5.3 Results

The results are presented according to the different aspects of using the Dem@Care system assessed in the evaluation.

5.3.1 Evaluation of usability

Sensor equipment

Four different sensors from the Dem@Care tool box of sensors were selected to be evaluated in the nursing home pilot evaluation.

Table 23. Overview of tested sensors

Sensor	Modality
DTI-2, UP24	Moving Intensity, Stress levels
Gear4/Aura	Sleep Monitoring
Microphone	Voice
Depth Camera	Posture, Location, Primitive Event

Since the test in the nursing home context had a special focus on clinical assessments it was already from the start of the project obvious that the number of sensors used with the person with dementia and BPSD had to be limited in number and carefully selected from the Dem@Care tool box of sensors. The nursing home is natural clinical context which is demanding in several ways and the acceptability of staff and the residents had to be considered carefully in order to be able to perform the tests in a meaningful way. Important aspects considered were what specific added value in the clinical assessment of BPSD could the sensor had a potential to contribute with. Other important issues related to the acceptability of the resident was whether it was easily wearable, would it draw the attention of the person with dementia, and was it enough robust in its functioning. The aspect that the equipment was easy to handle by staff members was also important considering the number of staff members involved in the test.

Based on these considerations the DTI-2 Bracelet with sensors collecting data on galvanic skin response (GSR), measuring stress /anxiety, an accelerometer measuring moments, and sensor for skin temperature was selected. The sensor was put on the wrist of the person with dementia in the morning and it was thereafter carried during the whole day until the person went to bed. The main clinical interest in this sensor related to the possibility of measuring stress/anxiety.

Figure 32. Gear4 sleep clock placement

The Gear4 Sleep clock, a sensor that measure breeding and movements of the person in the bed that can distinguish between three states, awake, light sleep, and deep sleep was also chosen. It was designed to be place next to the bed and had to be switched on by the staff when the person went to bed. In this way it measured sleep pattern night time. There was a clinical need to measure sleep all through the day and night but considering what sensors that were available, this was regarded as the best compromise available.

The Depth 3D camera that could measure moments of the person with dementia was placed in the private room as a consideration of protecting the privacy of other residents and to function as a complement to the Gear4 sensor. It could measure patterns of moments of the person with dementia.

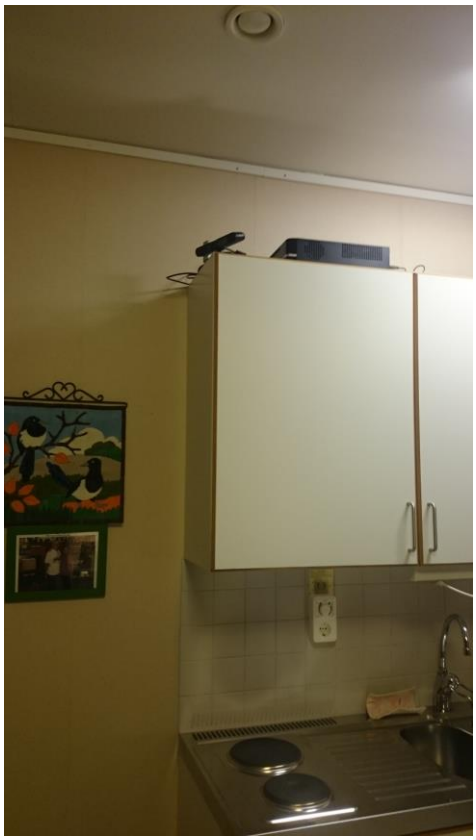


Figure 33. Depth 3D camera

The evaluation showed that in the beginning of the tests there were some problems with handling issues, as charging batteries and transferring data from the sensor to the system. There were also incidents where the person with BPSD had fiddled with the sleep clock and misplaced the IPhone that need to be attached. Over time, staff members learned how to deal with these types of problems and they became less frequent.

From a usability aspect, the information from the Gear4 sleep clock could be used already from the beginning of the project. It is using an iPhone on a dock station, and has a special application of its own that presents data about sleep patterns, which meant that data about sleep patterns could be analysed separately from the Dem@Care system.

The acceptability of the DTI-2 by the person with BPSD was never a big issue when the staff got used to handle it. In the beginning there were many issues related to the transfer of the data to the Dem@Care system, which was complicated. Another related issue was that it produced a lot of data that was difficult to interpret. The major change came in January, 2015 when the system started to be able to produce easy understandable reports of patterns of stress/anxiety. This information was found highly relevant in the clinical assessment of the person with BPSD.

The Depth 3D camera was easy to handle since it was mounted on the wall in the resident's room. In the beginning there were many issues related to transfer and interpretation of data produced. The sensor could provide information on the location of the resident in the private room, if the person was sitting down, lying in the bed, or walking around. The information never became clinically relevant, partly because the aggregation of data into an easy understandable reports never materialised, and partly because the added value of the information was never considered clinical relevant for assessing level of BPSD.

There was a general agreement among staff that the information from the Gear4 sleep clock on sleep patterns and the DTI-2 skin sensor for measuring stress/anxiety was very useful in the clinical assessment and evaluation of the person with BPSD.

The central unit of the system

The initial tests of the usability and usefulness of the central unit of the system focused in the nursing home context on informing the technical developers on functional requirements. This included an early expert evaluation involving both clinical and technical experts and feedback from researchers and clinical staff in the first two phases of the testing of pilot systems.

The final pilot central unit of the system could produce relevant aggregated reports on pattern of behaviour based on sensor data from the DTI-2 skin sensor, the Gear4 sleep sensor and automatic analysis. Therefore, usability and usefulness aspects could be assessed. The aggregated report revealed that staff required special training and sufficient computer knowledge in order to handle the transfer of files accumulated by the devices. Hence, while the use of the Dashboard itself is self-explanatory and easy, the system's usability is limited by the use of offline sensors. Unfortunately, this cannot be changed, but has been addressed by the adoption of other, online sensors that require no interference, in @Home pilots. With the support of a technician, special trained clinical staffs were able to independently use the analysis and visualization of the Dem@Nursing system.

Microphone for voice analysis

The use of microphone for voice analysis of mood was an option that was considered to be important from a clinical perspective since information on stress/anxiety and other aspects of mood is clinically important when assessing the problems of residents with BPSD. One challenge that delayed the introduction of this sensor was the difficulty of identifying suitable microphone equipment and a proper placement of the microphone. In the natural setting of the nursing home there are many residents and staff members and one challenge was to find a solution to record only the individual resident who the Dem@Care system was deployed with. At the end we used the microphone of an ordinary smartphone that was managed by a trained researcher to collect recordings when interacting with the resident suffering from BPSD.

There was not enough time within the framework of the project for IBM to analyses the recordings that were made with three residents and we have therefore never been able to test and evaluate the clinical usability of using voice recording to assess stress/ anxiety which was the prioritised aspect of mood to be evaluated. The plan is to continue developing the voice analysis of mood with additional research funding.

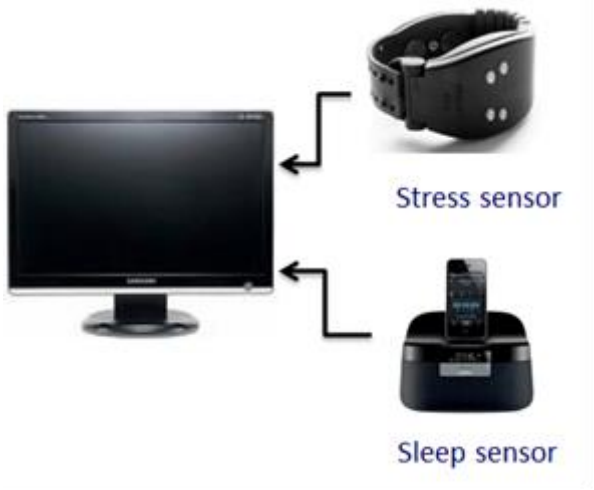


Figure 34. Tested system in final evaluation

5.3.2 Validation of sensor data

At the start of the project we were very unsure about how to value the sensor data, especially data on stress/anxiety. The GTI-2 was tested in the @Lab in Nice with a positive correlation with observed level of stress/anxiety. At the same time the Nursing home is a very different context from the lab as well are the problems of people with dementia suffering from BPSD compare with the problems of people who are in early stages of the disease.

We handled the validation of the information from both the Gear4 sleepclock and the DTI-2 bracelet in a very practical way, adapted to the naturalistic environment they were tested in. This meant that we used a structured observations form where staff members could indicate the time of the day when the person with BPSD was stressed/anxious. For sleep, a special observation form was used by staff working in the night.

The table below indicates a correlation of about 90 % in average between observed stress/anxiety and the aggregated reports from the GTI-2. It is important to remember that this comparison is made when staff directly observed incidents of stress/anxiety. The sensors data indicate more incidents than were observed by staff and also indicate more specific information on duration of stress/anxiety. In situations with no correlation between sensor data and observed incidents it seemed related to handling problems of the sensor bracelet.

Comparison between sensor data from the Gear4 sleepclock showed 100 % correlation with observed sleep pattern. As with the DTI-2 it is important to consider that the comparison is made between incidents when the sensor produced data and incidents of observed sleep pattern. The staff could not observe the residents continuously in the night and they followed a routine of regularly visiting the room of the resident and the observations were made in those occasions. The Gear 4 produced a more detailed and elaborative information than the staff could observe.

Table 24. Overview over participant in the intervention and control group

	Intervention group				**Control group**			
Variables	User 1	User 2	User 3	User 4	User 1	User 2	User 3	User 4
Gender	Fem.	Fem.	Male	Fem.	Fem.	Fem.	Fem.	Fem.
Age	65	81	85	69	81	93	94	82
Dementia diagnose	FD	AD	VD	AD	AD	AD	VD	VD
MMSE score	0	2	0	0	0	0	9	7
GDS score	6	6	6	6	6	6	6	6
First NPI-NH score	40	58	43	29	68	130	74	57
Second NPI-NH score	26	39	58	22	49	133	59	80
Third NPI-NH score	34	38	74	N/A	50	106	74	46

5.3.3 Evaluation of effectiveness

In order to better understand the use of the Dem@Care system in the clinical assessment and evaluation process of the the problems of each person with dementia suffering BPSD it will be illustrated by a description of a case.

The case of Signe

Signe had a diagnosis of dementia and was by staff assessed as having problems of BPSD. She was at a stage 6 on the Global Deterioration Scale [21], [22] and Mini Mental State Examination scored 0 points [4]. In the initial assessment she had the highest score in The NPI-NH instrument within the domain of aberrant motor behaviour; sleep; and appetite and eating disorders. At the second time of the second assessment for weeks after the deployment of the Dem@Care system data on behavioural patterns from sensors regarding the last four weeks were presented to the staff. The DTI-2 showed a pattern of stress/anxiety where stress levels were increasing at two different times during the day, and this pattern was the same most of the days during the weeks. The first increase was around 2 pm and the second around 5 pm and it lasted until 7 pm. In general, the stress level was higher between 5 pm and 7 pm. According to the sensor the stress level was never high during the midmorning.

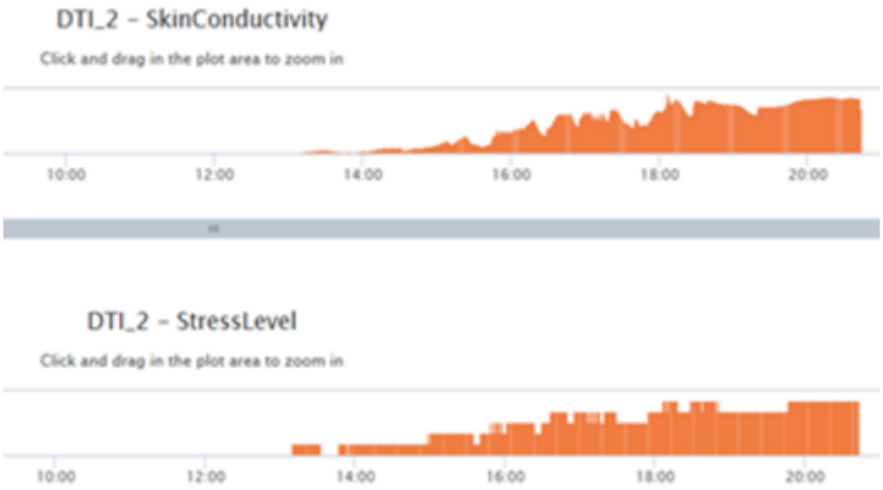


Figure 35. Second assessment. A graph of a typical day for Signe

Data from the Gear4 on sleep patterns showed interruptions of sleep during the night, which confirmed the observed assessment of the staff. The information from the DTI-2 confirmed the observations made by the staff that the aberrant motor behavior was higher during the evenings but it added more detailed information compared to what had been observed.
When the staff got together for the second assessment they reflected on what could be course of Signe´s BPSD pattern, what happened at the nursing home during these peaks of stress. They came to the conclusion that at 2 pm, a possible reason for Signe´s increased stress/anxiety was the shift of staff where some left and new started working. During the time period from 5 pm to 7 pm a lot went on at the ward. There was another shift in staff, they served dinner, the staff had their breaks and also many relatives came to visit the nursing home which could contribute to too much stimuli. This analysis of possible courses of was directly stimulated by the information from the Dem@Care system and stimulated a new direction of what intervention to consider. As a consequence the staff decided to consider what they could do about their working routines in order to reduce stimuli at the time Signe had peaks of stress/anxiety in early afternoon and in the evening. Data about sleep patterns confirmed what the staff already new and did not influence the choice of intervention.

Data from the sensors during the third and last assessment session after eight week showed pretty much the same pattern as at the second assessment after four weeks. The peaks of stress/anxiety were present during the same time periods as before.

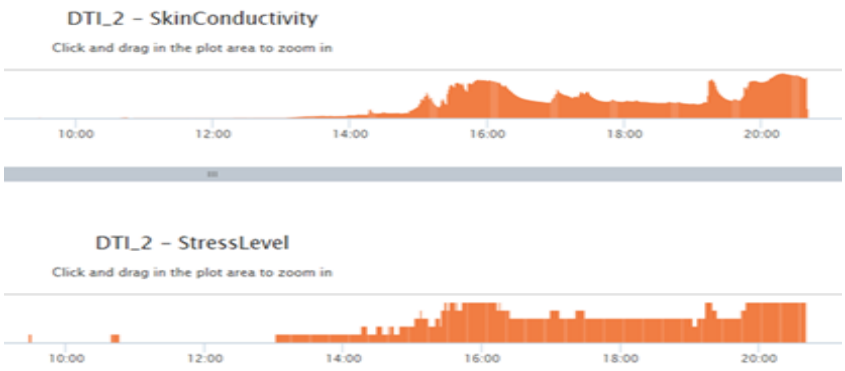


Figure 36. Third assessment, A graph of a typical day for Signe.

At this time the staff the staff decided on a more specific intervention. They decide that they would try to move more slowly, and try not to run around so much at the ward. They also decide that they would talk to all relatives and ask them to come other times than during the evening. If this not could be realised, the relatives were asked to visit their family member in their apartments instead of in the common areas of the ward. An intervention targeting the peak of stress starting around 2 pm was to spend time with Signe, to sit down with her and in this way calm her. The sleep pattern had improved with less sleep interruptions and the total amount of sleep had increased compared with the situation at the time of the second assessment, which the staff interpreted as an improvement of her BPSD problems.

NPI-NH Measurements

Evaluation of effectiveness of the Dem@Care system was carried out with the structured assessment form of the BPSD-registry (www.bpsd.se). This meant that it was based on measuring the NPI-NH [1] scores in a three step evaluation process over two months. The procedure was the same at all three assessment sessions, the first took place at the time for deploying the Dem@Care system, the second one moths later, and the third after two months. At each session a full assessment with the NPI-NH scale was carried out, followed by a discussion of what could be the courses of the BPSD, and when that was concluded an intervention strategy was decided on that would be evaluated in the next assessment session.

In addition to following the measurement procedures of the BPSD registry, all assessment sessions were also recorded in order to follow the development of the clinical reasoning within the group of staff members. Parallel with the interventions group was also a control group of people with BPSD who were assessed and evaluated with the same procedure as described in the BPSD registry. The only difference was that they did not have access to sensor data.

Table 25. Overview over participant in the intervention group

	Intervention group				**Control group**			
Variables	User 1	User 2	User 3	User 4	User 1	User 2	User 3	User 4
Gender	Fem.	Fem.	Male	Fem.	Fem.	Fem.	Fem.	Fem.
Age	65	81	85	69	81	93	94	82
Dementia diagnose	FD	AD	VD	AD	AD	AD	VD	VD
MMSE score	0	2	0	-	0	0	9	7
GDS score	6	6	6	-	6	6	6	6
First NPI-NH score	58	39	38	-	68	49	50	-
Second NPI-NH score	40	26	34		130	133	34	-
Third NPI-NH score	43	58	74		43	58	74	-

The interpretation of the three iterations of NPI-NH measuring is that there is no real trend between the intervention group and the control group in the scoring. The same is also through when comparing between the first and the last measurement for each individual.

Way of reasoning

A second way of assessing the effectiveness used in the evaluation was through collecting data about the clinical reasoning of the staff members who perform the assessment sessions for each person with BPSD. This means that we have recorded three sessions for each participant, four in the intervention group and four in the control group. In all there were 24 sessions recorded.

The analysis of the recorded sessions was made with method for discourse analysis, where the recordings were transcribed, and sequences of talk were analyzed [20]. The focus of the analysis was on how staff members argued about possible courses to the BPSD and how they argued about possible care interventions.

Results of the analysis showed that there was a difference between the way staff members reasoned in the intervention and the control group

Reasoning about course

Control group

In several group sessions the staff had problems of making correlations between possible courses and the triggering of the BPSD problems. The experience and observations of the residents' behavioral pattern and BPSD problems that were discussed tended to be straggly and

there was a lack of consistency in observations. Discussions of possible courses tended to follow a pattern where suggestions were more based on what they previous learned were possible courses than making inferences from observed pattern.

One staff stated; *The problem is that we have different opinions among ourselves. We have discussed these issues a lot, but we have for example different opinions on how to interpret expressions of stress/anxiety and that makes it difficult to agree on the patterns of it. Another problem is that we don't have consistent observations since we are many staff and we have not developed a good system for recording.*

Intervention group

In the clinical reasoning about possible courses of the BPSD it was obvious that staff members who had access to the Dem@Care sensor information tended to have more specific suggestions about possible courses compared to staff members in the control group. For example they could suggest that the total stimuli around lunch time were a possible course for being stressed at that period of the day. The staff seemed more confident about the pattern of behavioral changes when having access to the information provided by the sensors compared to a situation where they were solely depended on their own observations. The information from the Dem@Care system was well accepted since it in general confirmed their own observations but with more detailed information. This was true for both the information from the DTI-2 stress sensor and the Gear4 sleep sensor. When the information from the sensors were added to their own knowledge about the resident the reasoning about possible courses tended to be more nuanced and with a greater variation in suggested courses.

One staff member stated; It has been good to have access to this additional information from the sensors, we can have confirmation on things we have suspected and in a better way suggest realistic reasons for the residents behavior. You can have confirmation on when the stress/anxiety starts and when it ends.

Reasoning about care interventions

Control group

When analyzing the clinical reasoning in assessment of care interventions in the control group staff tended more often to have general suggestions on care interventions focusing on activities that the resident with BPSD liked to do. The suggested strategies suggested for interventions also tended to focus more on handling the BPSD symptoms then interventions that could prevent. There is a thread in the reasoning of staff members that they have problems of assessing the link between the BPSD problems, possible causes, possible interventions, and ways of evaluating the effect of interventions.

The suggested intervention tends to focus on distracting the residents in situations when they are stressed and less on preventing the stress/ anxiety. An example is that when one of the residents is stressed the staff tries to take her to her apartment and spend time with her. The staff seemed in general unsure about what care interventions to be used and tend to reason more about what doesn´t work than about specific interventions targeting the problems of the resident.

One staff member stated; we sometimes can suggest care interventions that we think can prevent the problems, but we have difficulty of agreeing on a specific plan on how to implement them.

Intervention group

In the clinical reasoning of staff in the intervention group they tended to suggest care interventions targeting the situation of the resident at specific times of the day when the Dem@Care system indicated peaks of stress. The staff members tend to be more confident in their reasoning suggesting specific care interventions that are less general compared to interventions suggested in the reasoning of the control group. An example that illustrates this is a clinical reasoning of the problems of one resident. Based on the information from the sensors the staff discussed possible intervention to prevent the peaks of stress/anxiety. The staff suggests several both minor and more general interventions that are specific for what they assess as being the resident's problems and that can preventing stress/ anxiety in the evening.

Another example is when staff for another resident suggests that the medication should be provided earlier in the morning so that it has a chance of having an effect before all the morning procedures starts. Another suggested intervention is to support the resident to rest after lunch and take a walk outdoors in the afternoon in order to prevent peaks of stress/ anxiety at those times.

A third resident tends to sleep a lot during the day which worries the staff. A check of the information from the sensor about sleep pattern in the night reassure them that the resident gets enough total sleep in the night, and no specific intervention is need targeting sleep.

Conclusion

The small number of people with BPSD in the Luleå evaluation of effectiveness, four in the intervention and four in the control groups, who so far been involved in the assessment of the effectiveness of the Dem@Care system in supporting the assessment of BPSD problems and evaluating the effects of care interventions does not allow us to make any robust conclusions. Measurement of NPI-NH scores before and after the intervention does not provide any consistent trend of minimizing the level of BPSD. A possible explanation could be that the evaluation period of two months might be too short.

Qualitative indicators from assessing the staff members' clinical reasoning reveal that staff members appreciate the added value of the information from sensor data and that it helps them in their assessment and evaluation process. The added value refers both to more specific information on the pattern of stress/anxiety and on patterns of sleep. As a consequence staff members in their clinical reasoning are also able to suggest more specific care interventions that can prevent incidents of BPSD and later on can be evaluated with the information from sensors.

5.3.4 Evaluation of the use of a 3D-sensor for monitoring behavioural patterns

Monitoring of behavioural patterns in Nursing Home residents becomes particularly challenging given the lack of sufficient time available for staff members. Sensors usage combined with innovative analytics for data fusion could provide valuable information to the staff members in the five functional areas of daily activities/nutrition, sleep pattern, physical activi-

ties, social interaction, and mood/stress and therefore, help detecting early subtle changes in the residents' behaviour. This study was carried out in a nursing home in Nice, France, and focused on usability, including acceptability and usefulness of the 3D-sensor in monitoring behavioural patterns in residents residing in a nursing home context.

The evaluation is mainly based on a quantitative approach and involves data from five nursing home residents who each have been recorded extensively with a 3D sensor over a length of three weeks. The system, consisting of a 3D-sensor for activity detection and an accelerometer for physical activity measurements, have been installed after given consent in order validate the recorded sensor data against structured clinical observations from the staff members.

The statistical information that have been extracted from the output of the event recognition algorithm on recorded videos from October 29th to November 4th 2014 at living room and bedroom sensor of patient from room 06.

The event reports are divided into three categories:

1) Events that occurred on a specific day (i.e November the 2nd)

2) Events that occurred in a specific period of the day (i.e from 6 a.m to 6 p.m)

3) Events that occurred on a specific day in a specific period (i.e from 6 a.m to 6 p.m on second of November)

For each category we extract the frequency and the duration of all the events. The former variable indicates how many times an event has occurred within a category, the latter shows the duration (in seconds) of each occurrence. To describe these two variables we use two plots: frequency plot and boxplot. Frequency plot group the number of the occurrences on the y - axis, whereas on the x-axis it shows the name of the events; Boxplot shows on the y-axis information about the duration (in seconds) of every event (on the x-axis). The red line is the median duration, and the blue box contains the lower and the upper quartile of the event's data.

All the information of each event within a certain category was saved in .csv files for later statistical analysis. For example, if we want to analyse the data per day, in specific what happened on November 2nd, we find all these information in the file named 02-11_statistics.csv, where the first row is the frequency, the second row the total duration, the third row the mean duration, and the fourth row the standard deviation of the mean.

Sensor recordings with a bed view were recorded for 18 days, sensor recordings from a living room view was recorded for 14 days, and there was an overlap of these two recordings of 11 days.

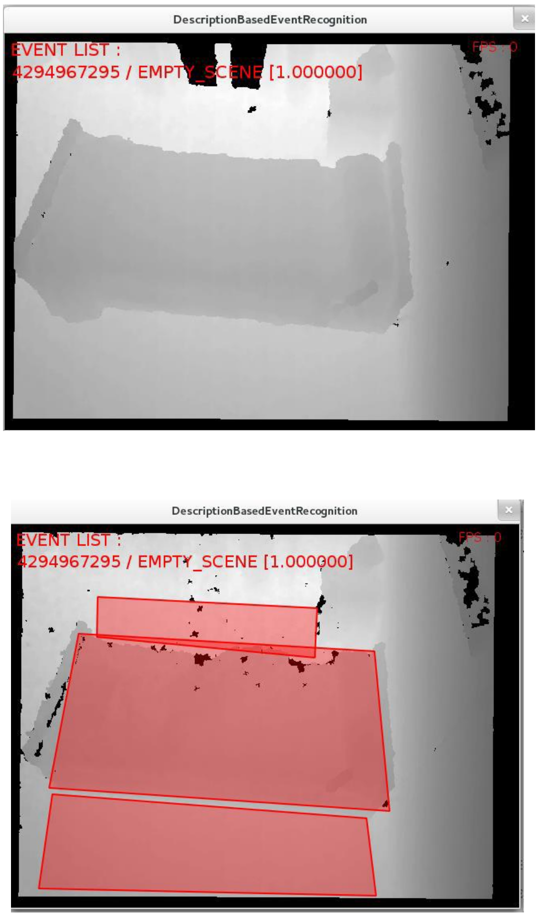


Illustration of the bed view

With and without recorded events

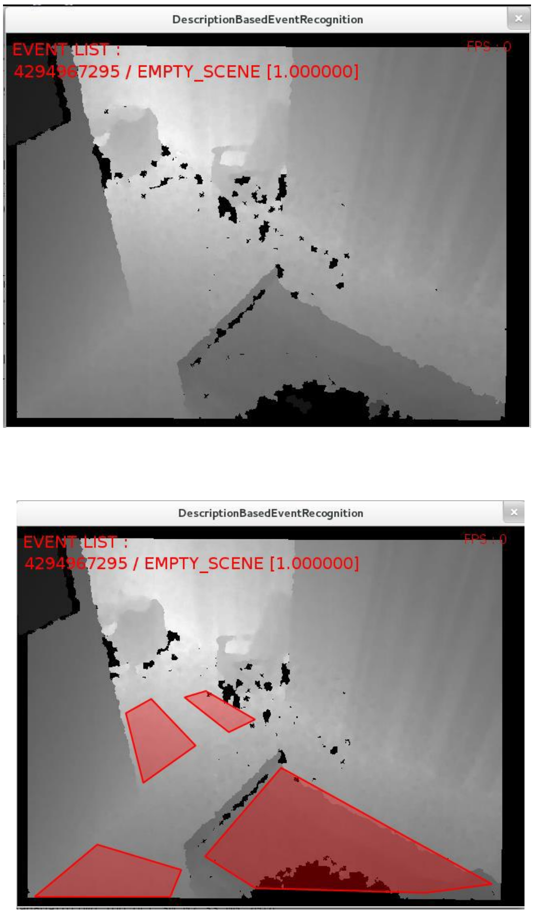
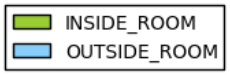


Illustration of the living room view

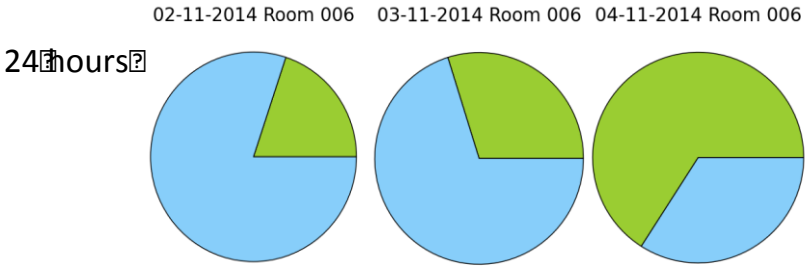
With and without recorded events

Results

The results are presented as graphs which illustrate the amount of time spent by the residents in the private room and the living room and type of activity as walking and sitting down.



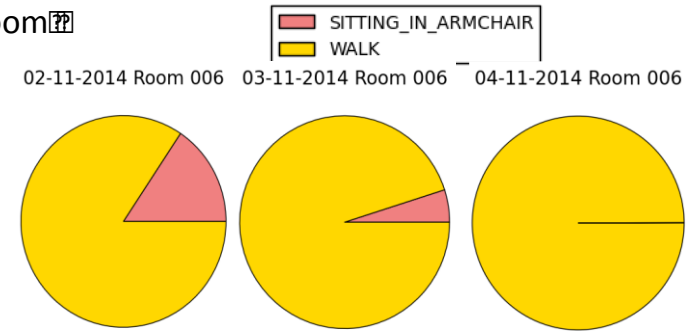
Living Room (Cont'd)

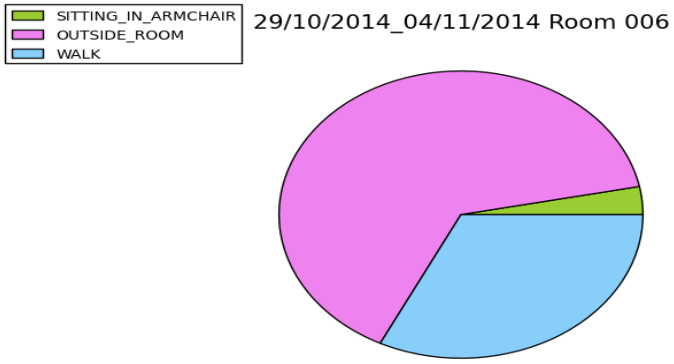


24 hours

Inside room

Time





Results night time

NIGHT 1				
	N. EVENTS	RECALL	PRECISION	F-SCORE
ENTER_IN_BED	6	100	66,6	80
BED_EXIT	6	100	100	100
AVERAGE		100	83,3	90

NIGHT 2				
	N. EVENTS	RECALL	PRECISION	F-SCORE
ENTER_IN_BED	4	100	100	100
BED_EXIT	4	50	100	66,6
AVARAGE		75	100	83,3

Night Activity report

NIGHT 1					
Name	Date	Hour	Min	Sec	Duration
BED_EXIT	29-oct-14	18	6	6	
ENTER_IN_BED	29-oct-14	18	6	49	27 seconds
BED_EXIT	29-oct-14	18	12	8	
ENTER_IN_BED	29-oct-14	18	12	38	18 seconds
BED_EXIT	29-oct-14	18	24	35	
ENTER_IN_BED	29-oct-14	19	26	2	1 minute and 47seconds
BED_EXIT	30-oct-14	2	33	2	
ENTER_IN_BED	30-oct-14	2	39	2	6 minutes
BED_EXIT	30-oct-14	5	44	23	
BED_EXIT	30-oct-14	6	53	36	

Daily Routine report

	DAY 1		DAY 2		DAY 3	
	N. EVENTS	F-SCORE	N. EVENTS	F-SCORE	N.EVENTS	F-Score
ENTER_AREA_IN_BEDROOM	49	84,9	74	93,4	10	65,2
LEAVE_AREA_IN_BEDROOM	49	97,9	74	94,6	34	76,3
ENTER_RESTROOM	12	70,9	17	74,4	34	89,7
EXIT_RESTROOM	12	61	17	96,7	62	98,36
SITTING_IN_SOFA	5	50	9	66,7	62	99,13
AVERAGE		72,94		85,16		85,738

Activity report

DAY 3					
Nme	Date	Hour	Min	Sec	Duration
ENTER_AREA_IN_BEDROOM	1-nov.-2014	7	3	9	
ENTER_RESTROOM	1-nov.-2014	7	4	33	
EXIT_RESTROOM	1-nov.-2014	7	4	56	
LEAVE_AREA_IN_BEDROOM	1-nov.-2014	7	5	35	
ENTER_AREA_IN_BEDROOM	1-nov.-2014	7	5	49	
SITTING_IN_ARMCHAIR	1-nov.-2014	7	5	55	13 seconds

Wandering behaviour example extracted from the third day (1st November). Example duration is about 3 minutes.

Accomplishment

- Improvement of event recognition in Nursing Home Dataset

- Modeling of a priori knowledge (contextual zones) in the scene and parameter tuning of low level algorithms

- Introduction of new event models

- Refinement of event recognition performance new event models

- Development of semi-supervised framework for continuous posture recognition in assisted living scenarios

The results indicate that the sensor technology can contribute additional support to the monitoring of behavioral patterns in nursing home residents.

6. @Home evaluation (Dublin, Ireland)

6.1 @Home Evaluation Aims and Objectives

The @Home evaluation aims to assess the Dem@Care system in the private homes of individuals with mild to moderate stage dementia. The goals and objectives are the same for the evaluation conducted in Dublin and the one conducted in Thessaloniki.

The specific research questions asked in the home are the following;

1. Is the system acceptable in the home, is it non-intrusive, and useful to the person with dementia and their family?
2. Are the functional requirements reflective of the reported needs of the person with dementia, as personally reported and reported by caregivers?
3. What is the functional status of the person with dementia as operationalised in the five domains, and can the system optimise status in these areas?
4. How autonomous and independent is the person with dementia, and can deployment of the system support this autonomy?

The goals of the final @Home pilot evaluation were to:

1. Continue data collection with our two active lead users (Sean – LU2 and John – LU3) with a view to (a) increasing the size of the longitudinal data set available for this participant, (b) extending data collection to incorporate psychometric questionnaires, (c) introducing the Dem@Care interfaces into the home, and (d) improving the overall end user experience of the acceptability and usability of the system.
2. Recruiting up to six people with dementia and a family caregiver to take part in the cognitive intervention study to determine the acceptability and effectiveness of using Dem@Care to support individualised psychosocial interventions in the home.
3. Continue to improve accuracy of sensor-level analysis and visualisation of these results.
4. Test data fusion and the visualisation of patterns and trends in participant data across sensors, thus providing the ability to identify patterns of deterioration over time.

Analysis

The @Home pilot studies followed a multiple case study design. Data will be analysed for each case study separately and findings reviewed to identify common themes across the case studies.

6.2 @Home Lead User Case Studies

This section summarises the @Home protocol for the final pilot in Dublin, Ireland. It then presents two lead user case studies that describe the data collection and the results of Dem@Care analyses of the @Home lead user data.

6.2.1 @Home Pilot Protocol

Much of the core functionality of the Dem@Care system had been deployed in the first and second pilots, and lead user data collection continued seamlessly from the intermediate to the final pilot using this predominately lab-based system and the previously established @Home protocol. The development focus for the last pilot shifted to high priority requirements for the home environment including the interface for the person with dementia, the fusing of data from various sensors, Lifelogging functionality, and the visualisation of this data in a way that was simple and easy for clinicians to use. Dem@Care system developments continued to be deployed in an iterative manner during year four such that system updates were received throughout the course of the final pilot and these were incorporated into the @Home deployments when stable.

Amendments to @Home Lead User Protocol for Pilot 3

Automatic analysis of the wearable camera (GoPro) video data was only available for a small amount of training data in the intermediate pilot. Accuracy levels were mixed; some activities (e.g. watering the plants) were identified with 85.5% accuracy, but others (e.g. making breakfast) were less accurate (45.6%). It was also evident that the uncontrollable nature of home environments was adding to the difficulty in processing this data for the lead user. It became clear that deploying the wearable camera to a new home environment would require significant annotation and training from clinicians and technicians and highly accurate results were unlikely to be achievable in the timeframe. As a result, the decision was made to concentrate on a detailed analysis of the 18 months of wearable camera data from the main lead user, and a protocol was developed to perform a manual analysis of this data. The results of this manual analysis were then compared to those from the Dem@Care system. The methodology, results, and discussion of these data are presented as part of the LU2 case study.

6.2.2 Case Study: Sean and Catriona (LU2)

A summary of the 19 months of sensor data collected for this dyad is provided in Table 26.

6.2.2.1 Sleep results

Nightly sleep patterns were monitored using the Gear4 sleep sensor in order to obtain an objective assessment of Sean's sleep duration and sleep quality.

Objective sleep quality as measured by the Gear4 sensor

Initial analysis of Sean's sleep data, as presented in the Intermediate Pilot Report (D8.4), indicated that he slept for an average of 8.91 hours a night (*SD* = 1.66), but he experienced an average 10.11 (*SD* = 3.99) sleep interruptions per night. Sean had more than five sleep interruptions on 87.4% of nights and more than seven interruptions on 73.8% of nights. The majority of these interruptions arose during a short period of time when his wife Catriona was getting ready to go to work, but they undoubtedly contributed to Sean's perception of the poor quality of his sleep. Using Dem@Care to visualise this data, allowed Sean and Catriona to see (a) the impact of these weekday morning interruptions and (b) to appreciate the amount of sleep obtained earlier in the night; for example, see Figure 37 (the interface is presented in section 2.3.1).

Table 26. Sensor data collected for @Home Lead User 2 (Sean)

Sensor	Deployed	Data Collected	Comments
Gear 4	556 days	525 days collected 467 with valid data	Not used when away from home or if carer is unwell or forgets. Some invalid days at the start of the data collection period, typically due to poor placement of the sensor. Very patchy data collection towards the end as the participant's cognitive function declined.
DTI-2	543 days	375 days collected 259 days valid data 87 days with daytime naps	Although worn most days, the sensor was not always switched on correctly. Some files could not be processed in December 2013, and in February 2014 which resulted in lost days. This was most likely related to a synchronisation issue. The last five months of data also could not be processed due to problems managing memory capacity on the device. Earlier versions of the data transfer process cleared out the device memory when data was transferred. A newer version of the transfer process was introduced which made the transfer much simpler, but no longer cleared out the device. The researchers were not aware of this change.
GoPro	556 days	658 clips 569 with good data ≈177 hours	Some data was lost due to the camera having accidently been changed to the wrong setting, clothes (e.g. a jacket) were sometimes placed over camera or the jacket was left on a chair with the camera running, and the camera was not always switched on correctly when the participant thought recording was taking place.

Figure 37. LU2 sleep patterns from 20/8/2014 to 10/10/2014

The same visualisations allow a clinician to determine baseline sleep characteristics for any participant, track changes to this baseline, and identify problematic patterns as they occur.

Individual differences can be expected in sleep (and stress) patterns and Dem@Care has the facility to change the sensitivity of the problem alerts provided to the clinician. Figure 38 presents the screen that a clinician (or technician) can use to manage the problem identification for each person. Parameters can be changed before the semantic interpretation process, developed by WP5, is run, or this process can be rerun for a set of data with higher or lower sensitivity levels as needed. This does require manual intervention from the clinician (or technician) when processing the data in the current system. A potential future development would be to capture an increased number of parameters for each participant (e.g. in a user profile) that can be adjusted over time but that would allow for individualised processing to be automated.

Figure 38. Flexible problem identification sensitivity in Dem@Care

Analysis of the full period of data collection shows that Sean slept for an average of 9.38 hours a night (SD = 3.84), and he experienced an average of 8.66 (SD = 4.66) sleep interruptions per night. Figure 39 presents a view of Sean's sleep quality for the full period of data collection.

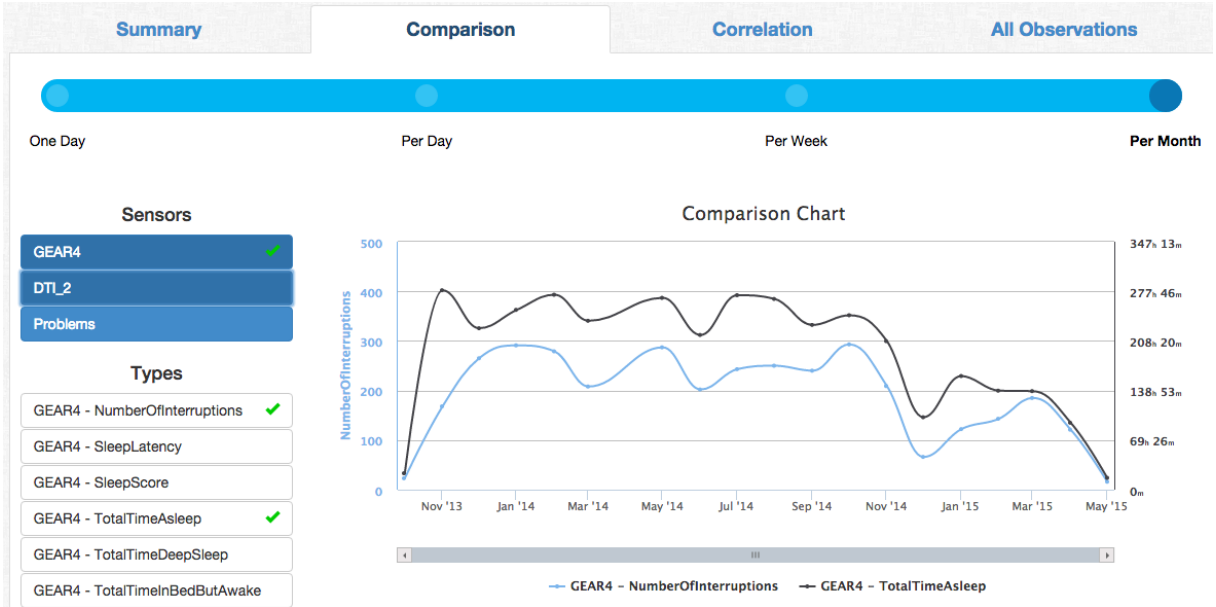


Figure 39. LU2 sleep patterns across the full data collection period

Highest average monthly sleep interruptions were found in December 2013 (M=12.61, SD=4.67), while lowest average monthly sleep interruptions were seen in July and in November 2014 (M=7.36, SD = 5.27; M=7.36, SD = 4.42 respectively). In general, a decreasing pattern of sleep interruptions was evident when looking at 6-monthly patterns over time. However, significant negative change was found to Sean's sleep duration patterns over the same time period. Highest average monthly sleep duration results were found in December 2013

(M=10.77, SD=3.32) and the lowest in March 2015 (M=6.90, SD=4.09) and April 2015 (M=6.70, SD=5.34), albeit that Sean's sleep patterns varied to a greater extent at this point. Over the course of the data collection period, no significant correlations were found between sleep interruptions and sleep duration.

Some caution needs to be taken in the interpretation of these results as there were higher levels of missing data in the latter months (10-12 days without data) and it is likely that the sleep sensor wasn't used during the more difficult days/nights. Interruptions in recent months may, therefore, be underestimated. Additionally, the impact of the interruption (e.g. time spent out of bed with each interruption) is not captured by the sleep sensor, so while total numbers may be reduced, the overall impact on quality of sleep from a smaller number of more problematic interruptions needs to be considered.

Perceived sleep quality

Self-reported sleeping patterns were captured by the Pittsburgh Sleep Quality Index (PQSI) [23]. Higher scores on this scale indicate dissatisfaction with sleep and scores above five indicate sleep pathology. The scale also provides scores for seven separate domains: duration of sleep (PSQIDURAT), sleep disturbance (PSQIDISTB), sleep latency (PSQILATEN), days dysfunction due to sleepiness (PSQIDAYDYS), sleep efficient (PSQIHSE), overall sleep quality (PQSISLPQUAL), and needing medication to sleep (PSQIMEDS).

Sean's perception of his sleep quality changed over the course of the data collection period. At baseline, Sean's assessment revealed some evidence of sleep pathology (PSQI = 6) with poor perceived quality of sleep contributing most to that score (PQSISLPQUAL = 3; PQSIDISTB, PQSIDAYSDY, and PQSIHSE = 1). Although Sean's overall PSQI score increased to 7 at the end of the first year of data collection, the PSQI domain scores highlighted a change in his reported sleep problems; perceived sleep quality improved (PQSISLPQUAL = 1), but a decline was seen in sleep latency (PSQILATEN moved from 0 to 2) and sleep efficiency (PSQIHSE moved from 1 to 2). When subjective and objective sleep measures are compared at baseline, the Dem@Care data shows that Sean was having a reasonable night's sleep but a really disturbed end to his sleep, possibly cutting into his last sleep cycle, so his satisfaction was really low. Being able to establish that fact allowed us to suggest changes that would make the early mornings less traumatic for him and some positive impact was seen from these changes over time.

Unfortunately the PSQI measure could not be repeated during the project as Sean very quickly lost insight into his retrospective sleep patterns. This supports the idea of people with dementia being 'in the moment' [24], [25] and the need for brief assessment as the individual wakes each day. The Gear4 sleep sensor provided the ability to capture this information as the sensor was switched off each morning (see Figure 40), but Sean often forgot to select an option and when his wife prompted him to do so, he typically hit 'Good'. It is likely, however, that someone with more insight into their sleep problems would be more able to use this facility. An alternative would be to incorporate a brief question into a participant's morning checklist, if they were using that functionality in the system.

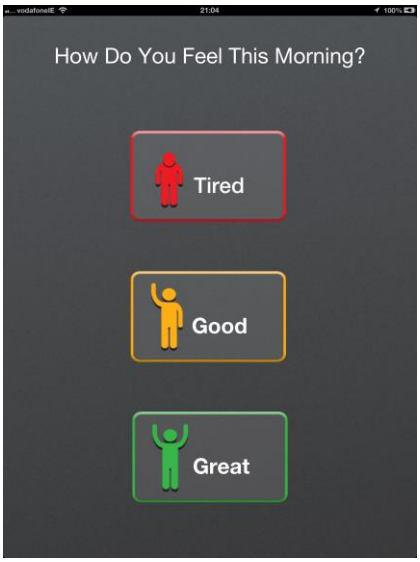


Figure 40. Gear 4 sleep quality check

Perceived sleep was also discussed in the regular data review sessions with the dyad and in the qualitative interviews at the end of the pilot. Sean was aware that he was going to bed quite early (*"Yes, I... seven o'clock"*). He attributed his tiredness to the medication he was taking (*"Yeah… it's the drugs really"*) and he felt that he slept well (*"I do get a good [night's sleep]"*). In the final interview, Catriona confirmed that Sean went to bed early.

> *"*[Sean] *went up last night at half six, so yeah he goes up very early, maybe 7, 8 you know what I mean, and straight into bed, watches a bit of TV or doesn't… he's just getting tireder and tireder all the time now.* [Sean] *is sleeping much more now than he was then* [when he started wearing the DTI2]. *Not just going up earlier… sometimes now in the afternoon he'll go up, which he never used to do… for an hour, an hour and a half."*

Catriona also highlighted a significant deterioration in Sean's sleeping patterns in recent months, with a noticeable difference in the type of interruptions that are now occurring during the night.

> *"His sleep patterns have really become very, very bad. He literally would sit up in the bed during the night, and you can see he is kind of in another zone, he doesn't really know where he is and he starts to dress himself and I have to keep persuading him… In the end I stop and I just let him get dressed and when he's dressed I say 'Now love it's time to get into bed' and then he'll get out of his clothes… This happened a few times, not every night but regularly, it's a regular thing"*

This demonstrates the importance of understanding what is happening during sleep interruptions rather than solely relying on a frequency count, which in this case would have suggested improvement rather than deterioration.

Longitudinal Analysis of Sleep Data

A longitudinal analysis of the intensity of Sean's sleep patterns was carried out using the total sleep duration captured by the Gear4 sleep sensor. As can be seen from Figure 41, a periodo-

gram of Sean's sleep data clearly demonstrates a 24-hour periodicity, corresponding to the circadian rhythm.

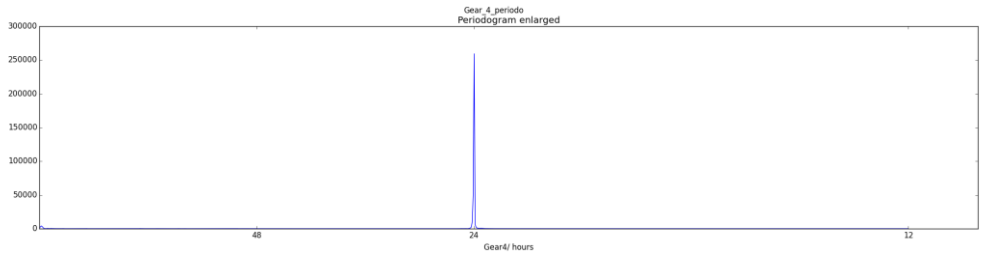


Figure 41. Periodogram of sleep data for LU2

Figure 42 corresponds to a measure of the intensity of Sean's sleep patterns. Examination of this graph shows some fluctuations in sleep pattern regularity. Areas 3, 5, and 6 represent times where Sean maintained a regular sleep schedule. Periods of low intensity correspond to holiday seasons around Easter (April 2014), summer holidays (June-July 2014), and Christmas (areas 1, 4 and 7). The sleep sensor was not used when Sean and Catriona were not at home so no data was captured at these times.

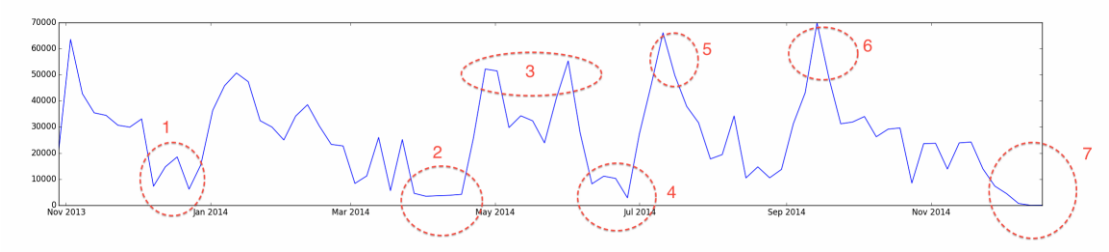


Figure 42. Intensity of sleep data for LU2 (24-hour periodicity)

6.2.2.2 Physical activity and stress levels

Analysis of DTI-2 sensor data related to physical activity

As presented in Figure 43, Sean demonstrated high levels of moving intensity and active energy expenditure at baseline. Within day variation was also evident. On days where Catriona was at work, Sean tended to rise late, have low levels of activity while preparing and eating breakfast, and then higher levels of activity during the first half of his waking day (see Figure 44 A to C). On days when Catriona wasn't working the couple often went out for the day and higher levels of activity were noted (see Figure 44 D). Days with generally lower activity levels were occasionally seen but these did not tend to have a significant impact on the average activity levels at this time.

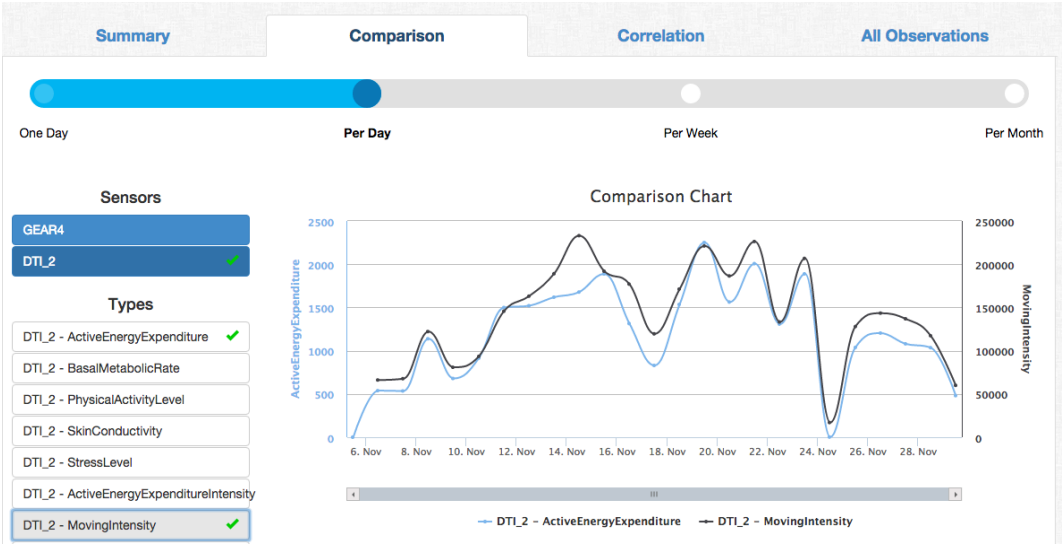


Figure 43. Daily levels of active energy expenditure and moving intensity in Month 1 for LU2

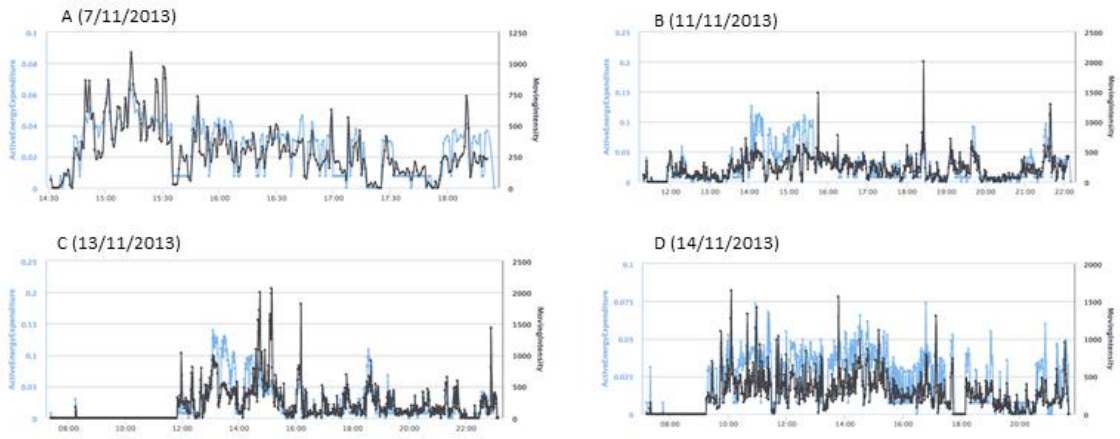


Figure 44. LU2 Daily levels of DTI-2 active energy expenditure and moving intensity for 4 specific days in November 2014

A fluctuating pattern of physical activity was seen across the full data collection period (see Figure 45). Within day activity levels and average monthly activity levels from November 2013 to August 2014 were very similar to those seen at baseline, but average monthly levels increased in September 2014 and again in November 2014.

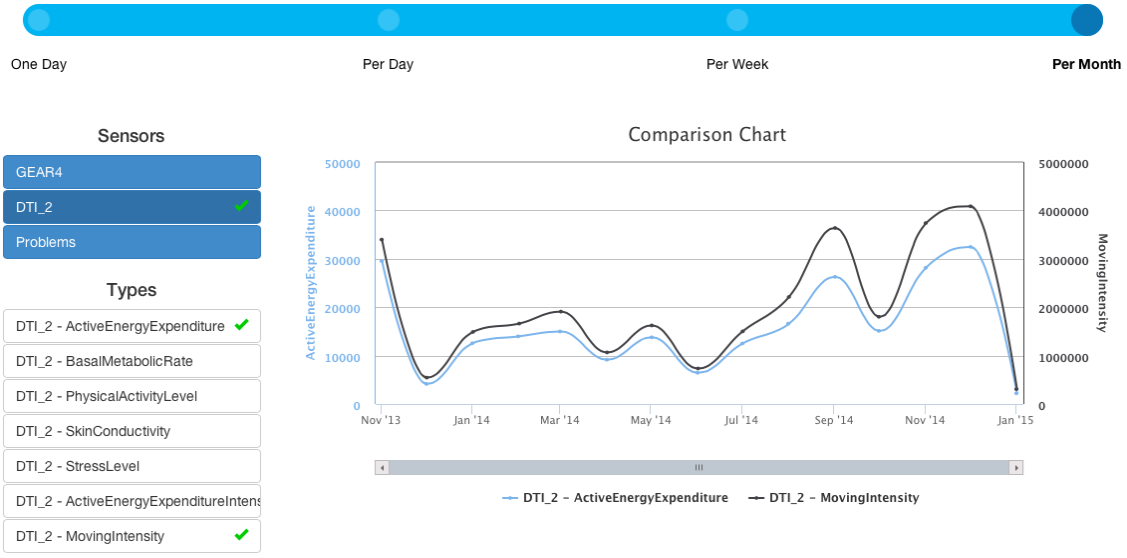


Figure 45. LU2 DTI-2 physical activity levels across the data collection period

It proved to be very difficult to establish a clear pattern of physical activity in the early months as data was not successfully collected every day. As yet, there is no facility within Dem@Care to remove missing days from the analysis and Figure 46 shows that there we pockets of time in each month were data was not captured. However, the general trend was similar to baseline and the subsequent periodicity analysis of the full dataset which does account for missing data (see below) supported the lack of regularly in this data.

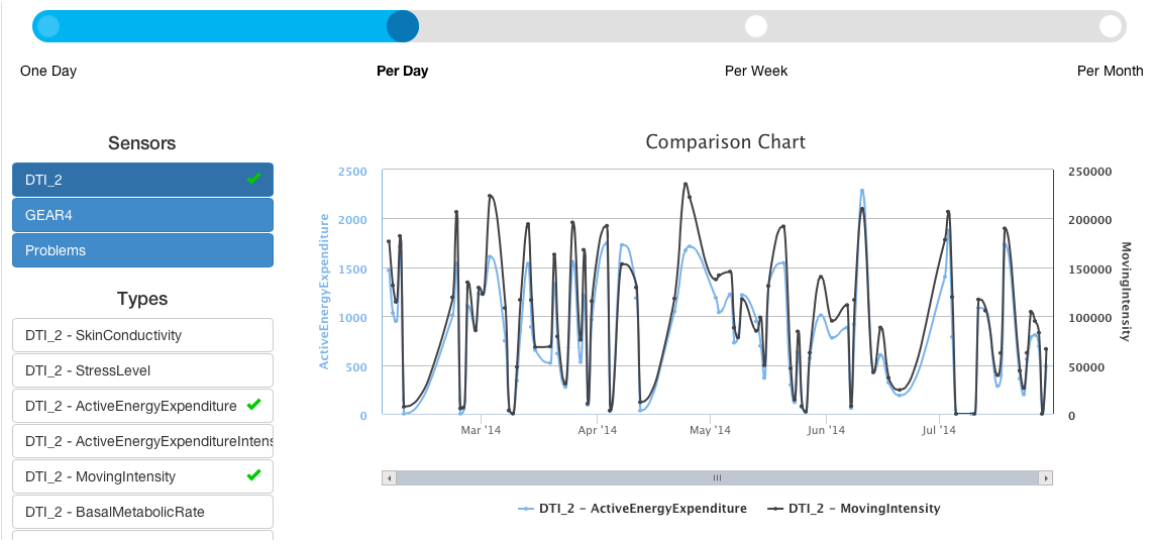


Figure 46. LU2 DTI-2 physical activity levels from January to August 2014

Closer examination of Sean's physical activity levels from September to December 2014 illustrate that physical activity did indeed increase but that this was generally sustained across this time period (see Figure 47). Very low levels of activity were noted for one week in October. The participants felt that this coincided with a period when Sean was unwell. Variation in activity levels across the day also remained. On days where Sean was at home alone, he tended to have a low period of activity in the late afternoon (see Figure 48 A); this wasn't seen on weekend days or when Catriona was out of work (see Figure 48 B). A clear pattern change

was identified in late October 2014 when Sean's evening activity levels significantly dropped. Little data is available for 2015 due to problems with the DTI-2 device memory but anecdotal evidence suggests that activity levels have continued to decrease and that this is particularly noticeable in the afternoons and evenings.

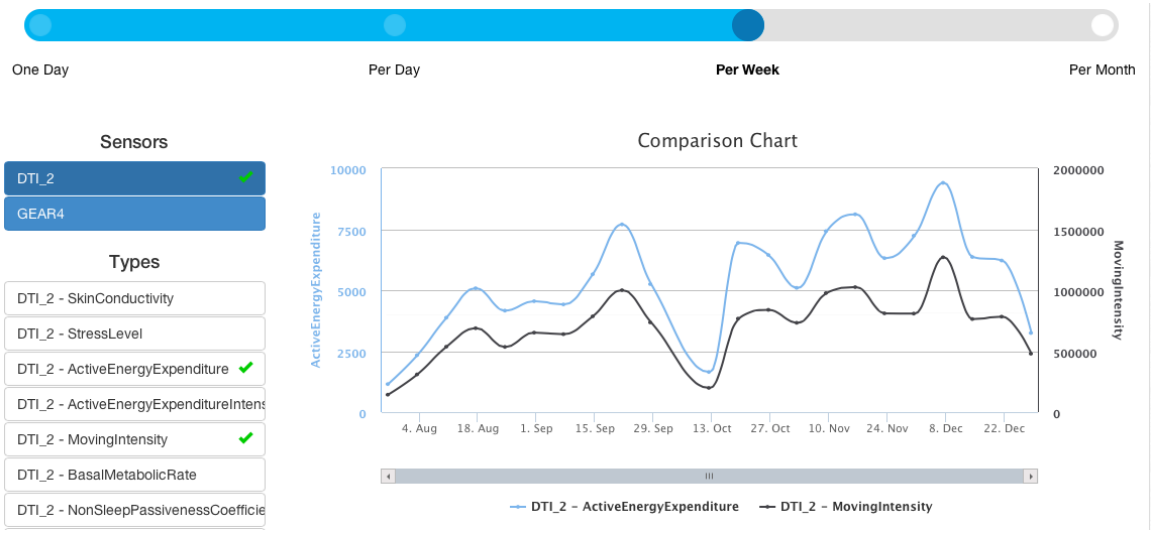


Figure 47. Daily levels of DTI-2 physical activity from August to December 2014

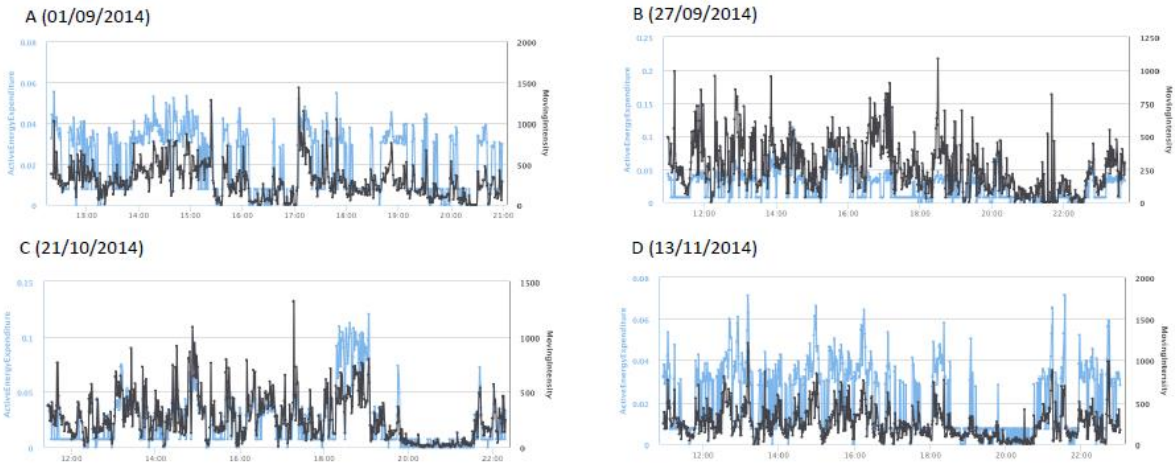


Figure 48. LU2 Daily levels of DTI-2 active energy expenditure and moving intensity for 4 specific days between September and November 2014

Perceived levels of physical activity

Sean and Catriona were very happy with his physical activity levels at baseline but they were both interested in monitoring these over time. No specific issues were identified, either by the researchers or by the participants themselves in the first15 months of data collection. In the last four months, Catriona felt that Sean was not as lively as he had been previously, although no specific mobility issues were identified in an interview in June 2015 when the sensors were returned. By the final interview in mid-September 2015, Catriona revealed that Sean's walking speed was declining and that he was finding it harder to take long walks. He had gradually stopped taking his dog for a walk, for example, and he was also getting increasingly tired during the day.

Longitudinal Analysis of Physical Activity Data

Figure 49 presents a periodogram of Sean's active energy expenditure as measured by the DTI-2 sensor and it shows that his movements followed a circadian pattern, exhibiting a 24-hour periodicity. Additional lesser peaks can be observed at the 12-, 6-, 4- and 3-hour periodicities. These are harmonics of the 24-hour periodicity (one-half, one-quarter, one-third and one-eighth, respectively).

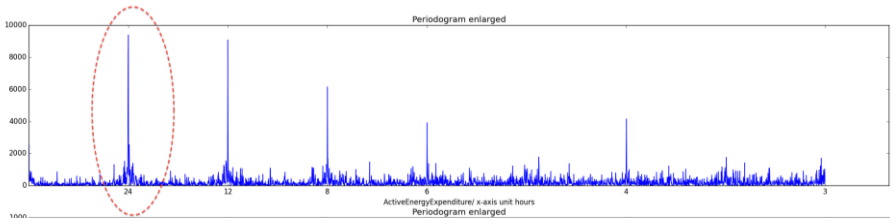


Figure 49. Periodogram of active energy expenditure for LU2

An analysis of the 24-hour periodicity for intensity, revealed an indication of the regularity of Sean's routine, and points where this regularity has been interrupted or diminished (see Figure 50). Three peaks have been highlighted. The leftmost peak represents the initial period of usage of the devices, and it can be seen that the periodicity has a high intensity, i.e., Sean had a very regular routine at baseline in the immediate period thereafter. There is no notable intensity to the signal until September 2014, which suggests that although Sean maintained similar levels of average monthly activity, there was no discernible pattern to his activity at this time. A more regular pattern emerged in September and this corresponds to an increase in activity levels seen in Dem@Care. The final peak in November 2014 suggests another shift in physical activity patterns. When interpreting these intensity graphs, it is important to note that peaks indicate regular patterns but not necessarily periods of high activity. The last peak is likely to refer to Sean’s reducing activity levels in the evening.

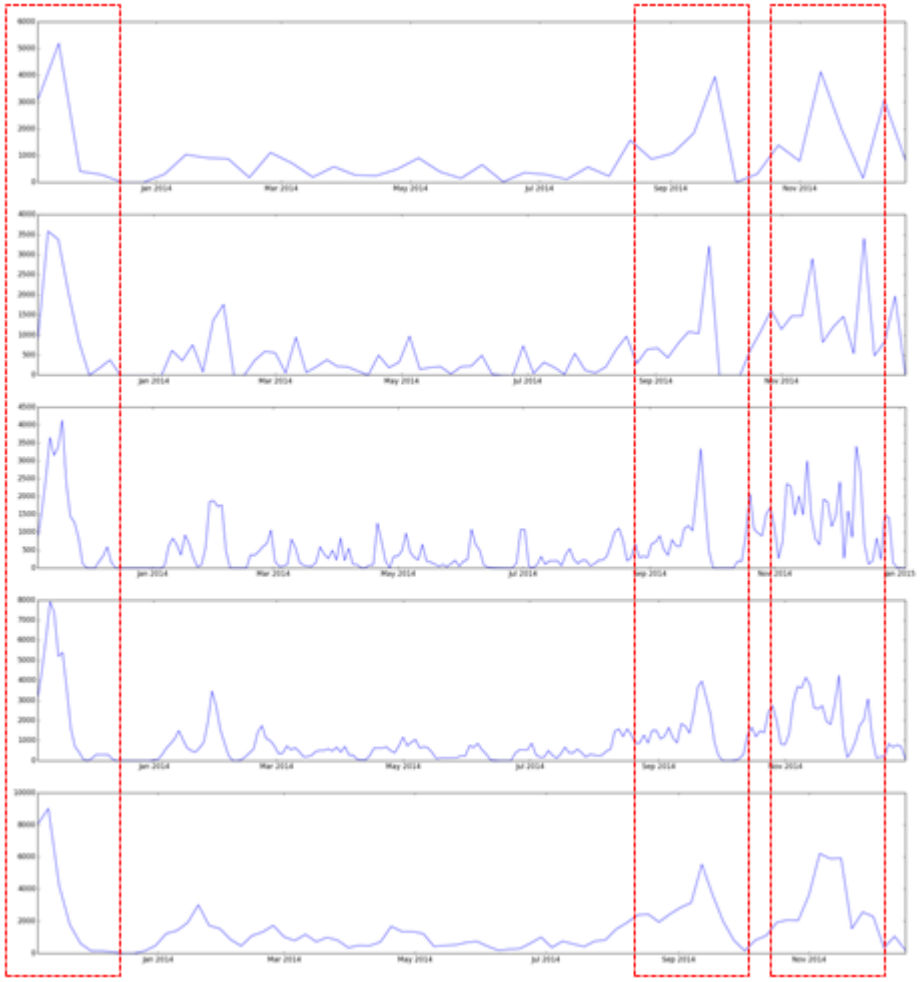


Figure 50. Intensity of active energy expenditure data for LU2

Analysis of DTI-2 sensor data related to stress

As presented in Figure 51, Sean's stress levels varied across the period of data collection although a general upward trend is seen in the last five months. This pattern of increasing stress levels persisted beyond the end of DTI-2 data collection and it seemed to coincide with a general decline in Sean's physical activity levels, cognitive functioning, and autonomy in activities of daily living. Ultimately, higher levels of stress and increasing difficulties using the sensors around May 2015 resulted in the withdrawal of the sensors and the completion of data collection for this participant. With regard to within day fluctuations in stress, similar patterns were seen across the time period. Low stress days seemed to consist of generally decreasing stress levels as the day progressed (see Figure 52 A). Medium stress days were more variable and they tended either to follow a pattern reasonably consistent medium levels of stress or increasing stress levels as the day progressed (see Figure 52 B and C respectively). Finally, consistent patterns of high stress across the day were evident for days in which the highest stress levels were recorded (see Figure 52 D).

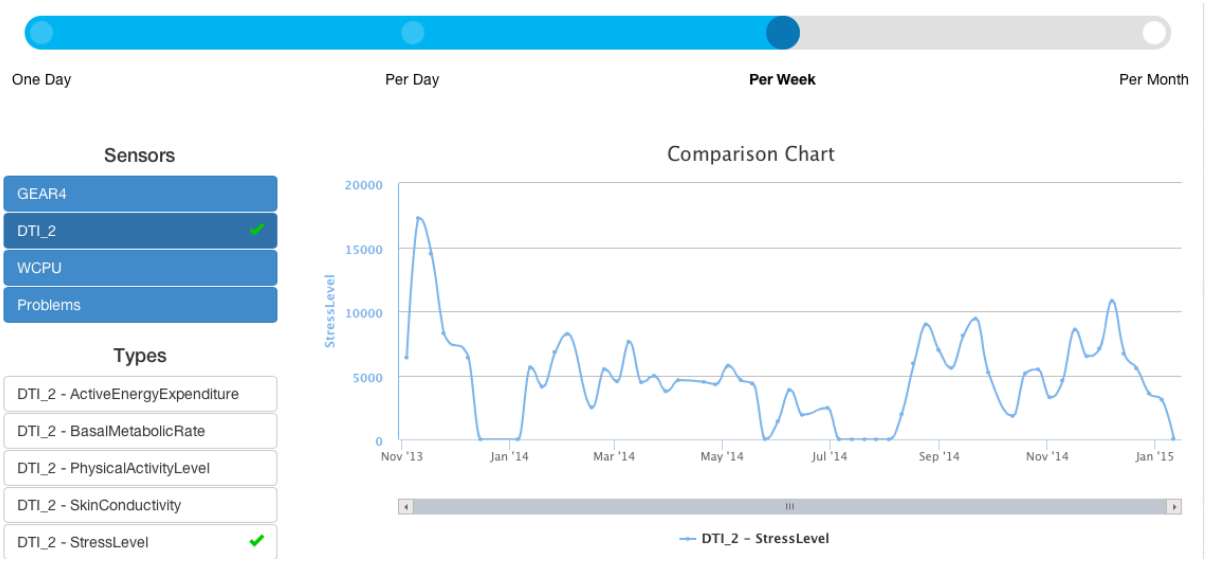


Figure 51. DTI-2 stress levels for LU2 across the full data collection period

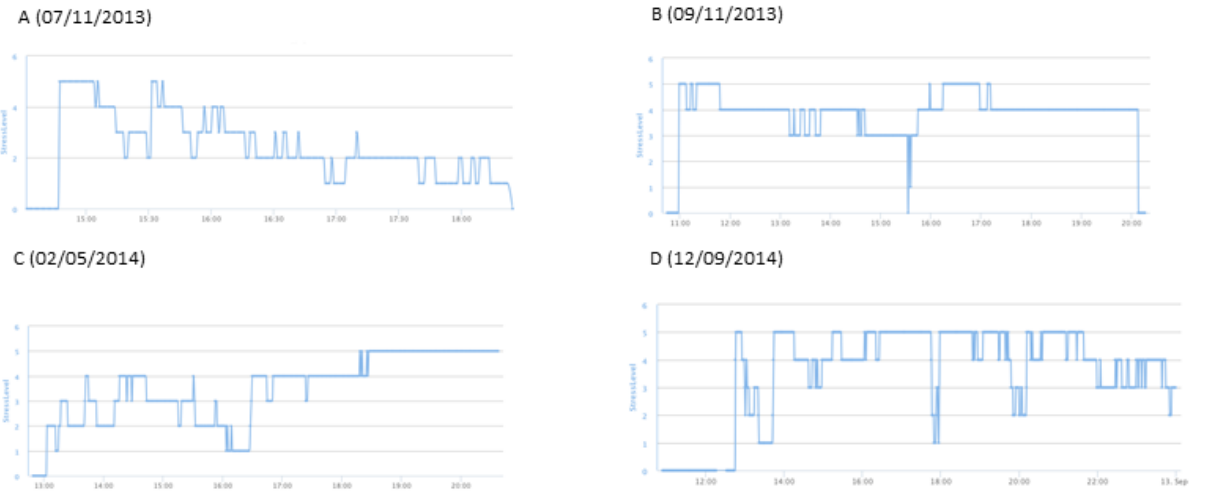


Figure 52. DTI-2 sample within day variation in stress levels

Perceived Stress levels

Sean and Catriona were asked to keep a mood diary for four weeks in an attempt to determine if a correlation could be seen between stress and mood. Each evening Catriona asked Sean how he felt that day and Sean provided a rating between 0 (very bad) and 100 (excellent). Sean's mean mood rating for the period was 56.33 (SD=14.57), but as Figure 53 demonstrates, mood fluctuated daily and two noticeably lower scores were evident which would have negatively impacted the mean rating. The low mood at point 1 on the graph was attributed to a poor sleep over the preceding weekend, whereas Sean had a sore foot on September 10th and this directly impacted his mood rating. In contrast, the highest peaks at points 2 and 4 were seen following pleasurable activities; attending an Alzheimer Café on August 26th and a concert on September 12th. These results further support the ability of people with dementia to report how they feel in the moment using simple reporting methods.

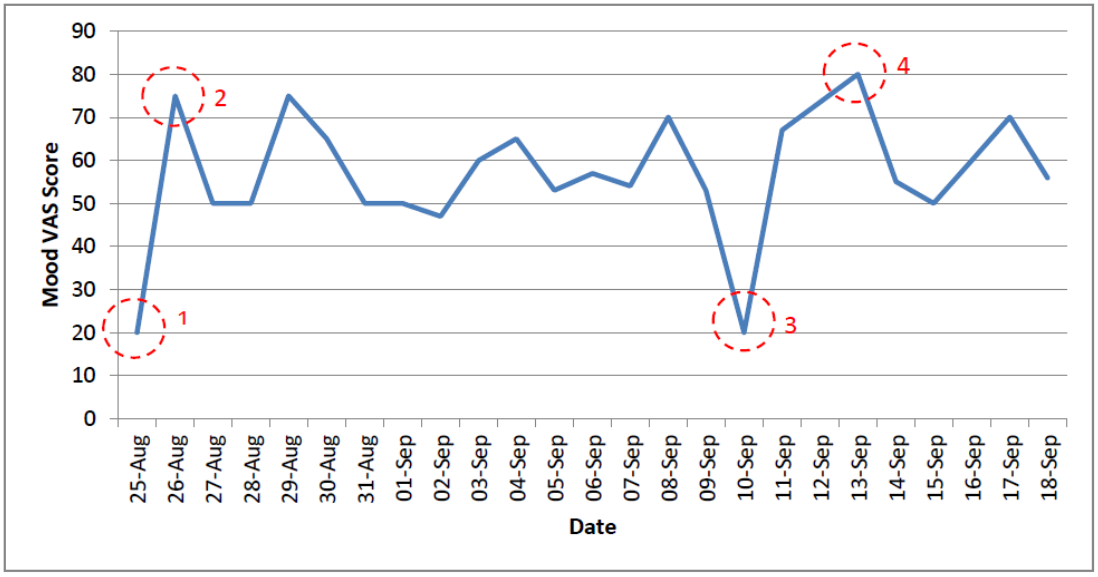


Figure 53. Daily mood scores for LU2 from 25/08/14 to 18/09/14

Interestingly, higher self-reported mood appears to correlate with higher DTI-2 stress readings (see Figure 54); the two peaks are certainly consistent across the graphs. In contrast, the dip at point three in the graph above is represented by a lower level of stress on September 10th in the graph below. The participant's found it very time-consuming to keep this mood diary and the inability to easily distinguish periods of high and low mood in the DTI-2 stress data, lead to a decision to stop the daily mood recording and to continue with the DTI-2 alone.

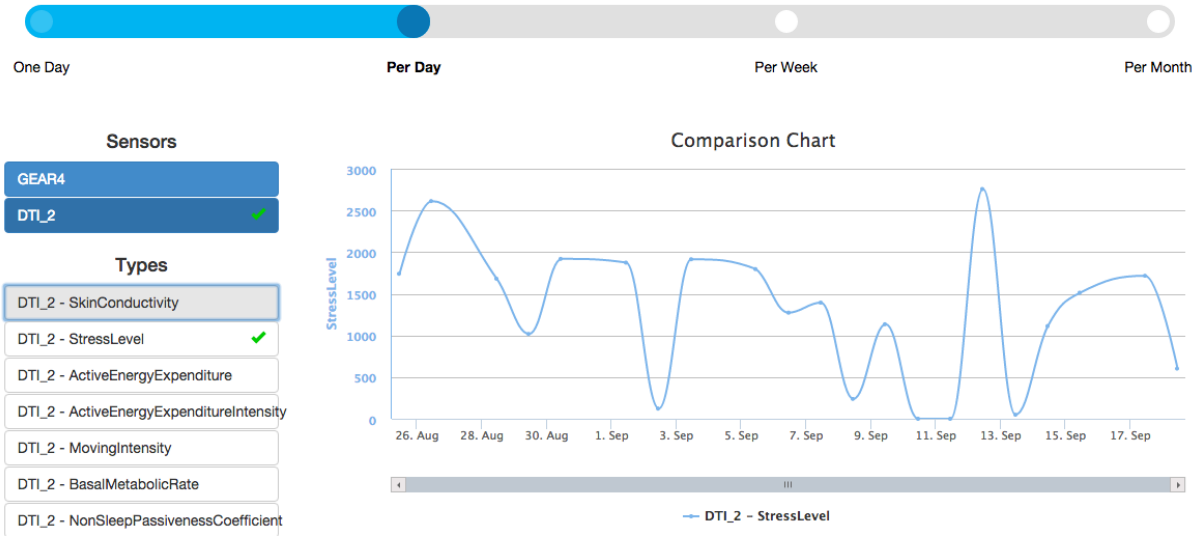


Figure 54. Daily DTI-2 stress levels for LU2 from 25/08/14 to 18/09/14

Longitudinal Analysis of Stress Data

Figure 55 presents the intensity of the periodicities of the stress-level signals recorded by the DTI-2 for Sean across the data collection period. Three peaks have been highlighted. The leftmost peak represents the initial period of usage of the devices, and it can be seen that the periodicity has a high intensity, i.e., Sean had a very regular stress levels during this time.

The following months show a period of no regularity, except for minor bumps around February, March, and May 2014. There is no notable intensity to the signal until September 2014, when there was a period of approximately 4 weeks where the intensity increased (albeit not to the level of the initial period). The signal intensity diminished again through October, with a minor bump in intensity around November 2014. These patterns are very similar to those seen with the DTI-2 physical activity data.

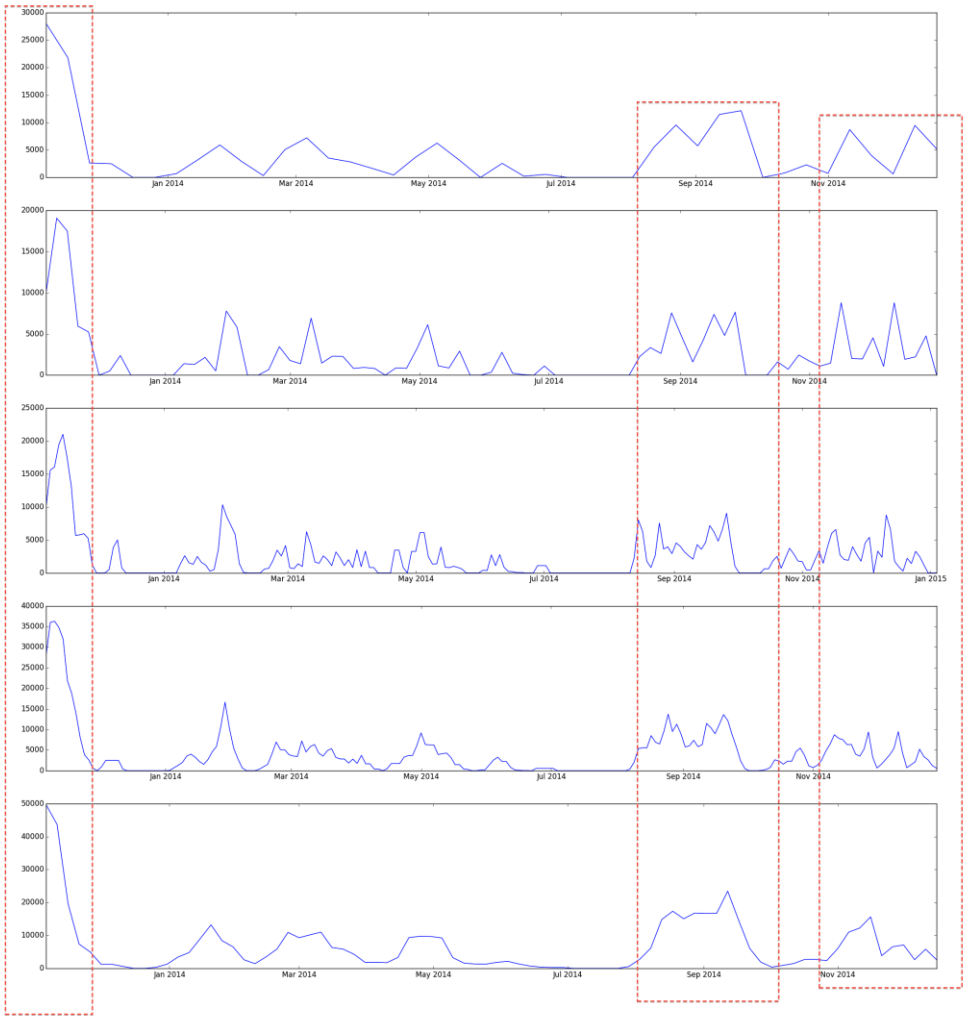


Figure 55. Intensity of stress-level periodicity for LU2

Relationship between sleep, stress, and physical activity data

Given the similarity in physical activity and stress patterns for Sean over the data collection period, it is unsurprising that a positive correlation was found between the two, as presented in Figure 56. The outliers towards the end of the dataset are likely to be artefacts of very low levels of available data at that point.

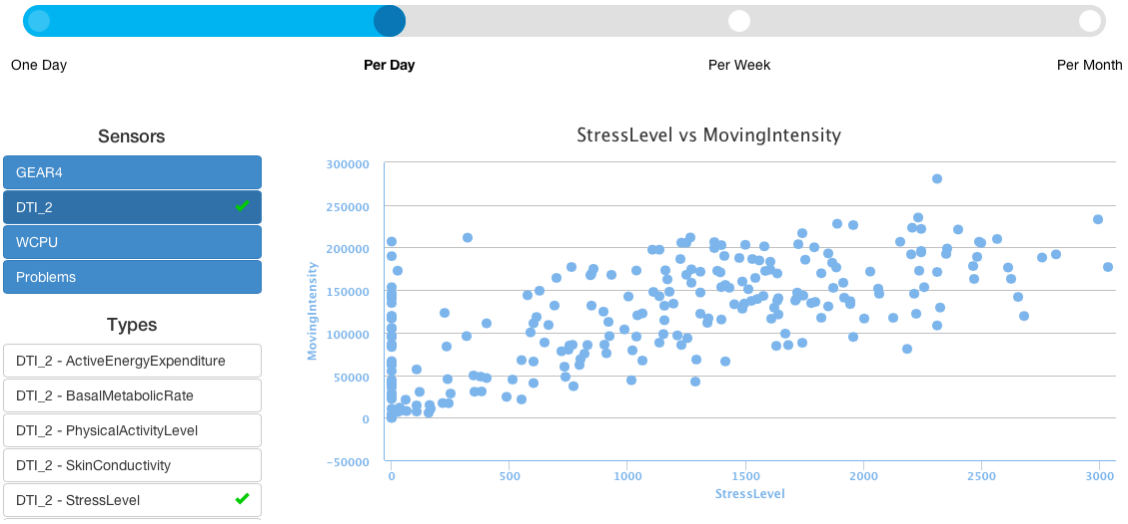


Figure 56. Correlation of Stress and Moving Intensity for LU2

No correlations were found between moving intensity and sleep duration, between moving intensity and sleep interruptions, between stress and sleep duration, or between stress and sleep interruptions.

6.2.2.3 Activities of Daily Living

As previously reported (see D8.4), Sean wore the GoPro camera for 1-2 hours a day, usually when he got up each morning, and a variety of typical daily tasks were recorded. On review of the initial four weeks of video data captured, eight activities were selected for continuous monitoring. During the following 12-week period, 134 recordings were captured (33.3 hours of video data) and representative samples of each activity were identified for annotation and the creation of associated taxonomies such that a location, activity, and object recognition model could be developed for the home environment. The @Home WCPU model was then validated using three types of calibration (Normalised, Platt, and PAV) in order to obtain overall accuracy levels for each activity. The annotated GoPro video taxonomies, and the overall model accuracy levels are summarised in Figure 57 below; a detailed explanation of this analysis is presented in D5.6 Multi-parametric Behaviour Interpretation v2 (Chapter 3) and in Buso and colleagues [26].

No one calibration method clearly achieved the best accuracy results across all activities; the most accurate method changes according to the specific activity. In general, activities that are performed in characteristic locations (e.g. feeding the birds), or with a small set of manipulated objects (e.g. take medication, water plants) are most successfully identified by the model. Activities such as ‘cleaning’, ‘prepare/eat breakfast’ present a much larger variations in locations and in objects used. To improve accuracy, more occurrences of these activities would need to be annotated and included in the training model

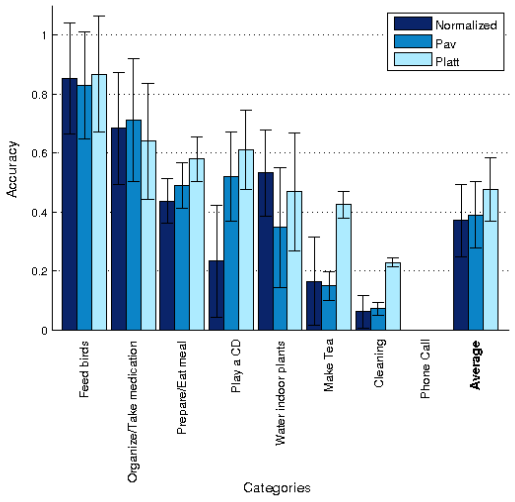


Figure 57. WCPU class per class accuracies

Accurately recognising the 'phone call' activity was most difficult, which could be expected as a phone call can take place in any room, it is difficult to recognise a small mobile phone in a person's hand and the phone itself leaves the camera's field of view once held to the ear. The suitability of a shoulder-mounted wearable camera therefore needs to be questioned for this particular activity.

The availability of the @Home WCPU model in pilot three enabled the loading and retrospective analysis of the GoPro data captured for this lead user. Researchers in DCU carried out a separate manual observational analysis of the same data in order to (a) validate the accuracy of the results generated by the model when applied to non-training data and (b) to determine the clinical usefulness of these results. As synchronisation of the GoPro camera remained an issue in the home environment throughout the project, it limited the extent to which the GoPro data could be fused with data from other sensors, but this did not impact the analysis of the standalone use of the activity recognition model.

Manual Observation Analysis of Activities of Daily Living

As making and eating breakfast is a highly rehearsed activity for Sean, this was separated from preparing and eating other meals in the manual analysis. Medication-related activities were also split into preparing and taking medication. Finally, the 'Play a CD' activity was not included in the manual analysis as there were too few examples of this activity over and above those annotated to train the model. As a result, nine activities were reviewed as part of this observational analysis.

Three videos for each activity were examined at baseline, 6-, 12-, and 18-months, and different types of errors and incidents were recorded. These errors included repeated or skipped steps, distractions (generated by Sean himself or others), mistakes, pauses/confusion and verbal prompts. Activity success was recorded as successful (completed with no errors), partially successful (completed but with some errors), or unsuccessful (not completed), along with the overall duration of the activity. The number of errors, the length of time per pause, the length

of time per activity and the success rate of each video was totalled and averages calculated for each activity (see Table 27).

Each video was initially analysed by a researcher who had no prior knowledge of the dyad; 10% of the data was analysed by a second researcher in order to provide inter-rater reliability. The second researcher had regularly visited with the dyad during the course of the Dem@Care pilot so they were familiar with this particular home environment. Discrepancies between the two ratings were discussed until agreement was reached.

Table 27 – Observational results of LU2 monitored activities of daily living

	Baseline			6 Months			12 Months			18 Months		
Activity	**Dur**	**E**	**S**	**Dur**	**E**	**S**	**Dur**	**E**	**S**	**Dur**	**E**	**S**
Prepare/Eat breakfast	26.31	7.33	3	30.22	4	3	24.51	13	3	40.30	18	3
Prepare/Eat other meal	16.18	4	1	16.47	3	2	N/A	N/A	N/A	17.25	5.5	1
Make tea	3.07	1	3	2.27	3.33	3	10.12	3	3	*6.04	7	1
Phone call	*5.29	2	1	2.37	0	3	0.55	0	3	*1.01	0	1
Organise medication	N/A	N/A	N/A	19.05	4	2	N/A	N/A	N/A	N/A	N/A	N/A
Take medication	0.57	1	2	2.10	2.66	3	2.57	5	2	1.14	3.33	3
Cleaning	1.2	0	1	0.53	0	1	1.04	1	2	N/A	N/A	N/A
Water Plants	*6.20	0	1	6.25	4.33	3	N/A	N/A	N/A	*1.29	1	0
Feed birds	3.58	3	2	N/A	N/A	N/A	4.35	5	2	21.10	14	2

Notes: Dur, Duration; E, Error; S, Success;
* indicates that video data only existed for one instance of this activity in this timeframe;
N/A indicates that no instances of this activity were captured in a given timeframe

1. Prepare / Eat Breakfast

The number of errors reduced by almost half between the baseline and the 6-month point which suggests that some benefit has been derived from monitoring and reviewing this activity on a regular basis. However, the number of errors increased greatly at 12- and 18-months, in comparison to the earlier time periods, and the average length of pauses during the activity also increased as time progressed. Although all reviewed instances of this activity completed successfully, the number of verbal prompts given to Sean during this activity had increased by month 18 indicating that this activity required more scaffolding. More of the individual items needed to make breakfast had been laid out on the table for Sean, whereas previously he would have retrieved some of these items himself. It was also evident that Sean was finding it increasingly harder to understand the meaning of the prompts given to him. This concurred with the feedback from his wife in the end of study interview.

"Still the same but longer, much longer… Two mornings ago I found him with the three pieces of cereal in the bowl and he was trying to put three more on top… he had a particularly bad night two or three nights ago and he had anoth-

er one last night, really bad, where he is awake a lot of the night, but that following morning when he came down he couldn't coordinate the breakfast so I am now starting to leave out everything including the milk and the yogurt… I monitor him more now and keeping an eye on him; 'there's the milk'."

2. Prepare / Eat Other Meal

At baseline and 6 months the main mealtime activity captured aside from making breakfast was making toast on the grill. The number of incidents remained fairly constant over these months, as did the number of pauses seen. The activity appeared to stop completely by month 12, although some instances were found in month 18. At that point, more assistance was provided by family members and in one case, the activity was taken over and completed by someone else.

3. Making Tea

At baseline, Sean was not encountering many difficulties when making himself a cup of tea, but errors started to appear more frequently at the six month point. This pattern remained stable through 12 months but another increase was evident in the number of errors observed by month 18.

4. Phone Call

Although Sean quite regularly answered the phone at baseline, the number of times this activity was captured declined over time. Catriona confirmed that she tended to call Sean while at work multiple times a day in the early months, but she tended to wait and call Sean at lunchtime in later months. This change occurred partly in response to a worry that Sean was not remembering to eat at lunchtime. It is likely that the reduction in activities captured is somewhat due to this change, although Catriona also commented that Sean's confidence in answering the phone had reduced significantly over time and that he doesn't use the phone at all now.

"Oh no, [phone] *is gone, that's been gone for ages. He couldn't tell me, he couldn't answer it, he … he couldn't be out anyway. That's completely gone."*

The wearable camera data is ideally suited to identifying this low level sequencing information and this enables a therapist or a caregiver to scaffold the activity so that it can be successfully achieved for longer. However, the wearable camera only captures 1.5 to 2 hours of data a day, so it is not the best choice for capturing the frequency of individual activities over time.

5. Organise Medication

Although a number of examples of this activity had been observed in the early weeks of the study and hence included in the training dataset, only two examples were found where Sean prepared the medication box. This task was generally completed by Catriona. As a result, it is difficult to draw any reliable conclusions from this data.

6. Take Medication

The number of errors in this activity increased noticeably at month 12 and one instance was not completed successfully. Catriona raised a concern in one of the review sessions around this time that Sean may not be taking his medication correctly despite his assertion that he was.

> *"You would have to look in the box because he would say he had, and he would think he had, but he wouldn't have, because I would have said it to him like, on some of the days that I would have forgotten to physically, visually check, I would have said 'Did you take your tablets?' and he would say 'yeah' and I would just accept that and then we would go to bed, and it's then in the morning and I would.. oh why didn't I look, if I'd have looked…"*

Additional support was given by the researcher to Sean and a reduction in errors was seen by month 18. However, the GoPro recordings took place in the mornings so all of these activities related to taking morning medication. In her final interview, Catriona explained that Sean was still having difficulty with night-time medication and that even with a checklist and prompts, it was essential that she physically inspected the medication box to ensure that all tablets had been taken correctly.

> *"What he is doing an awful lot now; there is three little boxes that he has to take and there is different amounts in the three boxes and he'll take the first two boxes, you know the days, but he'll forget the third one. That's a real common one… and what I do now is I physically open the boxes as well because he can't figure out… which day we are on. Even if I say 'It's Tuesday tonight love', he won't know which day is the Tuesday… this is what I mean about how things are changing, and quite rapidly."*

This again highlights the limitation that GoPro data recording only captures small parts of the day. The addition of motion sensors would identify if the medication box had been moved, but there would still be the issue of not knowing if all tablets had actually been taken. Given the importance of taking medication correctly, it is unlikely that carers will feel comfortable relying solely on sensor data for this activity.

7. Cleaning

Sean had a routine of cleaning the kitchen once he had finished breakfast and this activity was included in the initial training dataset, however, this activity reduced significantly over time and the detail of the tasks involved varied hugely across the instances of this activity. There were insufficient examples of repeated activities to provide reliable results of functional change over time.

8. Watering Plants

Most of the examples of watering the plants were found in the early months of the study when this was a regular day-time activity for Sean. The error count for this activity rose between baseline and 6-months and the activity itself had declined completely by the 12-month point. Although Sean did attempt this activity in month 18, it was a very brief attempt and the activity did not complete successfully.

9. Feeding Birds

Again this was a common activity for Sean in the early months and it was regularly completed successfully. No instances of this activity were recorded at month 6, but this may be explained by the fact that this is a seasonal activity and it is required less in the summer months. When the activity reappeared in later months, the number of errors increased quite significantly, as did the length of the activity. Catriona reported that although Sean continues to attempt this activity, he does not really engage in the activity itself, nor does he manage to complete it successfully at this point.

> *"He doesn't really feed the birds any more. I don't even raise it. If he doesn't do it, he doesn't do it. An odd time he'll go out but he is not actually feeding them."*

Results of the manual video analysis found a decline in everyday functional abilities around Month 12. Increased duration and increased errors rates were seen for such activities as making toast, making tea, washing an object, and taking medication. Around this time, family members began to scaffold many of these activities but fluctuating results were found for those in which an intervention was made. With preparing and eating breakfast, for example, the numbers of errors initially increased but then decreased as more prompts and help was given by others. These included family members placing breakfast items on the table before the activity started or bringing items to Sean, whereas previously he would have retrieved these items himself. This was shown to have positive impact in that overall error rates declined, but some negative effects were also seen. On some occasions Sean went to pick up the particular item regardless of it being on the table. This caused some confusion and increased the number of errors for that instance of the activity. In general, error rates increased for activities that remained unsupported over time.

These results should be interpreted in light of the following limitations:

- Not all activities were captured with the same frequency. In some cases, three examples could not be found for each time period.
- The routine followed in some of the activities was highly variable (for example, feeding the birds and watering the plants), so it was difficult to determine if the routine itself had changed.
- Due to the restricted field of vision of the camera, it was sometimes difficult to determine if a pause related to an error or to a distraction, or if Sean was doing something else outside of camera view.
- Activity complexity was not specifically included in the analysis. Some activities are more complicated and have more steps than others which could be a factor in the number of errors generated for those activities.

- Video recordings were not available for every day or for every part of the day. It is possible that 'good' days were over-represented in the sample while 'bad' days could have been missed.

In conclusion, the manual analysis of the GoPro data provides an insight into the rate and type of functional decline experienced by Sean over the course of the @Home pilots. The videos provide invaluable detail as to where and why these errors occur, which can be examined in order to determine how the activities may be better supported. They also show whether such support is achieving the desired effects, and which activities have been maintained more successfully over the time frame; a finding that is equally beneficial to the person with dementia and to their families. The pattern of decline found in this analysis also supports the carer's view of gradual decline over time.

> *"*[LU2] *is getting slower and less able to do the everyday things, like he can't even work the telly flick now, he's finding that hard. His phone is gone because he can't work it and sometimes even to find the fridge it can be difficult or he might try put his sock over his shoe, you know little things, all little, all minor but you can see the gradual decline."*

Dem@Care Analysis of Activities of Daily Living

Approximately 177 hours of GoPro video data was gathered for LU2 over the course of the @Home pilot. As described in the previous section, 33.3 hours of data were used to train the WCPU model for this participant's specific home environment. The remaining video data was analysed retrospectively during the final pilot as the WCPU models were not available until this point. Although all of the data has been gathered for the same activities and in the same home environment, a number of issues were found when this data was analysed in Dem@Care.

Firstly, the object recognition results associated with each activity can be visualised in Dem@Care, however, even though objects found within the video frame can be seen, it is not possible to determine if any of these objects are being used incorrectly, if repeated actions are taking place, or if there are sequencing problems within the activity. Nor can pauses, distractions, or prompts be identified. Given the sheer volume of data that is presented when low level objects are visualised (see Figure 58), and the fact that it is not useful in discerning repeated and missing steps, the @Home system was configured to display activities only.

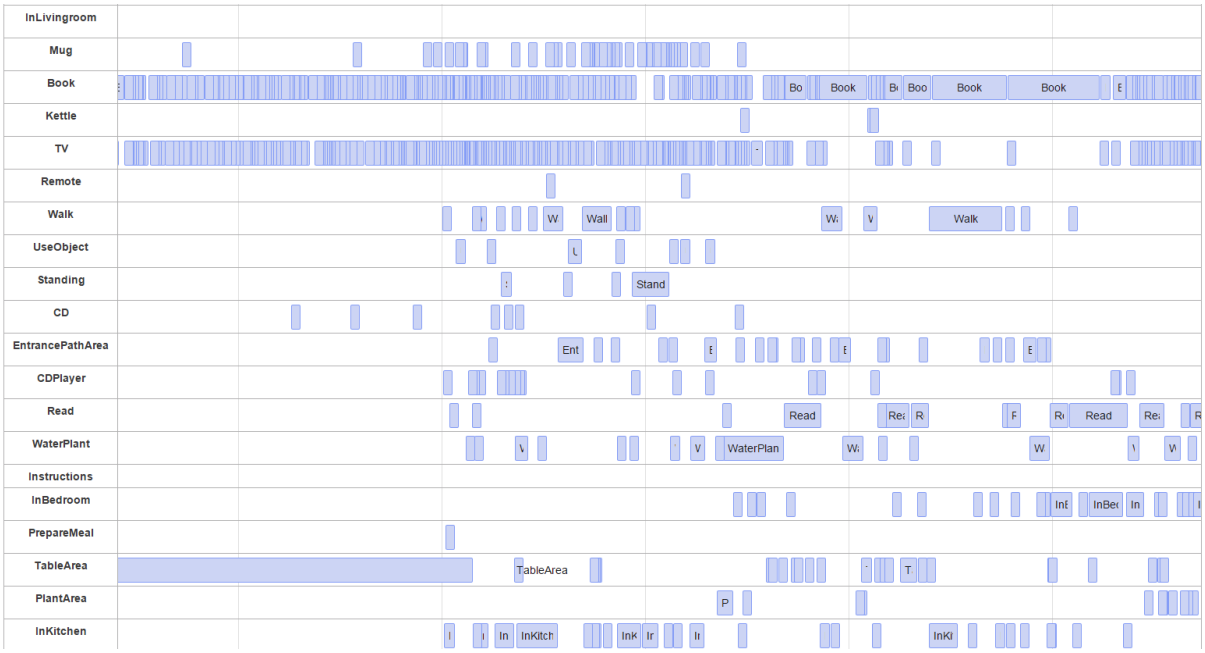


Figure 58. Example object and low-level activity visualisation for LU2

Secondly, this participant carries out a number of activities at their kitchen table, most notably (1) having breakfast, (2) Preparing the drug box, and (3) taking medication. The drug box is usually visible on the table even when it is not actually in use. The WCPU model typically identifies medication-related activities well. Twenty-two video clips containing medication activities were reviewed. These clips had previously been included in the manual observation analysis. The WCPU model successfully identified a medication-related activity on 19 occasions (86.4% accuracy), but the model was not able to successfully differentiate between 'Preparing the drug box' and 'Taking medication', nor was it able to identify that the participant had taken his medication correctly. It would not be appropriate, therefore, to use this functionality to monitor medication adherence.

The WCPU model performed poorly when attempting to differentiate medication-related activities from 'Having breakfast'. Forty video clips, also part of the manual analysis, were selected for review. The 'Having breakfast' activity was successfully identified in eight clips (20%), it was misclassified as 'Preparing the drug box' on 18 occasions (45%), and no activity was identified in the remaining 14 clips (35%). However, as can be seen from Figure 59, even when classified correctly, 'Having Breakfast' was only sporadically identified during the clip and many of the frames related to this activity were classified as 'Preparing the drug box'. It appears that the presence of the drug box is driving the activity recognition in these videos.

Figure 59. Example visualisation of high level activities for LU2

This highlights another difficulty with the interpretation of the video data from a clinical perspective. In this example, the participant has breakfast once but it appears as if he has multiple breakfasts or makes multiple attempts at this activity. The difficulty is that the objects associated with breakfast can move in and out of the camera frame as the wearer shifts body position. In addition, although a total activity duration figure can be read from the bar chart on the screen shown in Figure 59, this is not a true reflection of the elapsed time for the activity. The WCPU model also identifies basic activities such as walking and sitting, and when these appear within a high level activity such as 'Having breakfast' or 'Preparing drug box', they are extracted as different activities. When these issues are combined with the misclassification of frames that include the drug box, the resulting data becomes difficult for the clinician to interpret with ease.

The Dem@Care findings for the all of the videos that had been included in the manual observation analysis were reviewed in detail. Six instances of phone use were correctly identified from 10 videos that included phone activity (60% accuracy). The main difficulty the WCPU model encountered in this case is that a mobile phone is small, it is often only seen for a few frames, it can be poorly visible in those frames (e.g. partially hidden by the person's hand), and it is often not seen again until the end of the activity. When the phone is clearly visible the WCPU accuracy improves. The position of the camera on the person's shoulder is not best-suited to capturing this activity. Activities that involved a lot of walking were identified as 'Walking' rather than as the activity itself, almost as if the action of walking takes precedence over any objects recognised in the video clip. This problem occurred for three activities: watering the plants, making tea (as the participant tended to move around the kitchen while waiting for the kettle to boil), and cleaning. While the WCPU model did identify that an activity that we wished to monitor was taking place in these videos, the clinician needed the results of the manual analysis to accurately determine what this activity was. Dem@Care was not able to identify any instances of preparing a meal other than breakfast (e.g. making toast).

Only small amounts of training data were available for this activity which is likely to have contributed to these results. Dem@Care was also unable to identify any of the 'Feeding the birds' activity. Future development of the Dem@Care system would need to address these accuracy and visualisation issues.

Overall, the Dem@Care analysis was not as accurate as the manual analysis, nor did it reach the accuracy levels obtained with the annotated training data. These findings demonstrate the difficulty of obtaining accurate results in an uncontrolled home environment. Significant amounts of annotation will be required in order to obtain acceptable accuracy levels; this in turn requires significant time from researchers and technicians. It is therefore unlikely that the wearable camera will be a viable option for @Home deployment in its current state. That said, it does provide an opportunity to capture daily living in a familiar environment and it can supplement the information a clinician has available to them when looking at ways to scaffold activities for people with dementia. Rather than being used as a continuous monitoring tool, it is more likely that it could be deployed for short periods of focused monitoring and assessment similar to the way GPs currently request patients to use heart monitors for short periods at home. As more detailed activity recognition and object sequencing models become available, and the necessary researcher and technician time can be reduced, this functionality may be more suited to the home environment.

Relationship between sleep and activities of daily living

There was an observed link between poor sleep and low success rates with ADLs. This was becoming most evident in May 2015 but at this point the dyad wanted to return the sensors and withdraw from the Dem@Care pilot. Sean was becoming increasingly anxious about the sensors and they were becoming an additional burden to both participants rather than an integral part of Sean's care.

6.2.2.4 Social Interaction

Social interaction was not identified as a clinical need for Sean or as a concern for either himself or Catriona. They did kindly help us to test a mobile phone audio app to determine that is was of sufficient quality to support voice analysis. The testing confirmed that the app provided voice recordings that were of a high enough quality for voice analysis, but it also demonstrated that focused and reasonably lengthy conversations were needed and that capturing data for voice analysis should form part of a therapist-supported intervention. It was not suitable to a general conversational setting, nor to a researcher data collection visit. A form of ambient sound recording might have been useful in this scenario. It would need to be able to determine how much conversation the person with dementia initiated and responded to without analysing the actual content of the conversation itself (for ethical reasons). This is a potential area of future development for Dem@Care.

Sean was not a suitable participant for the psychosocial intervention that formed part of the final @Home pilot so no further voice recordings were analysed.

6.2.2.5 Psychometric Measures

Psychometric measures of quality of life, depression, and stress were administered at the beginning of the second pilot (08/2014), mid-way through the second pilot (11/2014) in time for the preparation of the second pilot report, and at the end of the dyad's involvement during the third pilot (06/2015). As can be seen from Table 28, Sean's Qol-AD scores remained un-

changed throughout across the pilots. His wife's proxy scores on the same showed a significant decrease in November 2014 but an increase which surpassed baseline levels in June 2015. Sean was experiencing high levels of stress towards the end of 2014 and this is reflected in Catriona's ratings but not his own, although this was reflected in his higher PSS score for the same period. As previously reported (D8.4), Sean found it considerably more difficult to complete the measures in November 2014 than he had on the previous occasion. He was unable to comprehend the questions, even when rephrased, in the final interview so no scores exist for June 2015.

Table 28. Psychometric data collected for @Home Lead User 2 (PwD)

Measure	**Time 1 (08/14)**	**Time 2 (11/14)**	**Time 3 (06/15)**
Qol-AD	42	42	42
Qol-AD Proxy	34	26	39
GDS	3	3	N/A*
PSS	16	20	N/A*

Note: QoL-AD, Quality of Life – Alzheimer's disease [5]; GDS, Geriatric Depression Scale [6]; PSS, Perceived Stress Scale [7]; *Participant unable to answer the measures at Time 3 – these items were covered in the qualitative interview instead.

Psychometric results for Catriona also show heightened anxiety levels in November 2014 that subsequently reduced, albeit that they remained higher than at baseline (see Table 29). In November, Catriona spoke of seeing deterioration in Sean's condition, her anxiety on his behalf, and her feeling that she would not be able to continue working to the same extent as she currently was. Catriona reduced her work hours in February 2015 and she feels that she is now better able to support Sean. She also feels that this has helped to reduced her overall stress levels, although she is concerned about Sean's continued deterioration and the financial implications of her reduced hours once her carer's allowance runs out (only available for two years regardless of the needs of the person being cared for).

Table 29. Psychometric data collected for @Home Lead User 2 (Carer)

Measure	**Time 1 (08/14)**	**Time 2 (11/14)**	**Time 3 (06/15)**
Carer-QoL	5	7	9
HADS	Anxiety (10) Depression (12)	Anxiety (19) Depression (11)	Anxiety (12) Depression (5)
RSS	Emotional (20) Social (15) Negative Feelings (0) Total (35)	Emotional (20) Social (18) Negative Feelings (1) Total (39)	Emotional (18) Social (17) Negative Feelings (3) Total (38)

Note: Carer-Qol, Carer Quality of Life [8]; HADS, Hospital Anxiety and Depression Scale [9]; RSS, Relatives Stress Scale [10].

6.2.2.6 Dem@Care Interfaces, Acceptability and Usability

Dem@Care Interfaces

Delays in the completion of the Dem@Care carer and patient interfaces meant that these could not be installed and used by the lead user dyad in advance of the third pilot. By the time stable versions were available for use, Sean's condition had deteriorated significantly and his wife reduced her work hours to be able to spend more time caring for Sean herself. Despite not using the interfaces on a daily basis, both participants were happy to evaluate the interfaces and discuss how they might have used them in earlier data collection phases.

Catriona particularly liked the date and time screensaver in the most recent version of the interface for the person with dementia. She suggested that the day and time could appear on the top of every screen including the daily schedule, checklists and reminders so that no matter which screen the person was looking at, they would be oriented to day and time of day. She also advocated for an increased use of visual prompts and voice alerts.

> *"I think pictures on things… I'm starting to think might be a good idea, yeah"*

> *"A voice thing [alert] would be a good idea as well, because I understand that reading is becoming kind of an issue as well, you know… so something that would say it 'Don't forget to take your drugs; Don't forget to lock the door; Don't forget to feed the birds', you know, whatever"*

The reminder functionality was seen as particularly useful especially for repeated activities and tasks that should happen at specific points in the day. Some of these reminders could also be useful for the carers themselves as the number of things they need to remember increases as more monitoring of their loved one is required.

> *"A reminder for [Sean] to take his tablets would be great, because I do find that worry when I get home in the afternoon and I look and .. '[Sean] you forgot our tablet" and even in the night... If I forget to check his tablets… see I used not check in the past because I didn't need to. I knew he took, he was doing that so long, but now that's gone, so now I physically have to check in the night, but sometimes I will forget; if there's a lot going down, and I won't realise until the morning… and he takes a huge amount of tablets in the night, so if he doesn't take them in the night, his next day is bonkers; things are askew if you like."*

The ability to incorporate a series of reminders and prompts into a daily online checklist was also something that Catriona thought she would have used. However, when Sean was asked if he preferred the written morning checklist or the online checklist, he clearly stated a preference for what he was familiar with; *"The piece of paper"*. Sean was not used to technology when he became a lead user. Although he had experience using a variety of carpentry machines, he had left school early and had never been exposed to technology. He did have an open attitude to technology, and he was able to build up a routine for using the sensors in the early months that was maintained until earlier this year. As Catriona explains, he was keen to be involved in research that could benefit others in the future and this motivated him to try the sensors and the Dem@Care system.

"[Sean] got into the routine of doing it [wearing the DTI2 and GoPro] because he took it quite seriously in the sense that he had great time for [researchers] and he knew you were doing good, so he knew you were good decent people if you like, and therefore it was easier for him to understand it because he knew there was something positive coming out of it and he also knew that [researchers] were very positive towards him so [researchers'] attitude was hugely helpful in him being able to do it and being comfortable about doing it."

Sensor acceptability and usability

Sean did find it difficult to get used to the sensors initially and a period of training with high levels of researcher and carer support were needed. Sean was able to incorporate wearing the DTI-2 and using the GoPro into his daily routine, although the video captured naturally occurring morning activities as attempts to introduce recording of specific activities were unsuccessful. Catriona was responsible for charging and synchronising all devices.

The System Usability Scale (SUS) [27] was used by all participants to rate their satisfaction with each of the Dem@Care sensors. SUS scores are expressed as a percentage satisfaction. Sean and Catriona rated the Gear 4 sleep sensor at 70%. Positive aspects included a very simple on/off button, and easy to understand visualisation of sleep patterns. Catriona noted that the simpler the sensors were the better ('*sensors for dummies*'). Negative aspects included a distracting light display (the clock element of the sensor) that needed to be covered at night. Much lower satisfaction ratings, 52.5%, were given for the DTI-2 actigraphy bracelet. Sean and Catriona experienced a lot of glitches when they first started to use the device although this improved with time. They main issues they found were: (1) there were four buttons on DTI-2 but no indication of what each one did; a sticker had to be added beside the on/off button, (2) it was not possible to look at the device and know it was switched on; a small light would have been useful, (3) the strap was very hard to use, velcro or a more standard watch trap would have worked a lot better, and (4) Catriona found the automatic synching process difficult given her general lack of experience with computers.

"The uncertainty sometimes of when something was on, is what always threw the two of us, I think, and me as well. That's why I was saying earlier on about the On and the Off button. You should be able to know if something is on. Like if you know your TV is on, there's a visual thing or the sound, whereas I found it hard to know. I know we did eventually get it, but I just found that whole thing… if the On and Off buttons could just be simplified, then anybody could do it" [Catriona]

Two different ratings were gathered for the GoPro camera; the first including the need to synchronise the device and the second without this aspect as researchers were aware that this caused significant difficulties and was likely to skew the results. When synchronisation was included, the GoPro rating was 42.5%. This improved to 72.5% when participants were asked to ignore this process. Positive aspects of this sensor included a simple one-click on/off button and easy charging mechanism. In fact, both Sean and Catriona reported that he '*loved*' the camera and enjoyed wearing it. Some problems were encountered with the extended-life battery and on occasion Sean accidently changed the settings on the camera from video to image recording. Overall, it was more intuitive and much easier to use once the need to synchronise was removed. Although this caused difficultly fusing this data with other sensor data in Dem@Care, this decision was essential in order to facilitate any data collection using this device.

When asked if she thought Sean would have been able to manage the sensors alone, Catriona felt that this was unlikely.

> *"It would have been hit and miss, I'd say… he would need to have somebody supervising them, you know. If I didn't tell him, he wouldn't do the little things, whatever it was. Sometimes he'd do it very smoothly, other times he'd hesitate, and you'd know he wasn't sure what was to go where, what he was even to do."* [Catriona]

Catriona and Sean were also asked to suggest when they thought the right time would be to introduce this type of ICT solution to a PwD and their family.

> *"You wouldn't introduce technology at that point [when a problem has already started], because the point he is at now, he has, you can see him negotiating, where is the fridge. When I said to him the other day 'Love will you shut the study door' and he's right beside... he is literally on top of it, and he doesn't get that that's the study door… and he wouldn't have done that before, so that's him losing the process of… so the idea of introducing something scientific or teckky at that point would be madness, so it wouldn't have worked. No, you'd need to get it earlier on. Now it would make it easier ok, if the person you are dealing with is kind of techy, ok, which in [Sean's] case isn't so… For anyone at all who would be comfortable around computers, I would imagine they would absolutely love it, regardless of where they are in the journey, I would nearly say."* [Catriona]

Overall, Catriona and Sean were interested in the functionality offered by Dem@Care. They thought it useful and they could have imagined how it might have been useful to them in an earlier phase of Sean's illness. Unfortunately Sean's dementia progressed significantly in the last six months which coincided with the time that the Dem@Care interfaces and integrated sensor feedback was available for them to use. As a result, it was not used as much as it might have been if it had been available a year earlier. That said, they valued the feedback from the sensor data which they went through with the researcher in the Clinician's Interface or using the Gear4 App in the case of the sleep data.

> *"I would be inclined to use it. I am a great believer in if something helps, or if something works, go with it, but if it doesn't, leave it, walk away."*

6.2.2.6 General Conclusions

The most beneficial aspect of the Dem@Care system for these participants was the objective measurement of sleep and actigraphy data. The ability to see Sean's sleep patterns over time, and the extent of the disruption caused in the mornings, enabled the couple to adjust their living patterns so that these disruptions could be minimised. They also enjoyed using this sensor and they found it relatively easy to operate. The patterns of physical activity and stress levels captured by the DTI-2 device were also very beneficial as the couple had expressed an interest in being able to monitor Sean's activity levels in more detail. Again the sensor was well liked although slightly more difficult to operate. It was unfortunate that data from early 2015 was lost as a distinct change in physical activity patterns and stress levels occurred around this time.

The most significant benefit for this couple was the opportunity to take part in dementia research which they really enjoyed. They were happy to test sensors in the early stages

of the project knowing that there would be glitches and that only limited feedback was available. They had reviewed early versions of the patient and carer interfaces and they were willing to use the updated interfaces but the timing of their availability unfortunately coincided with a decline in Sean's condition.

> *"It was just the humanity of it was hugely beneficial to him because he actually looked forward to it and he enjoyed it, and he did understand that somewhere along the line this is helping science, or you know future research…He got a buzz out of that. That was really important to him because he was being valued"* [Catriona]

6.2.3 Case Study: John and Ann (LU3)

A summary of the data collected for this lead user is provided in Table 30 below. Some difficulties were encountered with the use of the sleep sensor over the course of the data collection period. This initially resulted in lost data. An agreement was reached whereby the sensor need not be used if the informal caregiver (Ann) was unavailable to assist. Later in the data collection period, problems were encountered with occasional corrupt data in the sensor data file. This appeared to be the result of leaving the sensor to run continually (i.e. not stopping recordings in the morning and restarting them at night). As a result, some additional data was lost.

Table 30. Sensor data collected for @Home Lead User 3

Sensor	Deployed	Days Data	Comments
Gear 4	274 days	152 days	No data collected if carer was unavailable for any reason. Some daily records were also corrupted if the sensor had been left running for long periods of time.

Later in the data collection period, problems were encountered with occasional corrupt data in the sensor data file. This appeared to be the result of leaving the sensor to run continually (i.e. not stopping recordings in the morning and restarting them at night). As a result, some additional data was lost.

6.2.3.1 Sleep results

Objective and perceived sleep quality

John reported clear sleep pathology in his baseline assessment (PSQI = 9). As can be seen from Table 31, sleep efficiency, sleep disturbance, and overall sleep quality contributed most to this score with sleep duration and days dysfunction due to poor sleep also noted. Initial analysis of John's sleep data, as presented in the Intermediate Pilot Report (D8.4), indicated that he was experiencing more interruptions to his night's sleep (M = 10.68, SD = 3.90) than would be typical for a man of his age. At that point, data was analysed for 62 nights and John experienced more than 5 interruptions on 57 nights, and more than 7 interruptions on 49 nights. John does have a co-morbid urological condition although this alone did not explain

the level of interruptions as John reported that he would only go to the bathroom once or twice a night and that he often just lies in bed awake.

Table 31. PQSI total and domain scores for Lead User 3 across the data collection period

	Baseline	Intervention Start	Post-Intervention
PSQI Total	**9**	**7**	**7**
PSQIDURAT	1	0	0
PSQIDISTB	2	1	1
PSQILATEN	0	2	2
PSQIDAYDYS	1	1	1
PSQIHSE	3	2	2
PSQISLPQUAL	2	1	1
PSQIMEDS	0	0	0

Note: PSQIDURAT, sleep duration; PSQIDISTB, sleep distribution; PSQILATEN, sleep latency; PSQIDAYDYS, days disturbance due to poor sleep; PSQIHSE, sleep efficiency; PSQISLPQUAL, overall sleep quality; PSQIMEDS, needs medication to sleep.

A small but significant positive correlation was found between interruptions and sleep duration, $r = 0.30$, $p < .05$. Despite high numbers of interruptions, John was actually getting an average of 9.7 (*SD* = 1.75) hours sleep a night. John was aware of his interrupted sleep pattern at that time and it is likely that this knowledge was leading him to perceive that he was sleeping less than was actually the case. Although John was sceptical about the validity of the feedback in the early weeks, he did begin to perceive some improvement in his sleep in the months following the baseline measures.

John's weekly sleep duration and sleep interruption patterns from August 2014 to early May 2015 are presented in Figure 60. Analysis of the full period of data collection shows that John continued to have a similarly interrupted sleep pattern, but the results also show that he slept for an average of 11.61 hours a night (SD = 1.87), and he experienced an average of 9.68 (SD = 4.41) sleep interruptions per night. Most months John slept for an average of more than 11 hours (10.77 hours in March 2015). Periods with missing data are clearly visible (e.g. October 2014 and January 2015) and in general the numbers of days data reduced as time progressed.

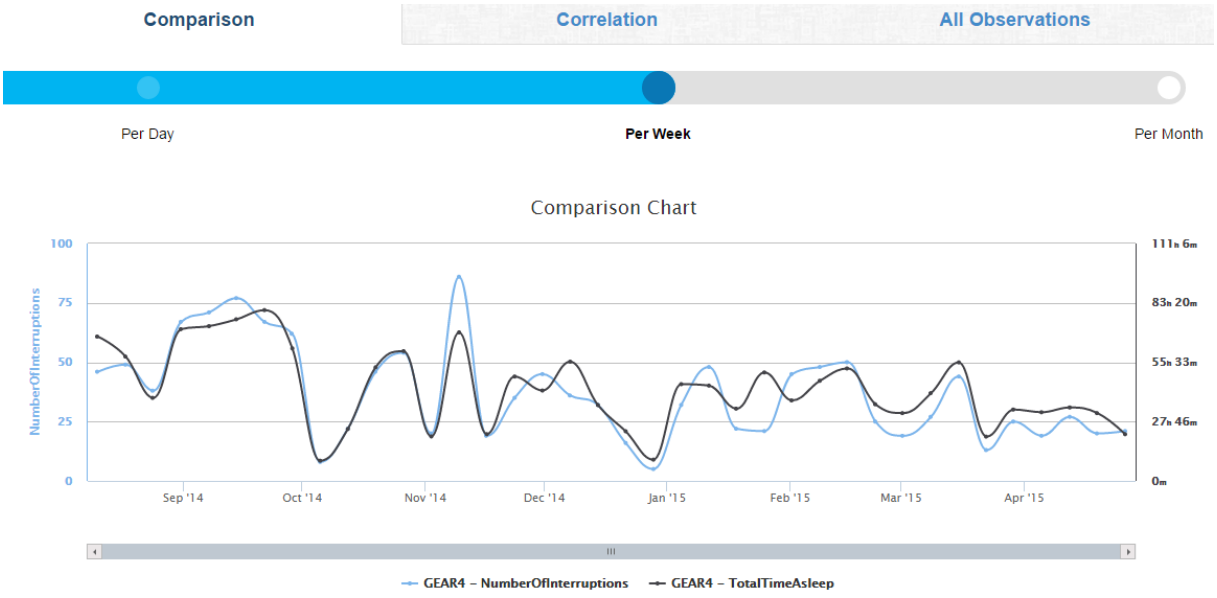


Figure 60. Weekly sleep duration and sleep interruptions patterns for lead user 3

The Dem@Care data demonstrated a change in John's typical sleep pattern during the second pilot around the time that the hour changed (end October 2014). John had begun napping in the afternoons and sleeping for two to three hours each time. While reviewing this feedback, John and Ann agreed that this was happening more than usual and we spoke of the potential negative impact that this could be having on John's nightly sleep. Ann mentioned that she usually switched off the sleep sensor in the mornings but has forgotten to do that a number of times. We could not therefore be certain that this was a change in John's sleep pattern and we agreed to keep monitoring the situation. The idea of using the DTI-2 bracelet during the day was discussed again but John was not comfortable to try the sensor at this point, and Ann was concerned with having another device that she would have to manage on his behalf. These findings further highlight the importance of '*always on'* sensors that require little or no interaction once they have been installed.

In March 2015, John began the psychosocial intervention that was offered as part of the third pilot; refer to the Cognitive Intervention Case Study 1 presentation below for the findings from this intervention. A slight improvement in perceived sleep quality was noted at the start of this intervention although sleep pathology was still indicated (PSQI = 7). Slight improvements were reported to sleep efficiency and sleep distribution, and sleep duration was no longer found to be an issue, however, sleep latency emerged as a new problem at this time (see Table 31). No change was seen in reported sleep patterns at the end of the intervention period, which coincided with the end of the data collection period also.

Longitudinal Analysis of Sleep Data

A periodogram of John's total sleep duration also exhibits a 24-hour periodicity, corresponding to the circadian rhythm (see Figure 61).

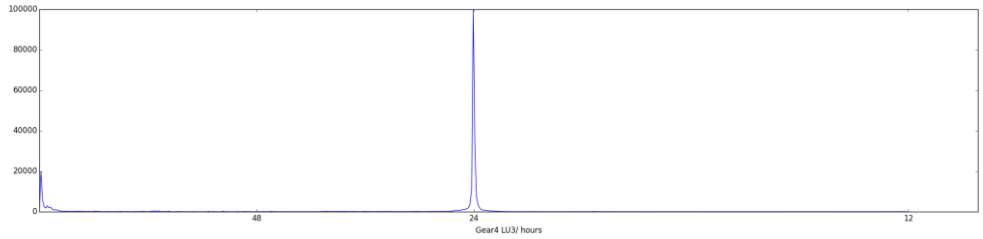


Figure 61. Periodogram of sleep data for LU3

Figure 62 corresponds to a measure of the intensity of John's sleep patterns. Examination of this graph suggests that John initially had regular sleep patterns and then a prolonged period of reduced intensity, but these results are likely to be an artefact of the analytical method and not a true reflection of John's sleeping patterns during the @Home pilot.

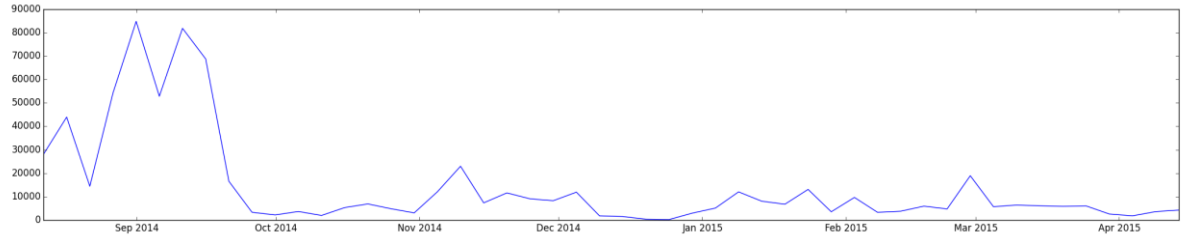


Figure 62. Intensity of sleep data for LU3 (24-hour periodicity)

While the methods used to create a periodogram successfully account for missing data, it is not possible to successfully manage missing data when analysing intensity. John never became comfortable operating the sleep sensor himself and he relied on the support of his wife. After an initial training period, they managed the sensor well and data was successfully captured most days. However, Ann's own health became increasingly problematic and she was unable to start and stop the sleep sensor for John which meant that sleep data was not captured for an increasing number of days as the pilot progressed. As a result, the longitudinal analysis of sleep data for this participant is limited in its ability to highlight clinically useful information about John's sleep patterns.

6.2.3.2 Psychometric Measures

The baseline clinical needs assessment for this participant was presented in the Second Pilot Evaluation Report (D8.4). Only those items that were tracked from that point onwards will be discussed here. A quality of life measure and associated proxy were introduced at time 2. As can be seen from Table 32 and Table 33, John's Qol-AD scores and Ann's proxy scores improved over the course of the intervention. A dip in John's physical activity levels had been noted in the lead up to the start of the intervention, and these also improved as he returned to more independent physical activity. Detailed results from his intervention are presented in with the Cognitive Intervention data below. Very little change was seen John's levels of social support; the higher the score, the more support available to him. Although he has no close friends who are still alive, he does have support from his family. John does experience some emotional loneliness (scores over 2 indicate significant loneliness). This is an area of risk for the future.

Table 32. Psychometric data collected for @Home Lead User 3 (PwD)

Measure	Time 1 (08/14)	Time 2 (03/15)	Time 3 (07/15)
Qol-AD	Not Included	39	36
Qol-AD Proxy	Not Included	40	36
Bristol ADLs	8	10	9
RAPA	Underactive – regular (level 4)	Underactive regular – light activities (level 3)	Underactive – regular (level 4)
LSNS	28	25	27
De Jong LS	Emotional (2) Social (1)	Emotional (1) Social (0)	Emotional (2) Social (0)

Note: QoL-AD, Quality of Life – Alzheimer's disease; Bristol ADLs, Bristol Activities of Daily Living Scale [11]; RAPA, Rapid Assessment of Physical Activity [28]; LSNS, Lubben Social Network Scale [29]; De Jong LS, De Jong Loneliness Scale [30].

In addition to the quality of life, anxiety and depression psychometric measures included for carers in the amended pilot protocol, the WHO Quality of Life (Brief) measure [31] was also used with Ann as she has significant physical health problems that can impact on her overall general health and well-being. These measures were administered pre- and post-intervention. As can be seen in Table 33, none of the quality of life measures showed much change over this time period, although some improvement was seen in anxiety levels. This is likely to be linked to John's enhanced independence and Ann having less concern for the future.

Table 33. Psychometric data collected for @Home Lead User 3 (Carer)

Measure	Time 1 (08/14)	Time 2 (03/15)	Time 3 (07/15)
Carer-QoL	Not Included	5	5
Carer-QoL VAS	Not Included	7	8
HADS	Not Included	Anxiety (9) Depression (2)	Anxiety (4) Depression (3)
RSS	Not Included	Emotional (15) Social (2) Negative Feelings (7) Total (24)	Emotional (14) Social (5) Negative Feelings (6) Total (25)
WHOQoL-BREF	Not Included	Quality of Life (4) Physical Health (20) Psychological (23) Social (12)	Quality of Life (5) Physical Health (20) Psychological (21) Social (10)

Note: Carer-QoL, Carer Quality of Life [32]; Bristol ADLs, Bristol Activities of Daily Living Scale [33]; RAPA, Rapid Assessment of Physical Activity [28]; LSNS, Lubben Social Network Scale [29]; De Jong LS, De Jong Loneliness Scale [30].

6.2.3.3 General Conclusions

Prior to their involvement in the Dem@Care project neither John nor Ann had much experience with technology. John was never comfortable interacting with the Gear4 sleep sensor himself and Ann required a significant amount of researcher support. John was also very hesitant to try other Dem@Care sensors and when he began to experience difficulties with some ADLs it was agreed that he might benefit from taking part in the CR intervention scheduled to take place during the third pilot. John's participation in the intervention was also seen as an

opportunity to investigate the potential for deploying additional sensors in the context of increased support being provided by the therapist.

6.3 @Home Cognitive Intervention (Dublin, Ireland)

DCU designed a psychosocial intervention that could be supported by the Dem@Care system which was carried out during the final pilot. The objective of the intervention was to allow for the introduction of the Dem@Care sensors with direct therapist support. The development of the intervention protocol was informed by research carried out by Linda Clare & colleagues [34]–[37]. This research focused on a particular psychosocial approach to supporting PwD termed "cognitive rehabilitation" (CR). CR aims to prevent or reduce excess disability and maximise engagement in activity and social participation, thus improving quality of life (QoL) and well-being [38]. The protocol for the Cognitive Rehabilitation Intervention has been described in detail in the Intermediate Pilot Evaluation Report (D8.4). Individual case studies and results from the intervention are reported here along with overall conclusions.

6.3.1 Methodology

6.3.1.1 Participant recruitment

Six participants were recruited to take part in this intervention; three male and three female. Four therapists delivered the intervention; each participant had one therapist working with them, the same therapist worked with both Participant 3 and Participant 4 and another therapist worked with both Participant 5 and Participant 6. All participants had a diagnosis of early to moderate stage dementia, and the average age of the participants was 77 years. One participant had previously been a lead user on this project, another had taken part in a reminiscence study previously run by a researcher in DCU, and one person was recruited through the DCU Memory Works clinic. The other three participants were recruited through our connections with Alzheimer Cafes, dementia support networks, and other DCU dementia-related projects.

Five of the recruited participants completed the full CR intervention. Upon meeting and starting to work with the sixth participant, "Jack", the therapist felt that he was not suited to participation in the Dem@Care project at that time. Jack is 84 years old and lives with his wife Cathy in a Dublin suburb. They have three adult sons, only one of whom lives in Ireland and he provides a lot of support to his parents. Jack was suspicious of the therapist when he first met her as he saw no issues in his day to day life and was unable to understand the objectives of the research; he believed the therapist was there to discuss back pain and exercises. Thus the therapist believed that Jack was not capable of providing informed consent. Cathy was under a great deal of stress in supporting Jack at this time as he was experiencing significant difficulties in everyday life. She presented with low mood at times and was very emotionally labile. A discussion was held about this case at one of the multidisciplinary team meetings. It was decided by the team that the couple were approaching a crisis point and involvement in research at this time was not in their best interest. It was agreed with Jack and Cathy that they would not participate in the CR intervention; however, the therapist remained in contact with them until they were successfully linked in with primary care services in their local community.

6.3.1.2 Intervention Design

In the first stage of the intervention the therapist identified the most prominent everyday difficulties experienced by the PwD, and together the therapist, PwD and a relative/caregiver set therapeutic goals relating to these difficulties. In line with the main areas of interest of Dem@Care this process was structured around the areas of mood/QoL, sleep, exercise and physical activity, social interaction, and activities of daily living (ADL). Psychometric measures relating to each area were carried out by a Dem@Care researcher with the PwD and their relative/carer.

Once therapeutic goals were agreed the therapist then designed and implemented strategies to address them. In keeping with the overall approach to the @Home pilots in Dublin, sensors were chosen from the toolbox to meet the specific clinical needs of the participant and to address the participant's therapeutic goals. Each participant took part in 12-14 sessions; the duration of each session was 90-120 minutes and all sessions took place in the participant's own home. Therapists audio recorded each session to allow for analysis of participants' speech fluency over the course of the intervention. Participant consent was first established at the outset of the intervention. Throughout the course of the intervention a rolling consent process was followed whereby, at the beginning of each therapy session, the therapist explained the aims of the Dem@Care project and the nature of the intervention, and re-established that the PwD and their relative were still happy to take part. Multidisciplinary team meetings were held regularly where therapists discussed each case, presented any developments that had been made and received input from other team members on how best to progress with their intervention. Therapists also attended regular supervision with a psychotherapist unaffiliated with the Dem@Care project, where they had the opportunity to discuss any feelings and emotions which had emerged as part of their therapeutic work.

A post-intervention qualitative interview was carried out with participants and carers where they were asked about the acceptability and usability of the various sensors. During a focus group interview therapists were asked to consider the usefulness of the available sensors in relation to their therapeutic work. Therapists were also asked to consider this question as part of a post-intervention written reflexive exercise.

6.3.2 Case Studies

Participant 1 – "John"

Background

John is 76 years old and lives with his wife Ann in their own home in a suburb of Dublin. They have three adult children; two sons and one daughter, and three grandchildren. John was first involved with the Dem@Care project as LU3. As mentioned in the LU3 case study presentation above, a baseline assessment was carried out with John in August 2014. At this time a need for sensor support for sleep was identified and the Gear4 sleep sensor was deployed. Prior to their involvement in the Dem@Care project neither John nor Ann had much experience with technology. During his time as a lead user, John did not interact with the Gear4 sleep sensor himself and Ann required a significant amount of researcher support in using the sensor. John also began to experience difficulties with some ADLs during this time and expressed feelings of boredom and loneliness to the Dem@Care researcher. In light of these emerging difficulties it was agreed that John might benefit from taking part in the CR

intervention. John's participation in the intervention was also seen as an opportunity to investigate the potential for deploying additional sensors in the context of increased support being provided by the therapist.

Requirements

Sleep

John experiences some sleep difficulties; at times he can find it difficult to fall asleep and he also wakes up during the night and leaves his bed as he has trouble getting back to sleep. At baseline, his assessment of sleep quality revealed some evidence of sleep pathology (PSQI = 7).

ADLs

At baseline John received a BADLS score of 9, which does not indicate dependence; however, some difficulties were identified. John had recently dropped and broken his mobile phone. He explained to the therapist that he was struggling with using the replacement phone as he felt the buttons and screen were too small and he had difficulty remembering how to access stored numbers to make a call. John's wife Ann also described his difficulty with the mobile phone and mentioned that the phone and phone charger were frequently misplaced. This meant that John was no longer using the phone and Ann worried about having no means of contacting him when he was out of the house alone. Ann also expressed concerns that John was struggling with aspects of his morning routine, she described how he had recently begun to forget to buy milk or bread during his morning trip to the shop, she was worried he might forget to switch off electrical appliances after cooking breakfast and mentioned that John was neglecting some aspects of self-care. Ann experiences her own physical health problems and was uncertain whether John would be able to manage if she were to be unwell or away from the home for any long periods of time. She expressed a particular concern that John would not manage cooking for himself. John comes from a large family and frequently spoke of how he was taught to cook by his mother and would have often helped out in the kitchen. John was confident in his ability to cook but did acknowledge that he was out of practice.

Social Interaction

Before retiring John had worked as a carpenter, a scout leader, and was an active member of his community; however, at this time he was no longer involved in any of these activities and described how he missed them and felt bored and lonely at times. At baseline, John's assessment of social interaction revealed that he was at high risk of social isolation (LSNS = 25).

Physical Activity and Exercise

John has no mobility problems and goes for a walk to the shop every day, however, the baseline assessment revealed that his levels of physical activity were suboptimal (RAPA = 3).

Mood

John reports feeling a little down from time to time, however, his GDS score (3) is not indicative of depressed mood.

Therapeutic Goals and Strategies

Apart from feeling bored at times and having problems using his mobile phone, overall John did not feel that he was experiencing any significant difficulties in his day to day life and felt

he could cope well with everything he needed to do. However, he was generally aware of his memory problems and wanted to do what he could to continue to live well and independently. Thus the primary goal at the outset of the intervention was to enhance the John's independence by strengthening his morning routine and supporting him in learning to use a mobile phone and in practicing cooking an evening meal.

To address John's difficulty with his mobile phone the therapist introduced an "easy to use" phone. During sessions John and the therapist practiced making and receiving calls with the new phone. The therapist also called the new phone each morning to provide John with additional practice on receiving calls and to give him a reminder to take the phone with him when he went to the shop each morning. These calls were gradually phased out during the course of the sessions. To strengthen John's morning routine the therapist introduced a morning checklist, a memory board and a number of reminder signs were placed around the house. John also took part in cooking sessions with the therapist so that he could practice cooking an evening meal. Although a lack of social interaction had been identified as an issue for John, addressing this did not form part of the therapeutic work as John expressed that he was not interested in joining any local clubs or social groups. Similarly, although John described some difficulty with sleep, he did not perceive this as being particularly problematic and did not express a desire to address sleep as part of their therapeutic work.

During the course of the intervention a further goal emerged which was to support John in taking his evening medication independently. The therapist introduced a "dementia friendly" clock (see Figure 63 below) which was placed on John's bedside table along with his medication organised in a dosette box. During sessions and with the therapist's support, John practiced looking at the clock to determine the day and time, and then taking the corresponding medication from the dosette box.

Figure 63. A "dementia friendly" clock

Sensor Deployment

(i) Gear4 Sleep Sensor

As previously mentioned the Gear4 sleep sensor was originally deployed during the participant's time as a lead user.

(ii) GoPro Camera

In order to know how best to support John's cooking the therapist required an objective indication of how he performed on this task. The therapist introduced the GoPro camera during their cooking sessions. John wore the GoPro camera while he cooked and after the sessions the therapist carried out a manual analysis of the video footage.

(iii) Voice Recording Application

As a lack of social interaction had been identified as an issue for John at the outset of the intervention the therapist was interested in investigating whether the increased social interaction provided by the therapist's weekly visits would have any impact on John's speech fluency or overall mood. This was evaluated through audio analysis of the session recordings.

As addressing physical activity did not form part of this intervention, deployment of the DTI2 sensor was not considered to be suitable as part of this intervention.

Results

Sensor Data

(i) Gear4 Sleep Sensor

During the course of the intervention (May 2015) a team decision was made to remove the sleep sensor. Justification for this decision is provided in the sensor acceptability, usability and usefulness section below. Results of sleep data collected up to this point are presented in the LU3 case study review above.

(ii) GoPro Camera

Manual analysis of the GoPro footage revealed that John was experiencing some difficulties while cooking. Overall it appeared that he struggled with sequencing as there were a number of pauses between different steps and a small number of repeated steps throughout the video. The analysis also revealed that John experienced some confusion relating to the location of different cooking utensils. The sequence of screenshots presented in Figure 64 below highlights an example of confusion over the location of a cooking pan. The audio recording accompanying the video reveals that at this point in the footage John asks aloud "*Where's the pan? Where's the pan? Where's the pan?*" Similar confusion was seen in relation to the location of different ingredients and there was also some uncertainty regarding the quantities of different ingredients which should be used.

Figure 64. Video footage screenshots highlighting confusion over location of frying pan

This analysis also highlighted that John was confused by the variety of different types of cooking utensils available and experienced difficulty in deciding which to use. Figure 65 below highlights an example of this occurring with a number of different pots. The audio recording accompanying the video reveals that when John selects one of the pots to use he says aloud "*I don't know if this is the right way to do it but…"*

Figure 65. Video footage screenshots highlighting confusion over the number of different pots

Overall the video analysis revealed that John was very capable of successfully preparing a meal but that some support would be beneficial for enhancing his efficiency and confidence in

completing the task. These findings allowed the therapist to develop a set of cooking instructions (see Figure 66 below); these included images of the correct cooking utensils to use and outlined the quantity needed for each ingredient. It was also agreed that John's wife Ann would set out the ingredients and utensils needed before he began to cook to reduce any confusion over the location of these items in the kitchen.

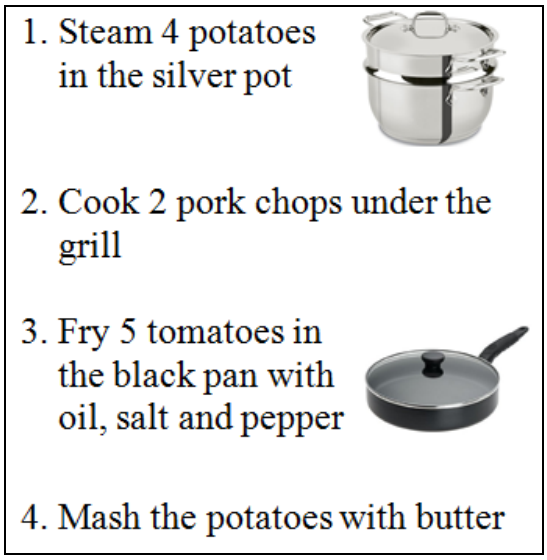


Figure 66. Cooking instructions

(iii) Voice Recording Application

The therapist reported that the weekly sessions with John may have lessened his feelings of loneliness and isolation. John expressed to the therapist on several occasions that he enjoyed the visits and having someone to talk to. The audio recordings of John's sessions with the therapist are currently being analysed, the results of this analysis are not yet available.

Acceptability, Usability and Usefulness of Sensors

Participant/Carer Evaluation

(i) Gear4 Sleep Sensor

Feedback on the acceptability and usability of the sensor was provided by Ann who managed all interaction with the Gear4 sleep sensor during its deployment. Ann reported that with time she began to find the sleep sensor easy to use and described how she found it useful as it relived some of her anxiety about John's sleep. Ann explained that before her involvement in the Dem@Care project she would have been fearful of technology and so she felt she needed support from the researcher when the sensor was first introduced, as there were a number of things she had to learn in order to be able to use it. Ann also described needing support when there were complications with the sensor; for example when it was accidentally unplugged. Ann felt that she received all the support she needed from the researcher and that this meant she could overcome her fears and learn to use the sensor independently. She felt a sense of comfort from knowing she could call the researcher and ask for help and that the researcher would make a visit to the house whenever needed. These qualitative reports are consistent

with Ann's ratings on the SUS which reveal that her percentage satisfaction with the Gear4 sleep sensor was 65%.

(ii) GoPro Camera

The therapist provided full support to John in relation to the use of the GoPro, including attaching the camera to the jacket and switching it on and off. John did not interact with the camera and at the post-intervention interview had no memory of having worn it during the sessions. Ann also had no interaction with the GoPro; therefore neither could provide informed feedback on its acceptability or usability.

Therapist Evaluation

(i) Gear4 Sleep Sensor

The Gear4 sleep sensor remained deployed with John during the first four weeks of the intervention; however, at this point the therapist became aware that the sensor had begun to cause him distress. As previously mentioned, at times John awakened during the night and tended to leave his bed, he worried that he would knock the sleep sensor off his bedside table and there was one occasion where he dreamt that he had accidentally smashed the screen of the iPad. The therapist also noted an overall lack of motivation or desire from John to engage with the sleep sensor. The therapist reported a number of possible reasons for John's lack of engagement with the sensor. Firstly, although John had described night time awakenings to the therapist at the outset of the intervention, he did not perceive these as being particularly problematic and did not express a desire to address sleep as part of their therapeutic work. Thus it was the therapist's judgement that the sleep sensor was no longer meeting a significant need from John's own perspective. Furthermore the therapist did not perceive the sleep sensor as providing a personally-suited or effective solution for John. This was due in part to his general disinclination toward technology, but also to the progressiveness of his cognitive deficits. It was evident to the therapist that, although John knew that the sensor had something to do with sleep, he had become increasingly uncertain about its exact function, thus the sleep data provided was no longer meaningful to him.

It is also important to mention that when the sleep sensor was first introduced Ann managed all interaction with it. However, at the time of the beginning of the intervention the Dem@Care researcher reported to the therapist that the most recent data (from the month of April 2015) revealed that the sensor had not been used on many occasions and other times had been left running and recording for long periods of time during the day, meaning Ann had not interacted with it as usual to indicate that John's night's sleep had ended. Upon investigation of this the therapist discovered that Ann was feeling a lack of motivation to engage with the sensor. She reported feelings of stress relating to John's progressing memory problems and at this point requested having less involvement in supporting John's use of the sensor and of his involvement in the intervention overall. Following discussion of these issues at a multidisciplinary meeting, a team decision was made to remove the sleep sensor at this point.

As part of the strategy to support John to independently take his medication, the position previously occupied by the sleep sensor on his bedside table was given to the "dementia friendly" clock. Although the introduction of the clock was not initially intended as a direct strategy for addressing John's reported sleep problems, interestingly he reported that the clock helped to orientate him when he awoke from sleep during the night and in the morning *"It's a lovely clock. It's great, because when I wake up during the night. Sometimes I wake up at 9*

o'clock... By the way, I'll tell you, I go to bed sometime between 8 and 9, and at about 10 o'clock I'll be awake again, and the first thing I'll do is look at that"… *"Even in the mornings I do look at that to see what day it is"*. John also reported that a particular advantage of this clock was its light up feature as this meant he could see it clearly in the dark. The therapist reported that the success of the clock was likely due to its low-tech nature as this meant it required no learning or interaction from John.

(ii) GoPro Camera

The therapist reported that the GoPro provided a useful therapeutic tool to determine how best to support John's cooking, however, she also highlighted that the camera did not provide a meaningful aid for John as he was unable to use it independently and had difficulty understanding its function in their therapeutic work. The therapist reported that it was necessary to re-establish consent with John a number of times during the two sessions when the GoPro was used, as he frequently forgot that he was wearing it and what its purpose was. In order to deploy the camera beyond the duration of the intervention John would have required significant support from Ann. Given Ann's request to have less involvement in supporting John's use of the sensors, long-term deployment was not deemed suitable by the therapist. Furthermore no clinical need relating to ADLs had been identified.

In this case automatic processing of the video data by the Dem@Care system was not used, as carrying out the required annotation process on these videos and training the WCPU component to recognize John's kitchen and the activity of cooking would have been a very time-consuming activity. This could not be achieved within the timeframe of the intervention. Furthermore the low-level sequencing information required by the therapist cannot be provided by Dem@Care as of yet. While the manual analysis of the GoPro data provided useful insights to the therapist she reported this too was a relatively time-consuming activity even with only a few hours of video, thus manual analysis of larger amounts of video footage would not be a realistic for a clinician. Based on these findings the therapist suggested a potential future use of the GoPro as a tool for capturing a once-off assessment of ADLs, rather than monitoring performance on an ongoing basis. The proposed advantage of using the GoPro in this way would be that the assessment could be carried out in the familiar environment of a person's own home and therefore may provide a more ecologically valid representation of their everyday functioning.

The extent of John's cognitive impairments meant that both the sleep sensor and GoPro were too complex for him to learn to use independently. This challenge also emerged in relation to the mobile phone despite its "easy to use" nature. High levels of therapist support were required to support John in becoming accustomed to using the phone (i.e. remembering to bring it with him when leaving the house), and to help him learn how to use the phone (i.e. making and receiving calls). However, by the end of the intervention John was remembering to take the phone out with him every day, he could answer calls independently and could make calls with support. The therapist reported that the success of the mobile phone was attributable to the high level of support provided and the fact that the phone's complexity was at an appropriate level for John's learning capacity. Overall, the therapist reported that the sensors were not well-suited to John due to his lack of comfort and familiarity with technology.

Despite this the therapist felt that the Dem@Care system may play a useful role in future interventions by supporting the PwD's autonomy via prompts, reminders, checklists and educational materials made available to them through their system interface. As previously men-

tioned, part of the therapist's work with John involved calling his new mobile phone each morning to give him a reminder to take it with him when he went out to the shop. This informed the design of a message sending and reminder functionality of the Dem@Care system (see Figure 67 below) for potential future use.

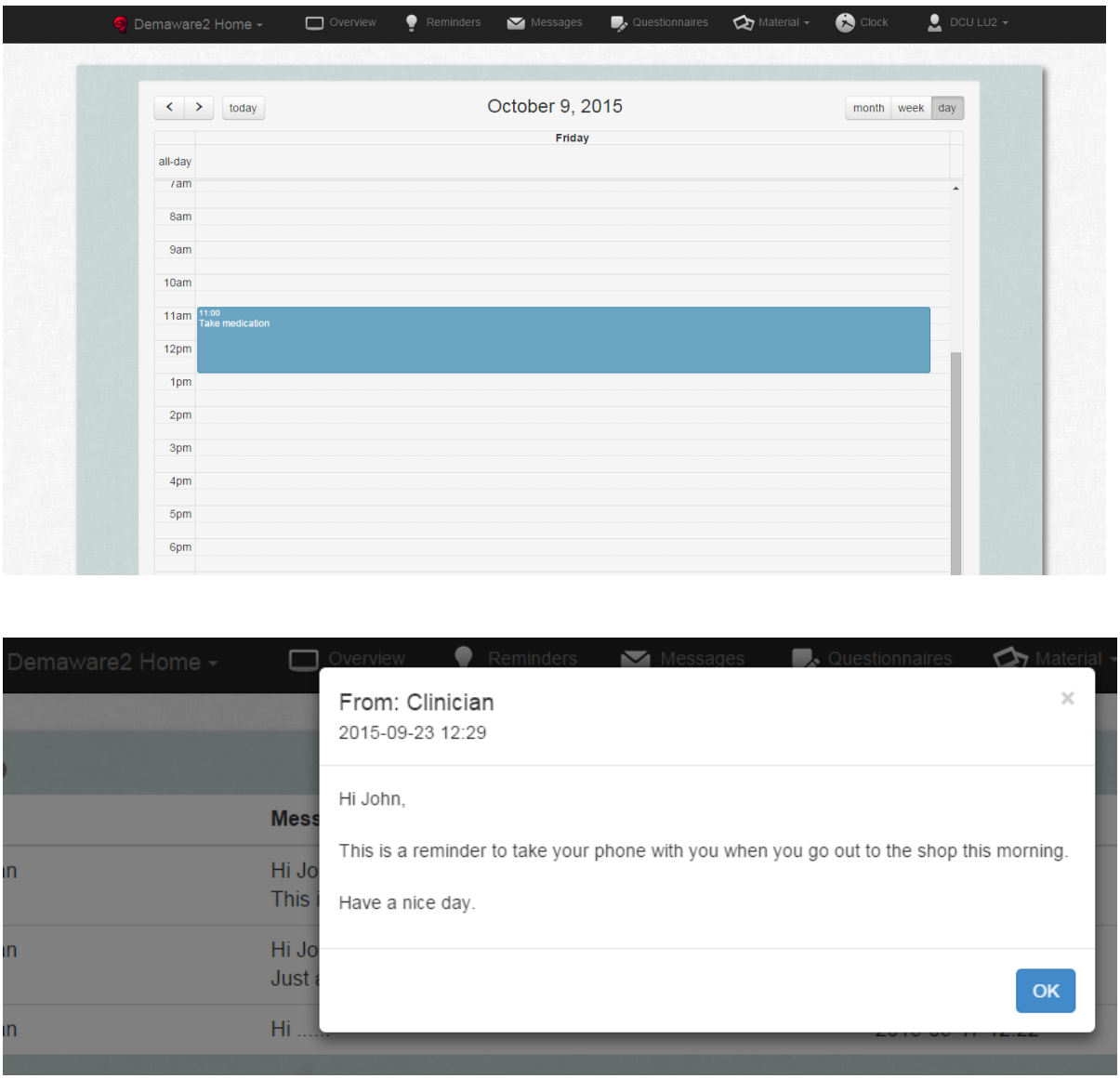


Figure 67. Message and reminder functionalities of the Dem@Care system

Similarly the therapist's work with John around cooking informed the design of an electronic version of the cooking instructions which were then included as part of the Dem@Care system. While the simple paper version of the instructions was found to be somewhat helpful in this case, at times John could not remember what stage he was at in the list of steps. It appeared to the therapist that having all of the instructions presented on one sheet may have been confusing or overwhelming for him. Therefore the therapist felt that an electronic version of the cooking instructions may hold potential benefit for future use, if it could help a PwD remain oriented to a particular step. This was achieved by developing a "tick-box" elec-

tronic version of the instructions, whereby a person can indicate that a particular step has been completed by ticking the corresponding box, and can then progress to the next step which will become highlighted (see Figure 68 below). Each step is also accompanied by an audio note which reads the instruction aloud.

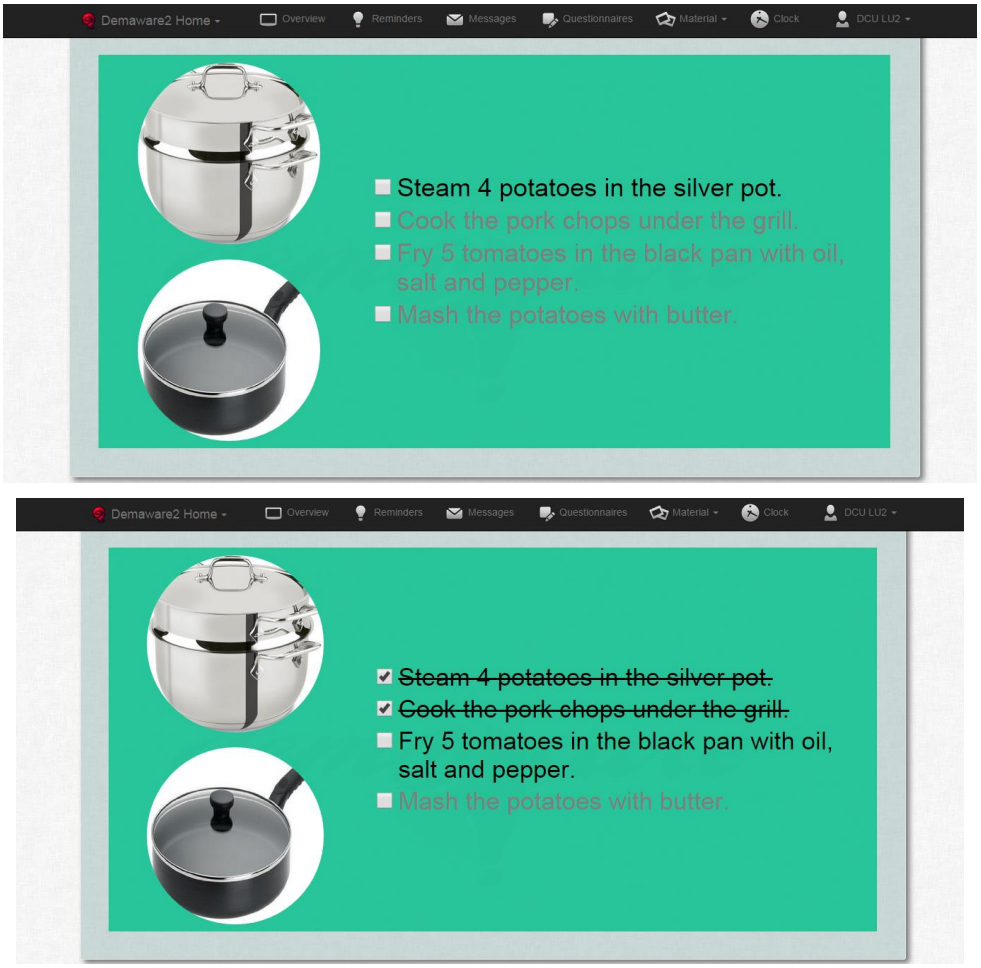


Figure 68. Electronic version of cooking instructions

Additional materials could be developed to support other particular therapeutic goals in the future; for example, a bedtime checklist could be used with someone who struggles to remember the things they need to do before going to sleep, while educational materials may be helpful for someone who wishes to address issues with attention (see Figure 69. below).

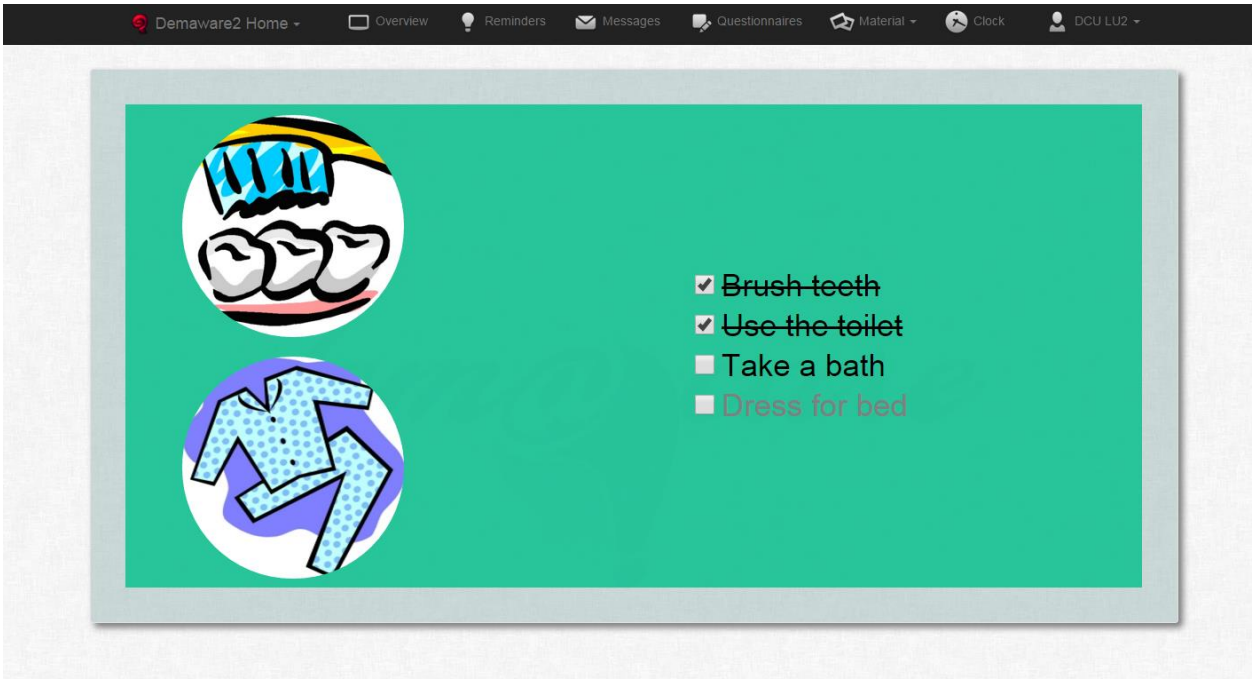


Figure 69. Bedtime checklist and educational materials

Due to the success of the "dementia-friendly" clock as part of this intervention, the therapist suggested the Dem@Care user interface should include a screensaver identical to that of the clock face (see Figure 70. below). This suggestion was also supported by the success of the clock in other case studies which will be discussed below.

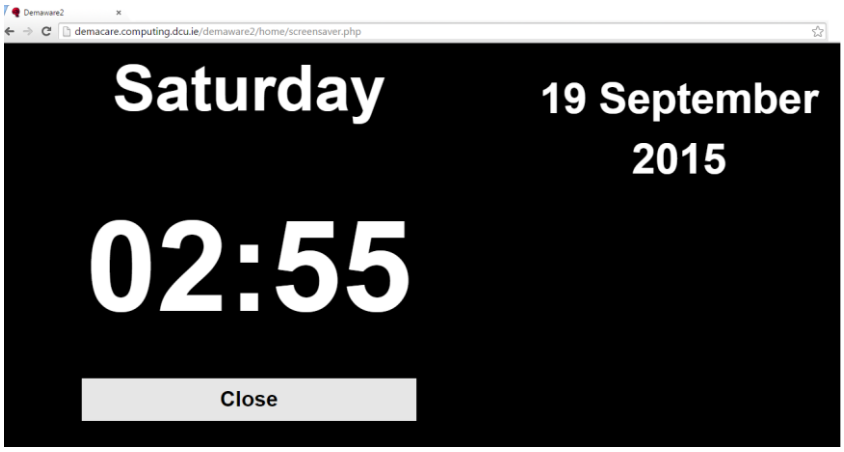


Figure 70. Dem@Care user interface screensaver

Participant 2 – "Susan"

Background

Susan is a 75 year old woman who lives with her husband Tom in their home in Dublin. She has four children, three of whom live abroad while one daughter lives nearby, although this daughter works fulltime. Her brothers and sisters see her occasionally but are not regular visitors. Susan does not acknowledge that she has dementia, she associates any issues with her memory to a fall she had while on holiday and the family is certain that they don't want to challenge this.

Requirements

In this case the researcher was unable to complete the psychometric measures with the Susan as she did not have full capacity to participate in this process in a meaningful way. Problematic areas in everyday life were assessed by the therapist qualitatively through general conversation with Susan. The main difficulty which emerged was a lack of social interaction. Susan was once a very active woman in her local community; she had been a member of a choir, a local pensioners group and attended the gym with her husband. Over the last number of years Susan's engagement with these activities gradually diminished which has also meant that she has become less physically active. Tom continues to be a member of a number of social groups and continues to attend the gym. Susan experiences this as a feeling of being left alone in the house for long periods, she spends a lot of time in her living room watching DVDs and listening to CDs and can experience periods of low mood. No issues were identified relating to sleep or ADLs, although Susan frequently loses personal items such as her keys, glasses and bus pass and has some difficulty with time orientation.

Therapeutic Goals and Strategies

The primary goal of this intervention was to increase Susan's opportunity for social engagement. It quickly became clear that she took great pleasure in music and singing. Following discussion during a multidisciplinary team meeting, a place was secured for Susan in an award winning choir group located just outside Dublin, which was set-up particularly for people affected by dementia and memory loss. Secondary goals which emerged were to help the Susan keep track of important personal items, to address her issue with time orientation and to incorporate physical activity into the weekly sessions.

Sensor Deployment

(i) Voice Recording Application
As lack of social interaction and language difficulties were identified as an issue for Susan, the therapist was interested in investigating whether the increased social interaction provided by the choir and the weekly therapy sessions would have an impact on her speech fluency or overall mood. This was evaluated through audio analysis of the session recordings.

(ii) Motion/Lost-Item Sensors
The therapist planned to introduce motion/lost-item sensors to help Susan keep track of her important personal items.

Results

Sensor Data

(i) Voice Recording Application
During the early phase of the intervention (sessions 1-4) the therapist reported that Susan was experiencing significant language difficulties; she moved between the past and present frequently, lost the thread of conversation quite regularly and had difficulty with word finding. Later therapist reports highlighted a noticeable improvement in language from session five onwards; the participant's capacity to hold conversation improved greatly and the nature of conversation grew less confused as the sessions progressed. The therapist also reported a positive change in Susan's mood as a result of the weekly therapy sessions and attendance at the choir. Susan described feeling valued and supported and it was evident that she truly enjoyed taking part in the intervention overall. The audio recordings of Susan's sessions with the therapist are currently being analysed, the results of this analysis are not yet available.

Acceptability, Usability and Usefulness of Sensors

Therapist Evaluation

Overall the therapist reported that Susan's goals were not well-suited to a technology-based solution which restricted the potential for introducing the Dem@Care sensors. The primary goal and focus of this intervention was to improve the participant's opportunities for social engagement and while the therapist was interested in investigating whether the intervention would have an impact on the participant's speech fluency or overall mood, she did not see a place for other sensors in relation to this goal.

While the therapist identified a lack of adequate physical activity as a problem she did not consider it appropriate to introduce sensor support. The therapist did incorporate exercise into some of the sessions, but this was not the main focus of any session. The therapist reported

that due to the advanced nature of Susan's cognitive impairments she would have needed significant support in order to understand the function of the sensor and this would have negatively impacted on their work toward the primary goal of improving opportunities for social engagement. The therapist also reported that she did not feel that the activity data would have been meaningful to Susan. Overall the therapist did not consider the DTI2 as a useful therapeutic resource for their work on achieving this goal.

While the therapist had hoped to introduce motion/lost item sensors as a strategy to help Susan keep track of her important personal items this did not prove to be a realistic solution as the sensors were too large to attach to her keys, glasses and bus pass. The therapist reported that if these sensors were considerably smaller they may have held more potential.

6.3.2.3 Participant 3 – "George"

Background

George is a 69 year old man who lives with his wife Joan in a town just outside of Dublin. They have two adult daughters and three grandchildren whom they see regularly. George is a retired business consultant who has a great deal of experience in working with technology. Although his short term memory is impaired, he generally functions well in everyday life. George is an articulate gentleman of an analytical nature, who enjoys the challenge of thinking about things from different perspectives and likes to understand the mechanisms behind things.

Requirements

Sleep

George reported no difficulties with sleep.

ADLs

George's baseline BADLS score (7) does not indicate dependence; however, his wife did report that he was experiencing some difficulties in using the house telephone and that he was beginning to struggle with driving.

Social Interaction

George reported no issues with social interaction; he spoke of having a loving and supportive family around him and of having recently become a member of a dementia working group, where he has made new friends and become involved in a number of activities. At baseline, George's assessment of social interaction revealed that he was at low risk of social isolation (LSNS = 25; DJLS = 0).

Physical Activity and Exercise

George has no mobility problems and would frequently go out for a walk with his wife, however, the baseline assessment revealed that his levels of physical activity were suboptimal (RAPA = 4).

Mood

When the therapist first met with George he was struggling with his diagnosis of dementia and this was having a negative impact on his well-being as he was experiencing periods of

low-mood and anxiety. George's baseline GDS score (4) was not indicative clinical levels of depression and his PSS score (11) did not indicate high levels of stress.

Therapeutic Goals and Strategies

The primary goal of this intervention was to support the participant to live as well as he can with the diagnosis of dementia and to help him manage his feelings of low mood, stress and anxiety. The therapist introduced a number of cognitive-behavioural and mindfulness based approaches to support the participant's acceptance of his dementia diagnosis and to enhance his mental well-being.

Sensor Deployment

(i) Voice Recording Application
As feelings of low-mood and anxiety had been identified as an issue for George at the outset of the intervention the therapist was interested in investigating whether any change in overall mood could be detected through audio analysis of the session recordings.

(ii) DTI2
The therapist introduced the DTI2 sensor in order to observe the participant's stress levels. A particular interest for George and the therapist was to look at his stress levels before and after taking part mindfulness and meditation exercises to see if they would observe any change. The therapist considered the use of the DTI2 in this way as being particularly suitable to George due to his occupational background in technology and his analytical nature.

As no issues with sleep or ADLs were identified, deployment of the Gear4 sleep sensor or the GoPro camera were not considered to be suitable as part of this intervention.

Results

Sensor Data

(i) DTI2
Although the DTI2 sensor was deployed during the intervention, the participant chose to discontinue his use of the sensor after only two attempts at wearing it. As a result only two data files were collected which did not allow any meaningful data analysis to be carried out. The reason for the participant's disengagement with the sensor was due to issues with its design; specifically the participant found it difficult to close the strap and was confused by the number of buttons on the device. Detailed feedback from the participant is provided in the Acceptability, Usability and Usefulness section below.

(ii) Voice Recording Application
At the outset of the intervention George rated his ability to manage feelings of anxiety and stress as fair and reported that he was dissatisfied with his ability to manage these feelings. By the end of the intervention George rated his ability to manage feelings of anxiety and stress as good and reported that he was now satisfied with his ability to manage these feelings. The therapist reported that George's feelings about his memory were more positive by the end of the therapeutic work and that this impacted positively on his quality of life and mood. George's GDS score (4) remained the same from pre to post-intervention; however, his score

on the PSS went down from 11 to 4. The audio recordings of George's sessions with the therapist are currently being analysed, the results of this analysis are not yet available.

Acceptability, Usability and Usefulness of Sensors

Participant Evaluation

(i) DTI2

The first issue reported by George was that the mechanism for closing the device strap was difficult and impractical; this resulted in him being fearful that the device was not secure and that it might fall off while he was wearing it.

> *"I think most people would struggle with putting on the watch, and it was getting it on. I can put that watch* [own watch] *on blindfolded, but the little plastic or rubber studs that you had to get through the holes*"…*"I was afraid at all times it would pop off, that the things would open, because that happened a few times, and you're diving for it, almost".*

The second difficulty George experienced related to the functioning of the DTI2; while he understood that he should only use one button to turn the device on and off he had difficulty remembering which button this was. This was despite the fact that a coloured sticker had been placed beside the correct button. George found the presence of the other buttons confusing and they bothered him as he didn't know if they had a function. George was also uncertain at times whether the device was on or not and he felt that he could not easily check this which created some stress for him. Written instructions and support from the therapist were provided in an attempt to help the participant overcome these difficulties; however, this was not successful.

> *"It was just the frustration of putting on, and getting it to stay on, when it was on, and by the time you did that, and you were then almost holding it like that so it wouldn't disappear somewhere, then to remember which button to press or not to press, you were forgetting it… well, I was forgetting it, and reaching for the notes again".*

George reported that if the DTI2 had a more user-friendly design it might have been very useful; however, in its current design he did not consider it to be a usable device. He suggested that the buttons should be colour coded and that the strap be replaced with one similar to that of an ordinary watch. These qualitative reports are consistent with George's ratings on the SUS which reveal that his percentage satisfaction with the DTI2 was only 7.5%.

Therapist Evaluation

Overall the therapist reported that George's therapeutic goals were not well-suited to a technology-based solution which restricted the potential for introducing the Dem@Care sensors; however, she felt they may potentially have a useful role in therapeutic interventions generally. The therapist reported some conflicting feelings in relation to this; at times she felt that from a research perspective she should perhaps try to find ways to introduce technology, however, it was important to her that she remain consistent with the toolbox approach and to only introduce a sensor where there was a potential therapeutic value to George. Similar to George's own view, the therapist felt that the DTI2 may have been a useful aid to her therapeutic work had the design issues been resolved.

6.3.2.4 Participant 4 – "Bridget"

Background

Bridget is a 68 year old lady who lives alone in her home in Dublin. Bridget left school at an early age and returned to education in her adult years. Since then she has worked and volunteered in the area of adult education. Bridget is a family-oriented and sociable woman; she is both a mother and grandmother. Before taking part in this intervention Bridget would have had very little experience of using technology and expressed a general disinclination toward it. At the time of the intervention Bridget had just begun formal investigations into her memory problems.

Requirements

Sleep

Bridget reported that from time to time she may have difficulty in getting to sleep if she has something worrying on her mind, but in general she does not have any significant difficulties with sleep. Bridget's PSQI score (5) revealed that she is a poor sleeper.

ADLs

Bridget lives alone and is very independent; she reported no difficulties with any ADLs. However, Bridget did report experiencing a great deal of confusion and disorientation related to dates, days of the week and time. This confusion and disorientation was most problematic in the morning when Bridget first woke up and also occurred at times when she awoke from sleep during the night. She also described confusion with appointments; she was unsure whether she was correctly remembering events which had occurred in the recent past and worried about missing future appointments.

Social Interaction

Bridget reported no issues with social interaction; she is in very regular contact with her children and grandchildren and spends most of her time with at least one family member every day. Bridget also has a number of close friends. At baseline, Bridget's assessment of social interaction revealed that she was at low risk of social isolation (LSNS = 33; DJLS = 0).

Physical Activity and Exercise

Bridget has no mobility problems and would generally describe herself as an active person, but she had recently stopped attending a local dance class and the baseline assessment revealed that her levels of physical activity were suboptimal (RAPA = 5).

Mood

Bridget did not report any significant problems with her mood; her baseline GDS score (3) was not indicative of depression and her PSS score (11) did not indicate high levels of stress. However, the disorientation Bridget was experiencing was making her somewhat anxious and was affecting her confidence; for example, this had led to her resign from a committee which she had been a part of for many years.

Therapeutic Goals and Strategies

The primary goal of this intervention was to help reduce Bridget's confusion and disorientation. The therapist introduced a number of cognitive aids to help orientate Bridget including a diary, a memory board placed on the wall in her kitchen and a "dementia-friendly" clock placed on her bedside table. A secondary goal which emerged was for Bridget to reengage in physical activity, and in particular to re-establish her attendance at the local dance class she had previously been a part of.

Sensor Deployment

(i) Gear4 Sleep Sensor

As Bridget was experiencing night-time awakenings, disorientation and reported some difficulty getting to sleep at times, the therapist introduced the Gear4 sleep sensor.

(ii) DTI2 Sensor

The therapist introduced the DTI2 sensor as part of Bridget's goal of reengaging in physical activity. It was planned that Bridget would wear the sensor on days when she attended the dance class and on days when she was less physically active. The therapist planned that together they would look at the different activity levels for those days and that this may provide some motivation for Bridget to continue attending the class.

(iii) Voice Recording Application

The therapist reported that Bridget was experiencing some language difficulties during their early sessions; she had difficulty with word finding and often used general nouns rather than specific names for objects or places. There was also some confusion evident in the flow of her conversation; at times Bridget could not remember what she had been about to ask or say to the therapist. The therapist was interested in investigating whether the increased opportunity for conversation provided by the therapeutic sessions would have an impact on the Bridget's speech fluency. This was evaluated through audio analysis of the session recordings.

As no issues with ADLs were identified, deployment of the GoPro camera was not considered to be suitable as part of this intervention.

Results

Sensor Data

(i) Gear4 Sleep Sensor

The sleep sensor was deployed for a total of two weeks, however, no data was collected during this time as Bridget had significant difficulty familiarising herself with the iPad and Gear4 app and therefore did not engage with the sensor. These difficulties are described in detail in the Acceptability, Usability and Usefulness section below.

(ii) DTI2

The DTI2 was deployed for a total of one week; however, no data was collected during this time period as Bridget forgot to wear it to her dance class as planned. Bridget did not wish to wear the DTI2 at any other time. These difficulties are described in detail in the Acceptability, Usability and Usefulness section below.

(iii) Voice Recording Application

The audio recordings of Bridget's sessions with the therapist are currently being analysed, the results of this analysis are not yet available.

Acceptability and Usability of Sensors

Participant Evaluation

(i) Gear4 Sleep Sensor

Overall Bridget reported that she simply did not like the sleep sensor and was not confident about how to use it. The following exchange between Bridget and the therapist highlights this;

> *"How did you find using the sleep sensor?"* [Therapist]
> *"Well, I think I done everything wrong. I don't think there was anything wrong with the thing. I don't know what I was doing…"* [Bridget]
> *No, well, don't be blaming yourself so. Did you find it easy to use or helpful?* [Therapist]
> *"No."* [Bridget]
> *No?* [Therapist]
> *"No, because I'm just desperate with anything like that."* [Bridget]

Bridget also worried that one her grandchildren might damage the sensor or iPad when playing in her bedroom. The therapist provided significant support to Bridget in an attempt to help her overcome these difficulties; however, this was not successful. The therapist also spent part of one session providing training for Bridget's daughter on how to use the sensor, however, as she does not live with Bridget this did not prove to be a practical solution. After two weeks Bridget removed the sleep sensor from her bedroom herself and asked the therapist to take it with her at the end of the session. These qualitative reports are consistent with Bridget's ratings on the SUS scale which reveal that her percentage satisfaction with the Gear4 sleep sensor was only 10%.

(ii) DTI2

Although the DTI2 was deployed for one week Bridget did not use it and therefore could provide informed feedback on its acceptability or usability.

Therapist Evaluation

Overall the therapist felt that technology-based solutions were not well-suited to Bridget as she was not confident or familiar with using technology. This was particularly problematic as Bridget lives alone and so she did not have day to day support from a relative. While Bridget was open to trying the Gear4 sleep sensor and the DTI2 it was evident that using them caused her to feel anxious and increased her apathy towards them. The therapist felt that Bridget did not perceive the Gear4 sleep sensor or the DTI2 as being helpful to her in overcoming her difficulties. While her goals were potentially well-suited to the introduction of sensors as a means of monitoring sleep and activity levels, in the end they did not play a meaningful role in the therapeutic work. When Bridget was asked by the therapist if there was anything she had not enjoyed about the therapy sessions she replied that

"the only thing I wouldn't be interested in is all the gadgets. That's all. Because that's not my thing. But anything that I'd be able to do, like myself, without depending on them, I'd like that".

The dementia-friendly clock proved to be a better solution for Bridget's problems with orientation. At the outset of the intervention Bridget rated her ability to manage her feelings of confusion and disorientation as fair but reported that she was dissatisfied with her ability to manage these feelings. By the end of the intervention Bridget rated her ability to manage feelings of confusion and disorientation as good/excellent and reported that she was now extremely satisfied with her ability to manage these feelings. Bridget attributed this change to the clock.

"I do notice that like if I was worried about anything I would wake up a few times.. like if I was worried about one of the kids or you know? But it wasn't just in my imagination that I was waking up a few times because, because of the clock… here I am, oh that's grand and I'll go back asleep again.. before I would be trying to look at my watch and I wouldn't have my glasses on and I would be, can't see you know. The best thing of all is the clock because it stops me from kind of going mad, you know saying Jesus what day is it or anything like that. The clock is really a great thing, it's great because I look at it for the dates and all. I feel kind of in control, do you know what I mean like in control of my day, I wake up and I know exactly".

The therapist reported that the success of the clock was likely due to its low-tech, simple nature and the fact that it required no interaction from Bridget.

6.3.2.5 Participant 5 – "Pamela"

Background

Pamela is an 87 year old lady who lives alone in her home in Dublin. Pauline has had a diagnosis of vascular dementia for the last couple of years and has managed to cope very well with the condition to date. She lives independently and does not require much support from her family. She has a number of hobbies and interests and volunteers at a local hospital. Pamela is very comfortable with technology and enjoys using an iPad and PC. At the time of the intervention Pamela was experiencing a number of physical health concerns including hip pain, problems with continence and bowel movements, thyroid issues and vertigo. Despite this she was very keen to take part in the intervention.

Requirements

Sleep

Pamela reported that she had recently had some problems with sleep due to the pain she was experiencing in her hip; however, in general she does not have any significant difficulties with sleep. Pamela's baseline PSQI score (5) indicated that she was experiencing poor sleep.

ADLs

Pamela lives alone and is very independent; she reported no difficulties with any ADLs. However, Pamela explained to the therapist that she had recently begun to have difficulty in using her iPad and PC which meant she was no longer engaging with online cognitive training exercises which she had previously enjoyed. Pamela also described having difficulty finding her house keys and mobile phone, with finding the words for things, especially names of locations when talking with people, and with remembering recent events.

Social Interaction

Pamela described feelings of loneliness since her husband has passed away and because her close friends do not live near to her. At baseline, Bridget's assessment of social interaction revealed that she was at low risk of social isolation (LSNS = 32).

Physical Activity and Exercise

Pamela would consider herself to be a generally active person, however, the baseline assessment revealed that her levels of physical activity were suboptimal (RAPA = 4). As previously mentioned Pamela was experiencing significant pain in one of her hips.

Mood

Pamela did not report any significant problems with her mood, her baseline GDS score (1) was not indicative of depression and her PSS score (9) did not indicate high levels of stress. However, Pamela did mention feeling stressed about trying to manage all her different medical appointments and trying to organise all her bill payments.

Therapeutic Goals and Strategies

The primary goal of this intervention was to support Pamela in relearning how to use her iPad and PC. As Pamela also described having difficulty with remembering the names of locations when talking with people and with remembering recent events, it was also planned that Pamela would take part in digital reminiscence therapy with the therapist. This would also provide Pamela with the opportunity for further practice using her PC.

Sensor Deployment

(i) "Autographer" wearable camera

The therapist introduced the "autographer" wearable camera for Pamela to wear when she took part in activities outside of her home. It was planned that together Pamela and the therapist would review the images during their therapy sessions and engage in conversation around them. A lifelogging application was developed by researchers in DCU which allows auto-captured images from a wearable camera to be displayed on a computer screen in a way that facilitates the therapist in their delivery of digital reminiscence therapy (details of the application development is provided in section 5.4 below). This application was installed on Pamela's PC.

Although sleep and physical activity emerged as potentially problematic areas, Pamela did not express a desire to address these as part of the therapeutic work thus deployment of the DTI2 and Gear4 sleep sensor was not considered to be suitable as part of this intervention. Similarly as no issues with ADLs emerged, deployment of the GoPro camera was not considered to be appropriate.

(ii) Voice Recording Application

When the therapist first met with Pamela she was experiencing some language difficulties; in particular she was having difficulty with remembering the names of locations when talking with people. The therapist was interested in investigating whether the increased opportunity for conversation provided by the therapeutic sessions would have an impact on the Pamela's speech fluency. This was evaluated through audio analysis of the session recordings.

(iii) Motion/Lost-Item Sensors

The therapist planned to introduce motion/lost-item sensors to help Pamela keep track of her keys and mobile phone.

Results

Sensor Data

(i) "Autographer" wearable camera

Due to her physical health problems Pamela had to cancel a number of appointments with the therapist and therefore the overall delivery of this intervention was very disjointed. Unfortunately this meant that the use of the autographer camera was not explored until the later stages of the intervention, when only a short amount of time was left to support Pamela in learning to use the camera and for her to incorporate it into everyday life. Providing additional sessions for Pamela was not possible as her health concerns had worsened by this point and she became hospitalised. Thus no lifelogging data was collected.

(ii) Voice Recording Application

The audio recordings of Paemla's sessions with the therapist are currently being analysed, the results of this analysis are not yet available.

Acceptability, Usability and Usefulness of Sensors

Participant Evaluation

As it was not possible for Pamela to learn to use the Autographer wearable camera within the timeframe of the intervention she could not provide informed feedback on its acceptability or usability.

Therapist Evaluation

Due to her physical health problems Pamela had to cancel a number of appointments with the therapist and therefore the overall delivery of this intervention was very disjointed. Unfortunately this meant that the use of the autographer camera was not explored until the later stages of the intervention, when only a short amount of time was left to support Pamela in learning to use the camera and for her to incorporate it into everyday life. The therapist did introduce the camera and began working with Pamela to help support her to be able to use it independently, however, it emerged that due to the extent of Pamela's memory impairments very high levels of support from the therapist would be required to achieve this. The idea of providing additional sessions for Pamela to provide her with the level of support required was explored, however, this did not prove to be possible as her health concerns had worsened by this point and she became hospitalised. Thus no lifelogging data was collected.

Overall the therapist felt that had there been more time available to support Pamela in learning to use the wearable camera and incorporate it into everyday life it is likely that she would have used it successfully. The therapist commented that practice of using new sensors

or technology is crititical to their successful integration into everyday life and that a great deal of practice may have to be provided in order for the person to use the device successfully. The therapist was able to provide Pamela with sufficient support to relearn to use her iPad and PC and this was very successful. At the outset of the intervention Pamela rated her ability to use her iPad and PC as fair but reported that she was dissatisfied with her current level of ability. By the end of the intervention Pamela rated her ability to use her iPad and PC as good and reported that she was now extremely satisfied with her level of ability. This suggests that providing sufficient levels of learning support to the person may allow for the best chance of successful deployment and use of sensors.

The therapist had hoped to introduce motion/lost item sensors as a strategy to help Pamela keep track of her keys and mobile phone, however, as in the case of Susan this did not prove to be a realistic solution as the sensors were too large. This therapist also reported that if these sensors were considerably smaller they may have held more potential.

6.3.3 Overall Findings across CR Intervention Case Studies

In all cases the intervention had a positive impact and all participants felt they had achieved their primary goals;

> "*I have no fears at all about moving forward. I think that I am in… I hate the term "a better place" because it's an overused term, but it describes where I am at the moment. I think I am better in that sense. I think I have a better understanding of myself and what this means to me, and I think, hopefully, I'll be able to continue to handle it okay and better and just see where it takes us at this stage, because even if I didn't have it and I was talking about the future, we'd be sitting here saying, 'We don't know where it's going to take us*'" [George]

> *"I found that I had given up hope of ever being back at this stage again, it was only by this person giving me… bits…and told me how to cope with things, and different things I need to visit. And in the end now, as you've arrived here today, I am very happy I have accomplished obviously what I set out to do"* [Pamela].

> *"I feel kind of in control, do you know what I mean? In control of my day. Like, I wake up and I know exactly…"* [Bridget]

In the cases where a carer or relative was involved in the intervention, they too felt like that the intervention had a positive impact;

> *"That was one thing I liked about [therapist], in that you took into account both of us. [PwD] is the person that has the problem. But I have a problem. It's not an isolation. It is, it's a different problem. I have the problem of dealing with his problem"* [Ann].

> *"My experience has been brilliant because just being able to talk...You know yourself that if you can talk about something and get it out there it takes some of the pressure off you. That's what I… no, I found it fantastic."* [Joan]

The therapists reported that at times they found it difficult to find opportunities to introduce the Dem@Care sensors and all agreed that this was largely due to the nature of the participants' goals. Therapists felt that many of the primary goals were not suited to a technology-based solution but required a more therapeutic approach; examples of such goals included managing feelings of stress and anxiety, learning to live as well as possible with a diagnosis of dementia and reengaging in social activities. Therapists also reported that often what was most important to the person was having an opportunity to talk about their feelings and things that were happening in their day to day lives. Therapists reported feeling conflict between trying to meet the aims of the research and allowing the PwD and their goals guide the direction of the intervention. However, all therapists agreed that it was important to only introduce sensors where they added to the therapeutic work in a meaningful way and that this was the approach they took.

The nature of participants' cognitive impairments also impacted on therapists' ability to successfully introduce sensors. All therapists reported that high levels of learning support were required for any sensors which were introduced, even with those participants who were more familiar with technology. However, the cases of John and his new mobile phone and Pamela and her iPad suggest that when sufficient levels of support are provided, learning or relearning how to use a piece of technology is possible. In the case of John (Gear4 sleep sensor), George (DTI2) and Bridget (Gear4 sleep sensor) the functioning of the sensors proved to be too complex for them to use independently. This was particularly relevant to Bridget, who lived alone and thus did not have the support of a relative when attempting to use the sensor. The therapist working with George highlighted the design issues of the DTI2 which also contributed to his disengagement with it. While the therapist working with John did introduce the GoPro camera this was only possible in the context of the high levels of support provided and would not have been suitable for longer term deployment without this. This therapist also highlighted the importance of an ongoing assessment of the suitability of sensors, as in John's case, while the Gear4 sleep sensor was initially successful, this changed over time. In the case of Susan, the therapist was reluctant to introduce sensors as she did not have capacity to understand their function or significance. Therapists felt that the extent of participants' cognitive impairments meant that they were potentially vulnerable and this heightened therapists' sense of responsibility. The therapist working with John emphasized particular considerations she had to make as a result of John's trust in her. She reported that when she suggested a new sensor to him he would ask her to decide for him whether he should use it or not, or replied that he was very appreciative of all she had done for him and if she wanted him to use the sensor he would.

Some therapists also found that participants' attitudes toward technology impacted on their ability to successfully introduce sensors. This was most clearly seen in the case of John and Bridget, both of whom were generally unfamiliar and uncomfortable with technology, thus technology-based solutions did not prove to be acceptable to them. In cases like these therapists highlighted the importance of considering non-technology or very low-tech strategies for addressing goals. The success of this approach could be seen in the cases of both John and Bridget and the "dementia-friendly" clock.

While appreciating the potential role of technology in psychosocial interventions with PwD, therapists highlighted the importance of human interaction and emphasised that technology should not aim to replace this;

> *"I feel there may be some occasions when technology can prove useful. However in general this experience suggests that human interaction is the primary factor in supporting the person. Thus any technology is simply another tool to be used in the context of human interaction rather than an alternative to this type of support".* [Therapist 2]

It was evident that human interaction was very important to the participants. When asked what in particular they liked about taking part in the intervention all participants mentioned that having someone to talk to, whom they felt comfortable and relaxed with, was very important;

> *"The most important thing I think about the sessions was that we got on well, and I really feel that we did. And it wasn't that I was talking to a doctor or a psychiatrist or anything, I think from very, very early on I was chatting to a friend".* [George]

> *"Just I thought it was very informal. It was just kind of like you were chatting to a friend, and it's completely different than going into a doctor or anything like that, you know wanting to ask questions or anything, and you just say, "He wouldn't be bothered." You wouldn't feel comfortable. I felt really comfortable or anything I wanted to know".* [Bridget]

> *"I do look forward to you coming, because, as I said, since you came and since [other researcher] has come, I never look at it as… because you are coming to see both of us… I don't look at you as intruding on our lives, I look at it as more of friendship, kind of thing. It mightn't be the way like, you know, "the friendship" kind of thing, but I feel comfortable with you. I don't resent you coming, I don't resent the questions. In actual fact, I can talk to you and I can be honest".* [Ann]

The therapists' time and support was also very important to participants;

> *"I do appreciate what you came to do. You weren't someone who walked in the door and said, 'Well, how are you this morning [John]?' and they were gone... But you came here, and you did help me without any doubt, and I tell you one thing, I hope, praise God, when you and me are finished, that I see you again. I want to see you again, and I hope... I'll never forget you as long as I live".* [John].

> *"When things didn't work you persevered, and you didn't get frustrated in any way, either with [PwD] or me, and you really put in the effort, you put in the effort to do what you did and, as you can see, most of it worked".* [Ann]

> *"I wasn't put in at the deep end at any stage. I was brought back and starting at the beginning with the parts that I could understand and cope with. I wasn't even just handed previous notes and told, 'Just read those or do that,' I was just brought along step by step, section by section".* [Pamela]

Despite the above challenges and considerations all therapists agreed there is a potential place for technology in psychosocial interventions with PwD. Therapists provided examples of how the Dem@Care system might be useful in future interventions to support the PwD's autonomy in everyday living via prompts, reminders, checklists and educational materials avail-

able to them through their system interface. Therapists could also see the potential benefit of the sensors for monitoring sleep, physical activity, IADLs, and mood as this would help inform interventions and track progress in these areas, however, success would be dependent on those factors outlined above; PwD's goals, design and functionality of the sensor, PwD's learning capacity, levels of learning support available and the person's attitude toward technology. The therapist working with John suggested a potential use for the GoPro as a tool for capturing a once-off assessment of ADLs in the PwD's own home.

6.4 @Home Lifelogging Pilot (Dublin, Ireland)

A final version of the Lifelogging application is now available, which can be used by a PwD, along with a carer or clinician, to review and reflect on their daily life based on auto-captured images taken by a wearable camera.

6.4.1 Pilot Deployment of Prototype Version

A pilot deployment of the initial prototype version of the lifelogging application was carried out with two researchers with extensive experience of working with PwD and delivering digital reminiscence therapy. The researchers wore a wearable camera over a number of days and loaded the collected images to the application; they then provided feedback on the usability of the application and made recommendations for further development. The application's finalised functionalities are described below.

6.4.2 Lifelogging Application Functionality

When a wearable camera (e.g. sensecam, autographer, narrative clip) is connected to a PC or laptop the stored auto-captured images are automatically transferred to the application. Users can choose to view these images by selecting a date using the calendar at the top left hand corner of the user interface (see Figure 71) below.

Figure 71. Lifelogging application user interface

The lifelogging application will then visualize a horizontal stream of the images captured on this day (see Figure 72 below).

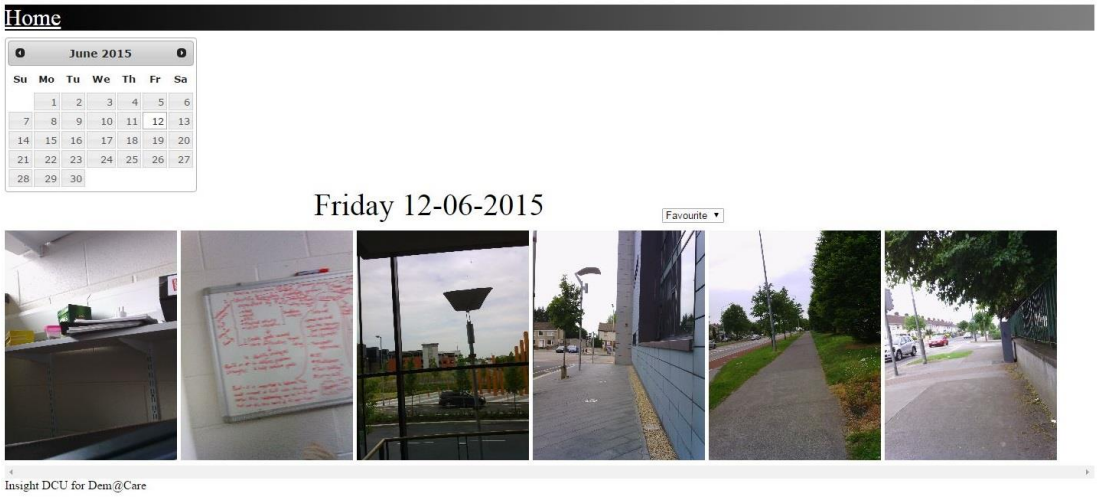


Figure 72. Visualisation of horizontal stream of images

When the user clicks on an image from a particular day they will be automatically redirected to a slideshow of images for that day. The user can choose to play, pause or stop the slideshow at any time and can decide the speed at which images are presented using the speed controller. Alternatively the user can manually move through the images using the arrows on either side of the image and using the scroll bar they can quickly move to different points in the stream of images (see Figure 73 below).

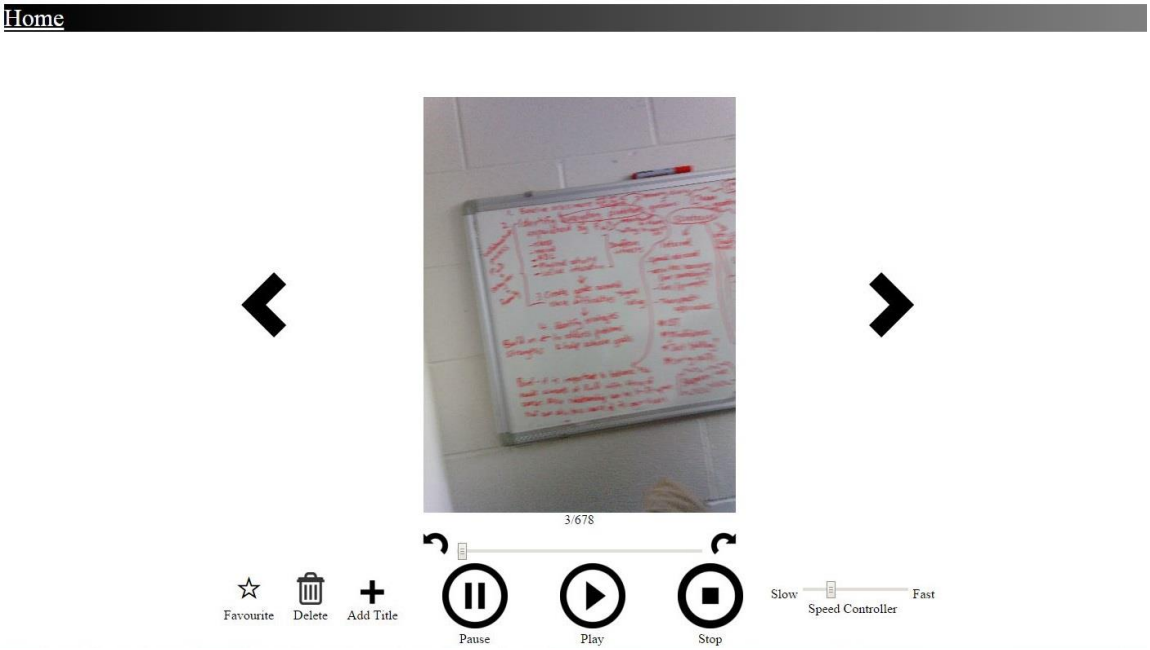


Figure 73. Slideshow functionality

The user can also choose to favourite or delete an image; they can also add a title to any image (see Figure 74 below).

Figure 74. Image title functionality

When the user returns to the home screen they can use the dropdown button to view their day in three different ways;

1. Selecting "All" will display the original unsegmented stream of images from the day (see Figure 74 above)
2. Selecting "Favourite" will display only those images which the user marked as a favourite in the slideshow (see Figure 75 below).

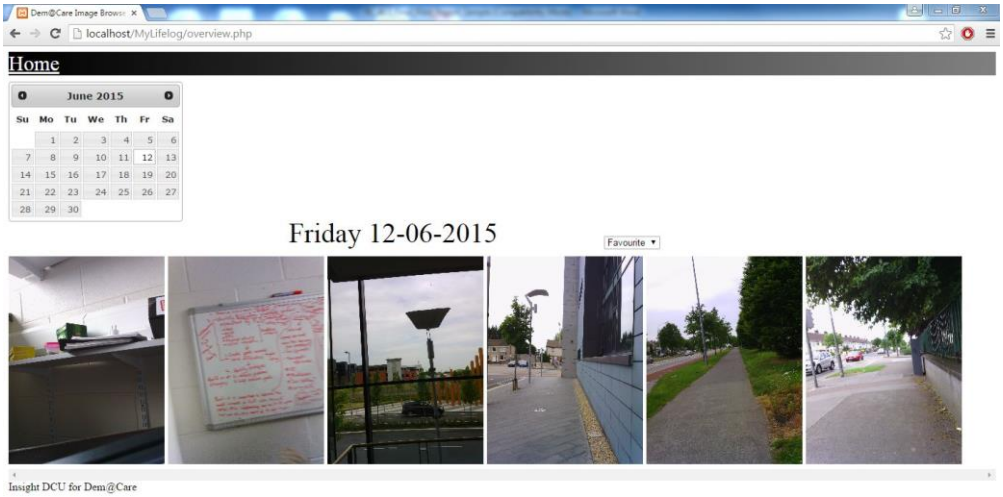


Figure 75. Managing Favourites functionality

3. Selecting "Event" will display sets of images which have been separated according to time i.e. each hour the camera was worn. The user can click into the images for a particular time and view the slideshow as usual. They can also add titles to the different sets of images (see Figure 76 below).

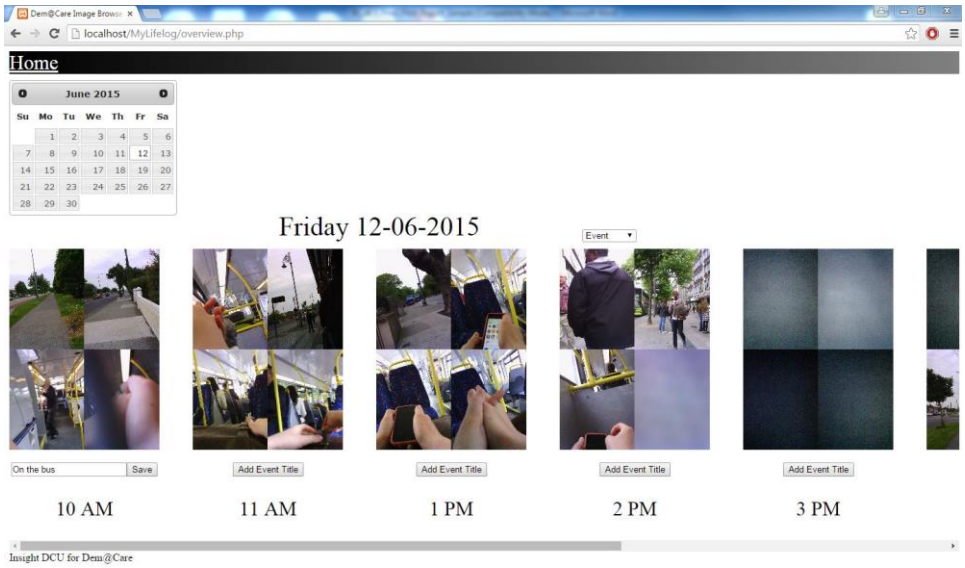


Figure 76. Managing Events functionality

6.4.3 Deployment of Lifelogging Application with PwD

As described in the CR Intervention Case Studies section above, it had been planned to deploy the lifelogging application and autographer camera with Pamela, however, this was not possible due to her worsening health difficulties.

6.5 Overall Findings from @Home (Dublin)

6.5.1 General Findings across Lead User and CR Intervention Case Studies

Across the lead user and CR intervention case studies it was found that the participant's relationship with the researcher or therapist was an important reason for their enjoyment and perceived benefit of being involved with the project. The idea that they were contributing to future developments in dementia research by being involved was also important to them.

> *"It was the idea that there was two people, or others like [researchers] that were so understanding of where [Sean] was at. Like [researchers] didn't treat it like an academic 'wham-bam-thank-you –mam here's the book now off you go', it wasn't that. It was just the humanity of it was hugely beneficial to him because he actually looked forward to it and he enjoyed it, and he did understand that somewhere along the line this is helping science, or you know future research…He got a buzz out of that. That was really important to him because he was being valued… and because [researchers] were so positive from the beginning, everything that came from that was really good… and not that you were using him, because he knew you weren't, he knew it was about science and about positive things in the future that could come from this for other people, and the fact that you appreciated it, and he liked that, and you could see it in him, and he has no problem."* [LU2 Carer – Caitriona]

> *"I'd attribute it to the fact, first of all, that you didn't come in here… you didn't make us feel that you are intruding on us. The way you've gone about it, be it your personality or your training or whatever, was excellent, that's the one thing. You*

didn't force us into anything, you explained that it was… we were helping you as much as you were helping us" [Case Study Carer 1 – Ann]

All researchers and therapists involved in the case studies agreed that sensor support should only be introduced as a result of need; the PwD should acknowledge this need themselves and should express a desire to address it. In cases where sensors are introduced the PwD should understand the function of the sensors and they should play a meaningful role in the PwD's efforts to address their particular problem; the PwD's general attitude plays an important role in determining this. The information provided by the sensors should also be meaningful and useful to the researcher or therapist. Overall researchers and therapists agreed that it is possible to introduce sensors to PwD in a way that is meaningful to them; however, it is likely that this will require high levels of support, particularly when sensors are first introduced. Across the lead user and CR intervention case studies the main reasons for disengagement with sensors were; design issues, the sensor being too complex for the PwD to use independently, the PwD not liking the sensor or having a disinclination toward technology in general or due to a progression of the PwD's cognitive deficits which resulted in the sensor no longer being useful or meaningful to them.

Researchers and therapists highlighted a number of important considerations which emerge from carrying out research with PwD. Firstly, working in the environment of the PwD's own home can bring complexities. At times the research process can be disrupted as a result of problems which arise in the day to day life of the PwD and their carer; these may include personal or family issues, health difficulties or problems emerging as a result of the progression of the PwD's cognitive deficits. It was agreed that PwD and carers who are under high levels of stress or who are approaching crisi points are not suitable for participation in research and should be linked in with appropriate services. Other practicalities such as holidays may also have an impact on the research process. As previously mentioned, the strong relationship which develops between the PwD and the researcher or therapist is an important factor impacting on the PwD's overall experience of the research. However, researchers and therapists should be mindful of this relationship and how it may influence the PwD's decision making during the research process. Furthermore, consideration is needed of how the PwD will cope when the research comes to an end. All researchers and therapists also highlighted that very careful consideration of the suitability of sensor deployment was required on an ongoing basis, particularly when working with PwD with significant cognitive deficits as introducing a sensor where the PwD may not have full capacity to understand its function raises an ethical dilemma.

6.5.2 Findings of Clinical Evaluation of Dem@Care System

A clinical expert review, in the form of a Dem@Care demonstration followed by semi-structured focus group discussions, was held in DCU in September 2015. Six clinicians attended; one clinical nurse, one occupational therapist, and four psychologists. The demonstration was given by the main Dem@Care researcher who also chaired the discussion. The focus group was recorded, transcribed, and analysed using inductive content analysis to identify the key themes that emerged. All participants were known to the researcher. One had hands-on experience of using the Dem@Care system, and one had previous experience using a static

camera (SenseCam) for reminiscence therapy. Three participants (P1, P3, and P6) were most vocal.

The main themes that emerged from the discussions were: (1) visualisation of sensor data; (2) value of sensor data; and (3) Dem@Care interfaces.

6.5.2.1 Visualisation of sensor data

Clinicians spoke in mostly favourable terms about the type of data available in Dem@Care and the flexibility with which this can be displayed. One of the most positive aspects was the ability to see trends over time within and across sensor data; for example, total amount of sleep versus total amount of exercise over a six month period.

> *"I think what is really good about it, is that it is very flexible so that you can see daily, you know what happened today… and then you can see over a week… and then you could go to over a month, what's the pattern?; then over six months, is there a general picture of decline in sleep performance?.. I think that that would be intensely useful to a clinician because as somebody who does assess people, and ask people on a daily basis in clinic 'How's your sleep?'... .nobody can tell me that"* [CFGD-P6]

One clinician saw the potential to market the solution beyond the healthcare field.

> "*I actually think… it's the sort of stuff you think athletes would love, you know being able to track all of this in terms of performance. It would be amazing.*" [CFGD-P2]

However, all participants expressed the view that there was too much data. The clinician only needs to see pertinent data otherwise the key messages will be lost; for example, all low level DTI-2 measurements are displayed on the summary tab whereas only a subset have real clinical value (moving intensity, active energy expenditure, and stress level).

> "*As a clinician you want …*" [CFGD-P2]
>
> "*the headlines*" [CFGD-P4]

One clinician was very sceptical about a GPs ability to understand the display, although this opinion was not shared by the rest of the group.

> *"… but the dangers in interpreting data without, you know … say it did end up in a GPs office who has been in practice for 20 years, and GPs by definition have to have very general knowledge, and may not be looking regularly at quantitative data, any more than myself, you are assuming an understanding of what is being presented, especially if you are going to give all of these..*" [CFGD-P2]

The following points were also discussed and they merit inclusion as it was felt that they would facilitate greater use of the Dem@Care system.

- Axis titles on graphs are unclear. Intelligent titles (e.g. titles specific to the data that is being displayed rather than generic titles) would be more useful.
- Parameters, such as alert levels or problem identification rules, would need to be customisable per PwD.

- There also needs to be some education around what different results mean; for example, the number calculated by the DTI-2 that represents the stress level.

6.5.2.2 Value of sensor data

Clinicians queried the value of knowing about bed exits without being able to identify the reason for the exit. They were made aware that a combination of sensors (e.g. sleep, ambient camera, motion) could be used to ascertain if a bed exit related to going to the bathroom, for example, but they felt that sensors should only be deployed in a person's home if there a clinical need has already been established. These two viewpoints are slightly contradictory and participants were not always in full agreement with each other, as can be seen from the following exchange.

> "*So this is just telling me that there are awake, but we don't know whether they have got up to go to the toilet*" [CFGD-P1]

> "*I mean it could be part of a suite of things that could pick up on UTI, but there would be more obvious signs of a UTI, and that's where I think technology gets overstated in a sense because, you know, really are you going to wait for the technology to tell you someone might have a UTI or is it the fact that they are going to be peeing and going 'Ow, it hurts'?"* [CFGD-P6]

> "*But if they are physically up out of bed for seven, like that might tell you about anxiety, it might tell you about an infection…"* [CFGD-P1]

> "*It does, it tells you something to investigate further*" [CFGD-P6]

> "*Instead of just telling you he's awake*" [CFGD-P1]

The clinicians were less interested in the wearable video analysis. They wanted to be able to tell if sequencing errors were occurring within an activity, and where these problems were happening. As yet, the wearable video analysis models are not capable of performing this level of fine-grained analysis. There was also a feeling that carers and PwD are able to tell the clinician if they are having a problem with something, or if something is taking longer now than it used to. They saw much greater value from the objective data that is harder to get; physical activity levels and sleep patterns.

> "*They are the things they come and report to me on a regular basis, whereas things like how much exercise they are or are not getting as compared to a few months ago, or how their sleep is, are incredibly difficult and less demonstrable things to… they don't get quantified, and quantifying them with the system is much more useful."* [CFGD-P6]

This point is supported by findings from the CR intervention where a number of participants felt they were getting adequate plenty of exercise, but psychometric measures illustrated that physical activity levels were sub-optimal. However, as one clinician pointed out

> "*But a lot of people don't have carers though… If I had that system and I had known that it would be able to tell me sleep and activity maybe there would be motivation, something different you could have done with it*." [CFGD-P3]

Interestingly, this discussion did lead to some suggestions about where this type of sensor recording could be useful. Ultimately, there would seem to be some value in deploying this sensor for short concentrated periods of time for a specific purpose; for example, instead of

sending an occupational therapist or nurse out to someone's home to do three or four assessments where they watch people make cups of tea. The value would be contingent on the clinician having the ability to analyse the raw video footage themselves. The deployment would be similar to sending a person home with a blood pressure monitor for a few days, or the way in which the GoPro camera was used to support the analysis of the cooking skills of one of our intervention participants (John).

Lack of agreement emerged in terms of whether or not clinicians would use this amount of data in daily practise

> "*I think it is unlikely a GP is going to do this. They wouldn't have the time… to review data*" [CFGD-P2]

> "*If there's a case worker I imagine… I know we don't have any case workers but, if there was a case worker, I could imagine that they could be interested in this*" [CFGD-P6]

> "*It depends on who's looking at it*" [CFGD-P3]

Participant narratives also revealed some anxiety at the idea of introducing such intense self-monitoring for a person with dementia. There was a reluctance to begin this debate in the focus group and there was a sense that this was a bigger question for another day.

> *"… intensely interested in monitoring of the self.. we do have to discuss is that a healthy thing to introduce into dementia?"* [CFGD-P6]

6.5.2.3 Dem@Care Interfaces

The participants felt that the Clinicians Interface was generally well-designed and very flexible, albeit that too much data is presented. In contrast, everyone felt that the carer interface was too complicated. They felt that a much higher degree of interpretation was needed rather than basing the interface on what was available for the clinician. It should be kept as simple as possible and it the data should be provided in a way that highlights the education and guidance that we want to give people about how the different domains influence each other. The clinician's appreciated that all of the required comparisons were available in the carer interface but that we could not assume that carers could be adept at interpreting graphs.

> "*For carers you can show a graph but it should say something like 'notice how exercise and sleep quality mirror each other' or 'it doesn't seem to make any difference what exercise is done, there is no improvement in sleep quality. Maybe it is because the exercise is being done before bed and that's not...', you know or suggest some.. obviously the more individualised they are the better, but if they were even generic suggestions… there could be an algorithm behind the graph that says that when you see this pattern there's some feedback to the carer about what this means; in a very basic way in the first instance, and then a generic list of suggestions why that might be."* [CFGD-P6]

One participant suggested that summary level reports could also be automatically created to summarise data over the last week, over the last month, and over the last six months. They should highlight trends (positive and negative), illustrate the cross-domain impact of change (e.g. see how your reduced physical activity levels have coincided with poorer sleep), and provide guidance. Clinician's felt that this addition would suit PwD and family caregivers who prefer information to be 'pushed' to them or who

were perhaps less confident with technology. Participants also felt that the type of feedback currently available for carers should be available for the PwD themselves, especially if we anticipate that people with MCI and early stage dementia will use the system. The idea of being able to ask the clinician a question was also raised.

> "*It's a similar idea to a system that I've seen a few years ago at a conference where an MRI kind of results were shared on a system between a clinician and a patient, and they both had access to them, and the patient was able to go and ask 'what does this mean?' and the clinician would actually put in an interpretation of certain things and give a message under a graph to a patient. So that would be interesting…."* [CFGD-P3]

As mentioned in the CR Intervention Case Studies section above, the Dem@Care Patient Interface has recently been updated to include a screen saver that mimicked the dementia clock that had been so successful with participants. Clinician's felt that this was a strong addition to the system, and that it could be further improved by creating a visible and audible alert when a message comes in or a reminder comes due.

> "*I think if it defaults to the clock and something new comes in, an audio prompt that something new has come in would be good.. like a text message alert*" [CFGD-P4]

They also felt that the use of voice and audio prompts was excellent, but that screen icons should be much bigger; for example, presented in a large circle and with demonstrative pictures. Using a generic voice was considered much better than using the voice of a family member which clinicians felt would be confusing and potentially constructed by the PwD to be 'surveillance'.

6.5.2.4 Evaluation Summary

Overall, the clinicians were very impressed with the capabilities of the Dem@Care system. They felt that one of its great strengths was the ability to provide objective data for functional domains where accurate introspection is extremely difficult, even for people with no cognitive impairment. Another positive aspect is the flexibility of the visualisations, although simplifying displays for all end users especially PwD and carers, would likely result in greater use of the system.

7. @Home evaluation (Thessaloniki, Greece)

7.1 @Home Description and Evaluation Aims

The Thessaloniki @Home pilots were based on the Dublin @Home outcomes. Taking into account these previous and after a point parallel results and experiences, the Thessaloniki pilots were designed to be adapted accordingly in the following main two areas:

- *Robust Technical Solutions:* all components and sensors have been tested both on the Thessaloniki @Lab pilots and on a test home environment (prior to the pilots) in order avoid problems or issues in data collection and analysis
- *Clinical settings:* the recruited participants were selected based on specific criteria. They should not suffer from severe dementia and they had to live alone. In Thessaloniki @Home pilots we focus on stages 3–5 of the disease according to GDS, in which the deficits are mild and patients are able to accept assistive intervention. At these stages, the patient experiences difficulties in planning, organizing and sequencing that prevent him/her from performing tasks in an ordered and sequenced manner. Distractions (a phone call or an unusual sound) or a short-term memory problem may lead the patient to skip steps or to perform actions that are unrelated to his/her original goal. Monitoring and interventions can help a patient to remain independent for as long as possible.

We have recruited 4 participants (3 MCI and 1 AD). The first three involved in a 4-month period and the forth in a 2-month period protocol. All the participants were recruited from the Alzheimer Day Care center in Thessaloniki, Greece.

Table 34. The duration of each protocol

March 2015	April 2015	May 2015	June 2015	July 2015	August 2015	September 2015	October 2015	November 2015
Pilot 1								
			Pilot 2					
					Pilot 3			
							Pilot 4	

There are 4 key points in the pilots:

- A **pre and a post clinician assessment** were conducted in order to identify any kind of improvement for the participants. The pre-test was conducted between 1 and 2 weeks prior to the interventions, while the post-test was conducted between 1 and 2 weeks following the end of the intervention. A second assessment took place in the middle period of the protocol. Each time, measures were taken in one testing session that lasted approximately 60 minutes. The pre-test also included semi-structured interviews regarding participant's common home activities and areas in order to have the most proper system installation.

- An **initial monitoring period** for the clinician: during the first days of each pilot he clinician monitored the recorded and analysed data from the system in order to identify problems or issues. Based on this analysis, the first interventions introduced to the participant.
- The **continuously monitoring and evaluation** of the system output combined with weekly visits, allow the clinician to adjust the interventions or introduce new ones.
- Based on the clinician's input the system was able to provide **automatically advices and/or reminders to the participants** or to their carers through the patient/carer UI. Moreover, the clinician was able to provide manually guidelines or advices through the same interface.

The home pilots' data analysis and the overall outcomes that are performed in the following section include:

- Dem@Care output for sleep, motion activity and daily activities for specific periods of each pilot
- Statistical analysis of the system output for sleep and motion activity
- Pre and post clinical assessment
- Patient or carer evaluation of the end-user UI
- Overall statistical analysis for the pre and post clinical assessments

The goals of the Thessaloniki @Home pilot evaluation were:

1. Installation of the Dem@Care system in 4 different homes with full set of sensors
2. Full data collection from the 4 homes
3. Measuring the acceptability of the system (installation, sensors) from the participants, their caregivers and experts.
4. Automate cognitive health assessment by using machine learning algorithms to classify individuals as cognitively healthy, MCI, or dementia based on the collected sensor data
5. Introducing, evaluating and improving the Dem@Care UI both to the participants and the caregivers and measuring the acceptability.
6. Enhance participants' quality of life and improve their cognitive functions and functionality based on clinical assessment of the participants after a 4-month protocol

Interventions

In Thessaloniki pilots each participant followed various interventions. These interventions were selected by the clinician based on the Dem@Care data analysis and pre-protocol interviews. In the following a small description of these interventions is provided.

Table 35. List of interventions for each pilot

Interventions	**1st Home**	**2nd Home**	**3rd Home**	**4th Home**
Reminiscence	+	+	+	+
Gymnastic for Elders	+	+		+
Personal Psychotherapy/ Reality orientation therapy	+	+	+	
Group psychotherapy	+			
Relaxation exercises	+		+	
Semantic Memory exercises		+		+
Dance Lessons			+	
Computer Exercises			+	
Memory Exercises (pictures, faces and words)				+
Prospective Memory Exercises (Audio-visual material)		+		+

Reminiscence

Reminiscence therapy, inducing a vocal recall of past activities, events, and experiences in the life of a person by using tangible prompts, has great potential as an effective intervention in the improvement of cognitive functions and depressive symptoms in elderly people with dementia [39]–[42]. In our case the clinician was visited the participants on a regular basis (once a week) for a reminiscence session. Session topics included ‘‘first meeting’’, ‘‘childhood experiences’’, ‘‘food’’, ‘‘old time music’’, ‘‘festival’’, ‘‘my family’’, “Christmas”, ‘‘when I was teenager’’. Some memory triggers such as photographs, foods, music, household and other familiar items from the past were also used.

Psychotherapy:

It has been proved that depression can be treated with moderate success by using psychological interventions. Psychotherapy is used widely and practiced. Several of the newer psychotherapeutic approaches tailored specifically to the treatment of depression have fared well in direct comparisons with medications. The practice guideline published by the Agency for Health Care Policy and Research (AHCPR) suggested that combined treatment is indicated for patients with more complex or chronic disorders.

CBT and Related Approaches

Cognitive behavioral therapy (CBT) is one of the earliest and most frequently studied of the cognitive-behavioral approaches. Early studies suggested that acute phase CT might be preferable to medication treatment in the reduction of depressive symptoms in both primary care and psychiatric samples. Subsequent trials that implemented medication treatment more adequately typically have found CT to be as effective as medications [43].

Relaxation exercises

Our clinician applied a systematic relaxation technique to the participants. Based on several studies [44] the participants were expected to improve short-term memory, concentration, general intelligence and emotion.

Gymnastic for Elders at Home and Gym

There is strong evidence that a physically active life is beneficial and indicates positive effects on mental health outcomes in adults [45]. A recent Cochrane review indicates a positive effect from physical activity on self-esteem [46]. Exercise is expected to reduce depression and anxiety in people with cognitive impairment.

Video-Imaging and memory exercises

Recent reviews and meta-analysis [47] showed that sensor-based interventions (e.g. aromatherapy), one-to-one social interaction, individualised music, recreation therapy and family videotapes reduced significantly BPSD.

Memory exercises (Prompting actions)

Various suggestions have been made about how to technologically support people with dementia when carrying out simple daily tasks. At a specific visit from the clinician, a white board (36 cm x 56 cm) was introduced to the participants. The board was divided into four sections: ‘‘likes’’, ‘‘dislikes’’, ‘‘problems’’, and ‘‘reminders’’. The participant was asked to fill in the various sections during the week to note activities that like to do, or that the caregiver and person with dementia are doing together. The reminders section was used as a memory aid. On the next visit, the clinician and the participants discussed the notes written on the white board.

Reality orientation therapy

This is a technique for people with dementia with memory loss and time–space disorientation [48]. For example, the use of large signposts, in conjunction with training sessions, has been found to minimise spatial disorientation and incontinence for people with severe dementia [49]. The goal of this intervention was to improve participants’ orientation. For example, based on prompts from the system and specific tasks from clinician that the participant had to complete, he/she was expected to become more skilful with the time management and daily program.

Expert evaluation

In order to evaluate the user interface satisfaction and the usefulness of the clinician interface for the home pilots, we conducted expert evaluation with 10 domain experts. The description and the positive results are presented in section 7.6.

7.2 Home Pilot 1

7.2.1 Profile

A.V. is a 74-year-old woman with a diagnosis of mild cognitive impairment and depression. She had complex physical and cognitive limitations. Her score on the MMSE was 29 of 30, MoCA was 26 of 30, Hamilton 15 and Anxiety Inventory 17 indicating maximum problems of mood and cognition. She had been living in her home alone for almost 20 years and she was previously a primary school teacher. Moreover, she was very depressed during the last decades because of her divorce with her husband. Her emotional reaction and behaviour was very unstable while she used to forget things in the daily routine. Furthermore, Mrs A.V had intense problems with her personal hygiene. When she was starting to clean her house, she was dropping after 1 hour because she was bored or tired. Finally, she had limited social interaction.

Patient's Statements on the beginning:

"I cannot complete even one work in the house. I start cleaning the bathroom and then I stopped and preferred to lounge in my couch and watch TV…I see the house in such a mess and the moment I realise that I have to do something I am too lazy to do anything. So I don't do anything"

"There was a time when I used to do everything successfully. I took care of my children..I was cleaning, cooking, remembering all that staff a woman has to do etc. After my husband's divorce my memory is terrible. I am going to the next room and I forget what I have to take. Yesterday my children called me and told me mom where are you we are waiting you for a dinner…I have totally forgotten it. Can you believe it?"

"Before two weeks I was out to shop groceries and when I came out of the store I was totally disoriented. For a moment I didn't know which road to choose back to home. And this grocery I am visiting for over 10 years. My mind wasn't in my body… I don't know what is happening but I am not the same active person I used to be"

"Everyone hates me. I don't have friends. Everyone hurts me with his words. I used to have two good friends but before two weeks they visited me and they told me that I ignore them and my behaviour is terrible… After that I was crying for over 5 hours... I don't understand why people behave me like this"

Selection Criteria and Clinical Assessment

Initially, the criteria for MCI followed two conceptual models: one associated only with memory deficits, and the other with a broader range of deficits of other areas of cognition and behaviour. Because memory deficits are the clinical hallmark of dementia, most of the criteria developed to characterize MCI required the presence of memory deficits in isolation. However, other clinicians felt that the memory-centred definition of MCI was too restrictive because it did not capture other cognitive problems that often occur in the elderly population. For example, the International Psychogeriatric Association and the World Health Organization proposed the term "age-associated cognitive decline" (AACD) to describe subjects with a wider range of cognitive deficits. The most recent criteria for MCI encompassed all possible cognitive manifestations of the syndrome and four subgroups have been proposed: deficits only in

memory functions; memory deficits plus deficits in another cognitive domain; deficits in a single no memory domain; and deficits in more than one no memory domain. This has expanded the knowledge of the MCI syndrome and allowed examination of the relationship between MCI syndromes and other dementias that do not have memory deficits.

The National Institute on Aging and Alzheimer's Association (NIA-AA) criteria for MCI were created to characterize a syndrome that is most likely associated with AD pathology. The purpose of these criteria was to identify subjects in the pre-AD state, and they require that patients with MCI must have impairments in one or more cognitive domains. Although the criteria emphasized the presence of memory deficits as the central characteristic of the syndrome that can progress to AD, they recognized that there are forms of AD (e.g, visual or language variants) that do not have memory deficits in their early stages. MCI subjects with multiple disease processes that can affect cognition can progress to AD, and not all AD patients have memory loss at initial presentation; usually, mild no memory function deficits are difficult to detect with brief cognitive evaluations. Thus the installation of the Dem@Care system was very useful to detect the progress of a patient in the early stages of cognitive dysfunction after specific interventions and assistive technology support.

Table 36. Signs and symptoms for patient selection

Complaints of cognitive deficits Some patients with early mild cognitive impairment report cognitive deficits
Global measures of cognition could be within normal limits For example, the Mini-Mental State Examination
Cognitive deficits identified by neuropsychological testing Deficits in memory and non-memory tests. Evidence of progression in cognitive testing supports the diagnosis
Preservation of activities of daily living Some instrumental activities of daily living could be impaired (e.g. establishment of an account balance).
Psychiatric, or systemic disorders that may cause cognitive deficits Patients with mild cognitive impairment with comorbid conditions (for example, metabolic disorders, depression) can also progress to Alzheimer disease.
Dementia has been excluded For example, impairments in at least two cognitive domains are severe enough to interfere with the patient's instrumental activities of daily living or activities of daily living. Clinical judgement is recommended in borderline cases

7.2.2 Installation

Before the installation in the first participant home, we did extensive tests of Dem@Care system in real home and Lab conditions in order to identify any problems or issues.

In the following table, the sensors and the relevant areas or items of the home installation are presented.

Table 37. Sensor-Activities

Sensors	
Presence sensor	- Bathroom - Kitchen
Tag (motion sensor)	- Door - Dug Cabinet - Fridge door - Herbs - Iron - Pillbox - Tv remote - Vacuum
Activity sensor (UP24)	- Wearable sensor
Sleep sensor	- Sleep sensor
Plug sensor	- Boiler - Cooker - Iron - Tv - Vacuum - Washing Machine
IP camera	- Kitchen

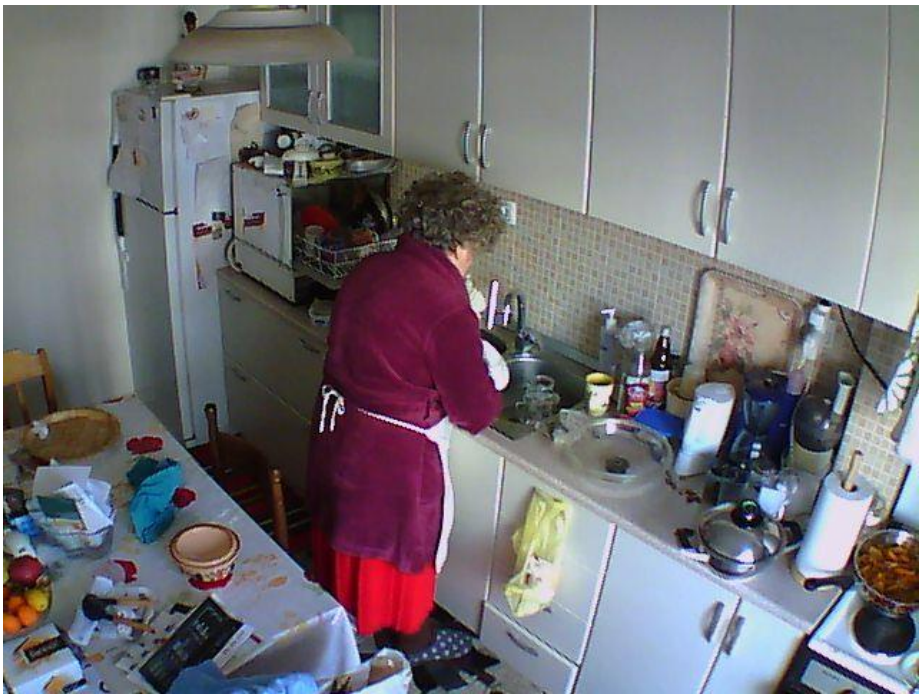


Figure 77. IP camera capture from the patient preparing a food in the kitchen. A coprehensive video analysis showing to the clinician the sequence of activities in the kitchen

Figure 78. Wearable sensors that detect activity, and smart plugs in cooker and boiler and tags in medication box, fridge and boiler

7.2.3 Interventions

The interventions were based on a) the Dem@Care data analysis that was available to the clinician and b) the participant's preferences and needs after guided advances from clinician.

Based on the initial sleep quality as detected from the system, the clinician was able to determine that there were more than usual interruptions during night sleep (more than 4) and very long sleep latency. As she mentioned to the clinician she wasn't able to relax and sleep easily. Also she was very anxious for no specific reason and she has started worry about her cognition during daytime.

Based on these observations the clinician started personalized psychotherapy once a week in order to understand better her initial problem, solve it and help her to continue a normal life. Once a week the clinician visited the patient to do Relaxation therapy exercises. These approaches were based on Cognitive Behavioural Therapy and specifically on Beck's Cognitive Restructuring technique. She also attended group psychotherapy with other people with depression and behavioural problems in Alzheimer Care Center.

Moreover, based on the system output it was clear that the participant had no social life and she was avoiding to leave her home. For these reasons the clinician introduced and advised her to do some gymnastics twice a week with other people of the same age in daily Alzheimer Day Care Centre. This intervention proved very efficiently and had positive results not only to her social life but also to the sleep quality.

During the middle period of the intervention, the clinician detected from the system that the participant started to have better sleep but still limited home daily activities. Moreover, in the weekly meetings she stated that she started feeling better but her memory hasn't improved as much as she wished. Based on the above the clinician introduced a specific weekly program with house works that participant had to do (e.g. ironing). Also, the clinician introduced Reminiscence therapy to enhance both the retrospective memory and emotional status. Furthermore she was informed about a choir program in order to take part in concerts with people of her age, with the same characteristics and preferences. From the Dem@Care interface the clinician could detect increased moving intensity and fewer hours inside the home.

7.2.4 Measurements: Sleep

In the beginning of the protocol, the participant had very intense sleep problems (Figure 79) (long "shallow sleep", total sleeping hours, many hours in bed awake). In the middle period, there was an improvement in all aspects and in the final period there was a clear improvement. In the following figures, graphs from the Dem@Care interface the clinician observed specific measurements of sleep in one-day. Moreover, information about total time of sleep latency, total time of shallow sleep, deep sleep, asleep and number of interruptions are presented in the summary.

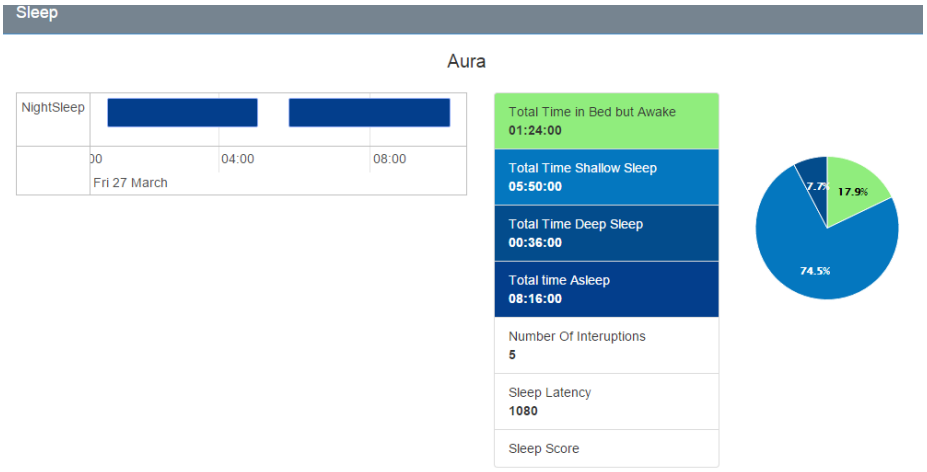


Figure 79. Sleep quality: Beginning of the protocol

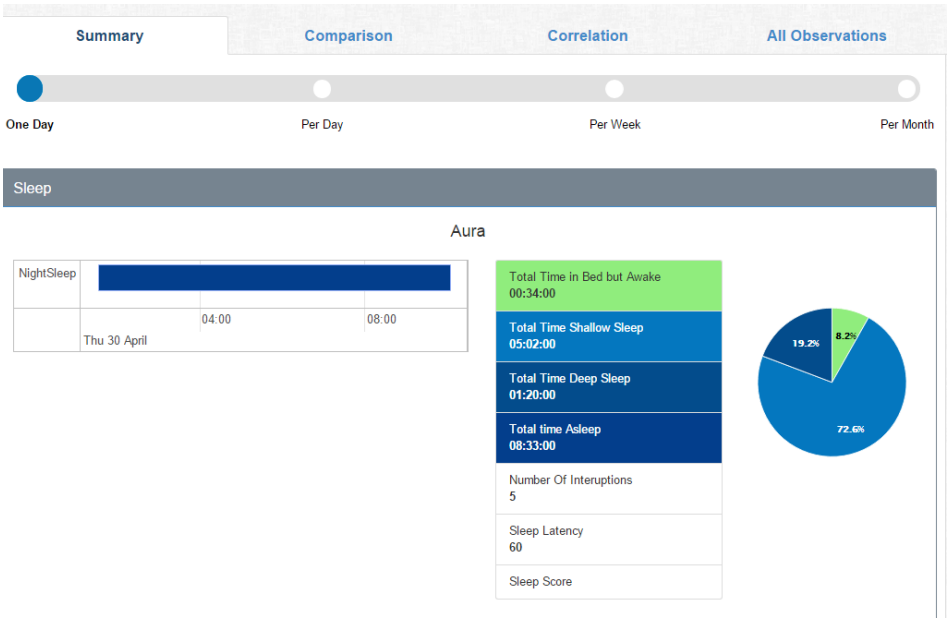


Figure 80. Sleep quality: In the middle of the protocol

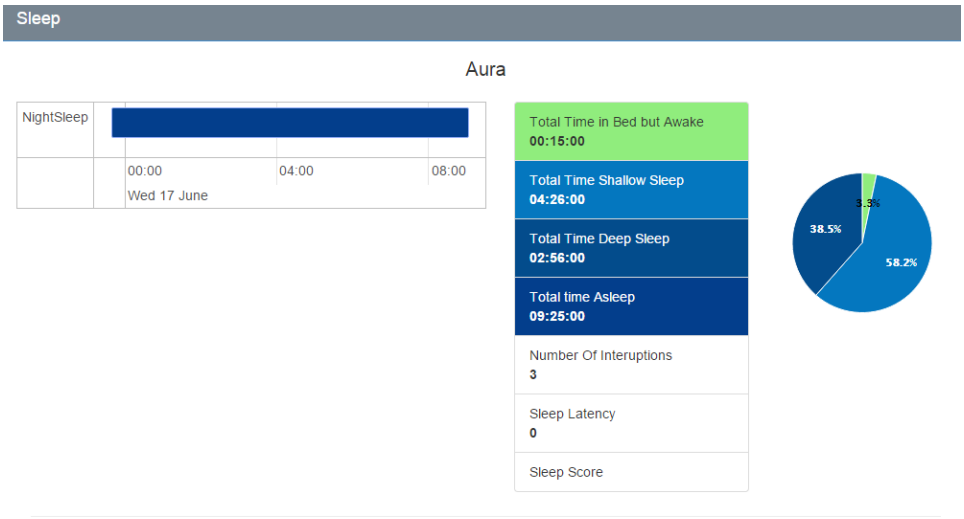


Figure 81. Sleep quality: In the final period of the protocol

Specific observations of sleep via interface

Based on system output, it was identified that on the beginning of the protocol the participant was more than an hour in her bed awake (Total time in bed awake: 1:24 hrs, 17,9%), though in the majority of adults at this stage covers 5-10% of their total time sleeping. Her total shallow sleep duration was more than 5 hours - the majority of total time sleep (Total time shallow sleep: 5:50 hrs, 74,5%) while in the majority of adults' shallow sleep covers 45-55% of their total time of sleep. Also her deep sleep was also low (0:36 hrs, 7.7%), while the total time of deep sleep in adults is an average of 15-25%. Furthermore, the numbers of interruption were around 5 during a night.

In the middle period an improvement in the sleep was obvious as the participant had less time in bed awake (Total time in bed awake: 0:34 hrs, 8, 2%). Her total shallow sleep duration was reduced (Total time shallow sleep: 5:02 hrs, 72,6%). Also her deep sleep was increased (1:20 hrs, 19.2%), while the number of interruptions remained the same. In the final period the clinician observed reduction of total time awake of the patient in bed during night time (0:15 hrs, 3.3%), total time of shallow sleep (4:26 hrs, 58.2%), increased duration of total time of deep sleep duration (2:56 hrs, 38.5%). Moreover, the total time of sleep also increased (from 8 hrs on the beginning to 9 hours and a half in the final period) and number of interruptions decreased.

Using the graphs for a specific period we are able to see that in the first period of the protocol the participant has very high values of sleep interruptions. The average number of interruptions is more than 3 per night.

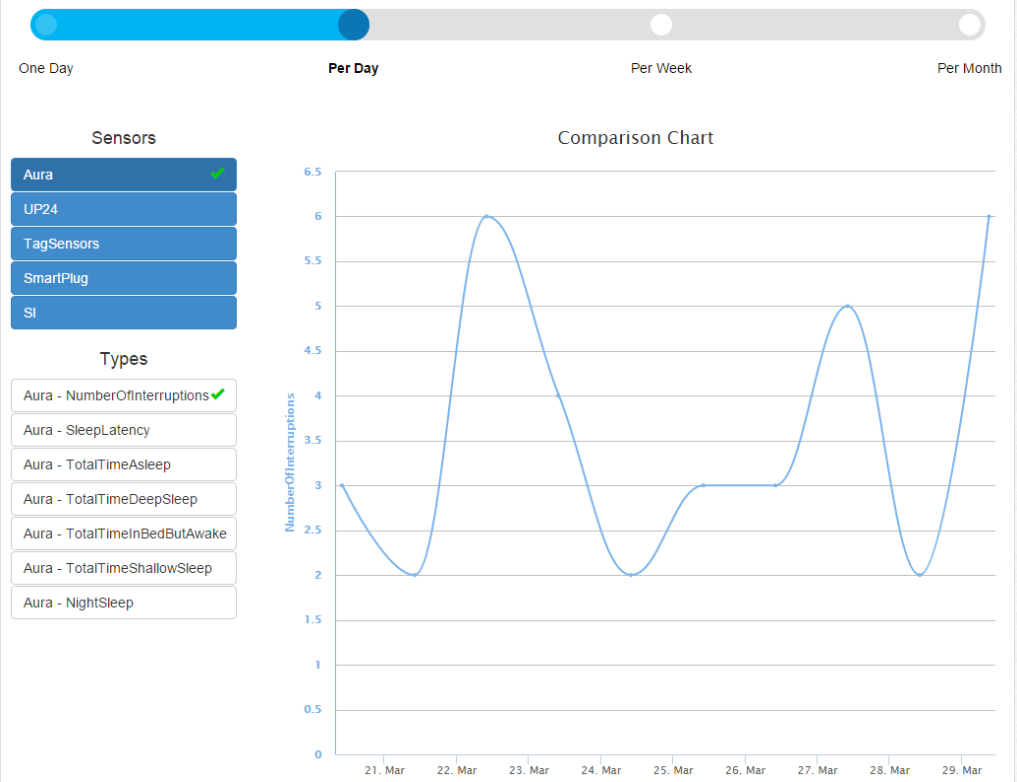


Figure 82. Observations in the comparison per day chart, with number of interruptions of selected days in the beginning of the protocol (mean interruptions per night was 3).

After the first interventions, we were able to see more stable values in interruptions during sleep. In this graph is obvious that the majority of interruptions per night are less than 3 and except from 2 nights where based on her feedback the participant was very stressed.

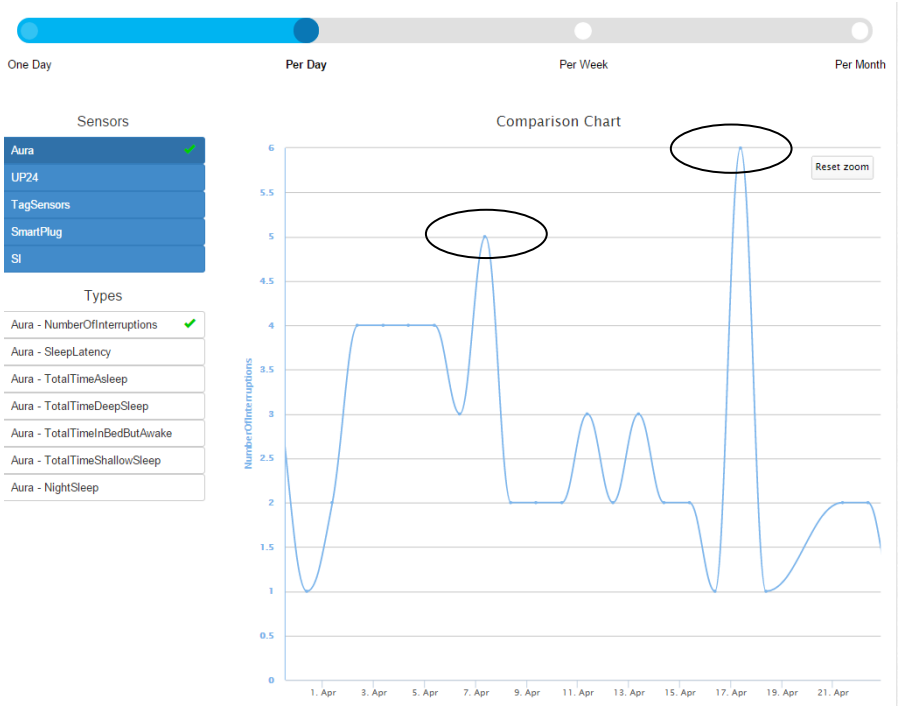


Figure 83. Observations in the comparison per day chart. Number of interruptions of selected days in the middle period of the protocol (mean interruptions per night was 2.5).

During the final period of the protocol, we see an important improvement regarding the sleep interruptions. The patient was calm during night time with fewer interruptions.

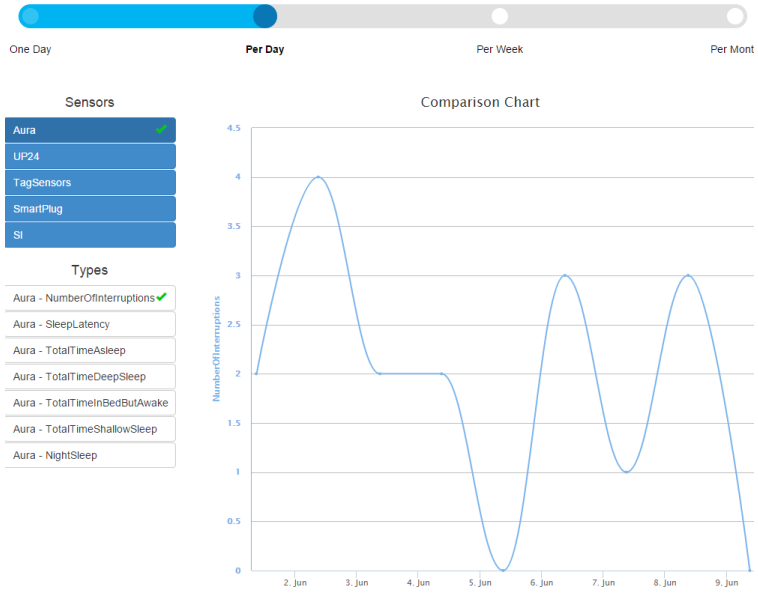


Figure 84. Observations in the comparison per day chart, with number of interruptions of selected days in the final period of the protocol (mean interruptions per night was 1.5).

A per week analysis for all the protocol period reveals that the participant had a continually improvement in sleep quality.

Figure 85. Observations in the comparison per week chart, with number of interruptions of all the weeks of the protocol

In Dashboard session the clinician can define specific problems the SI wants to appear. The clinician set thresholds for specific activities: Sleep Duration: 7 hours, Number of Interruptions: (more than) 2, sleep latency: (more than) 30 minutes, days of reoccuring problem :3

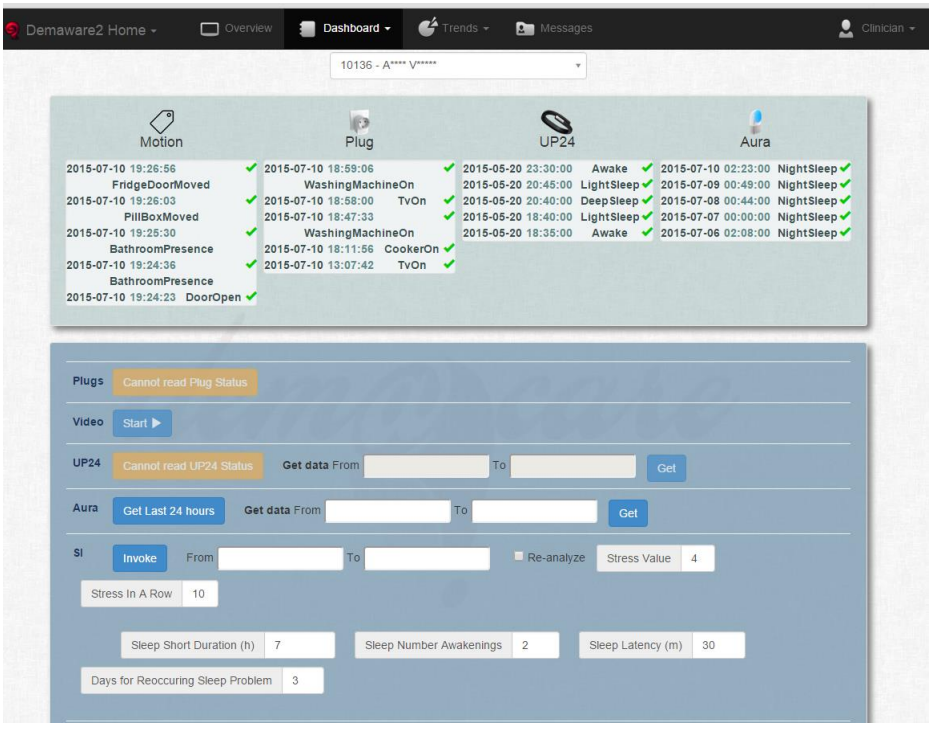


Figure 86. Dashboard where the clinician sets the thresholds for SI

The SI analysis revealed that based on the clinician's input, there was a decrease of number of interruptions, short sleep duration, total time awake in bed (March-April 70 problems detected, May 54 problems detected and June-July 20 problems)

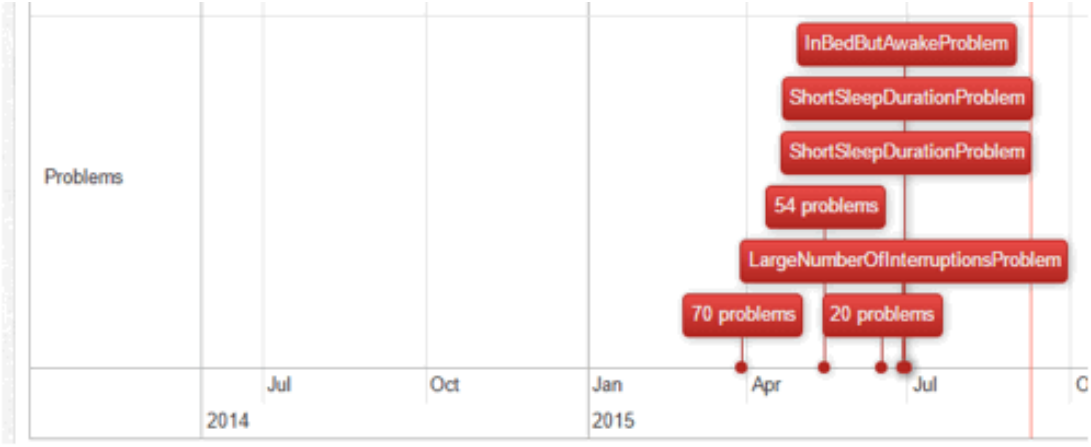


Figure 87. SI problems detection over the whole protocol period

In order to investigate our hypothesis, linear regression analysis was used to find any improvement and changes over time of the patient's sleep. The level of significance we set was a=0.05.

Table 38. Statistics of the sleep aspects

	Regression analysis (Sig)
Sleep duration	**0.000*** **
Sleep Latency	**0.000*** **
Deep sleep duration	**0.000*** **

***p<001

The statistical analysis revealed significant improvement over the time in 3 out of 4 values. These results indicate very important improvement in sleep patterns. We must take into account that our participant's initial problem was sleep and via the installation and interventions improvement is detected in almost all domains of sleep.

7.2.5 Measurements: Activity

Our participant had very decreased moving intensity during the first period. She preferred to stay at home and watch TV instead of going out for a walk.

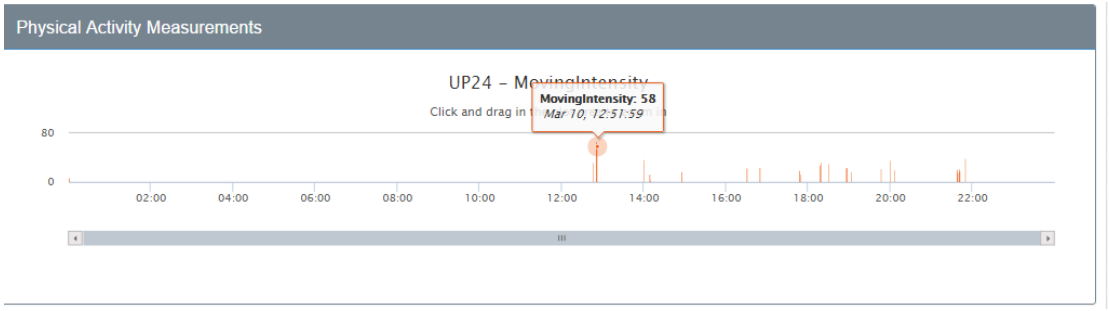


Figure 88. In one-day summary session in the beginning of the protocol. Moving intensity as detected by the Up24 bracelet.

In the middle period the patient started doing the introduced exercises in the gym and at home after specific guidelines from the clinician. She used to attend specific gymnastic for elders.

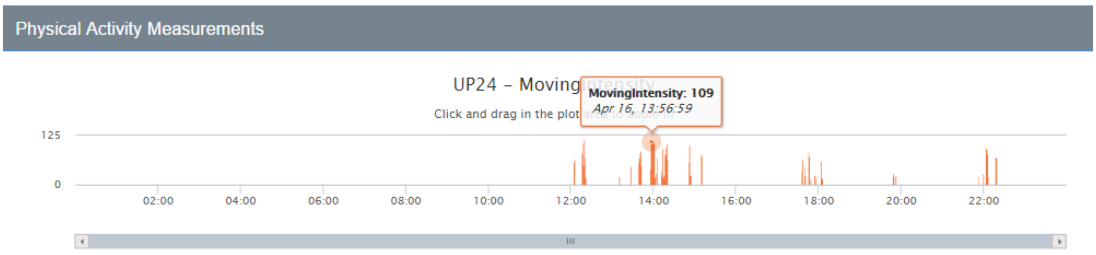


Figure 89. In one-day Summary session in the middle of the protocol, with moving intensity as detected by the Up24 bracelet

During the last phase of the protocol the participant was very active during day time. She was following a specific program at gym but also started doing many house works during the day.

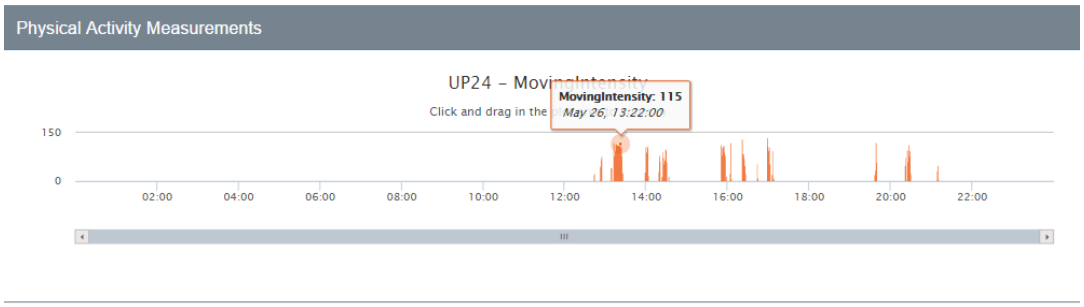


Figure 90. A one-day Summary session in the final period of the protocol, with moving intensity as detected by the Up24 bracelet

Graph for a specific period highlights the problems in moving intensity. Most of the values are below 8000.

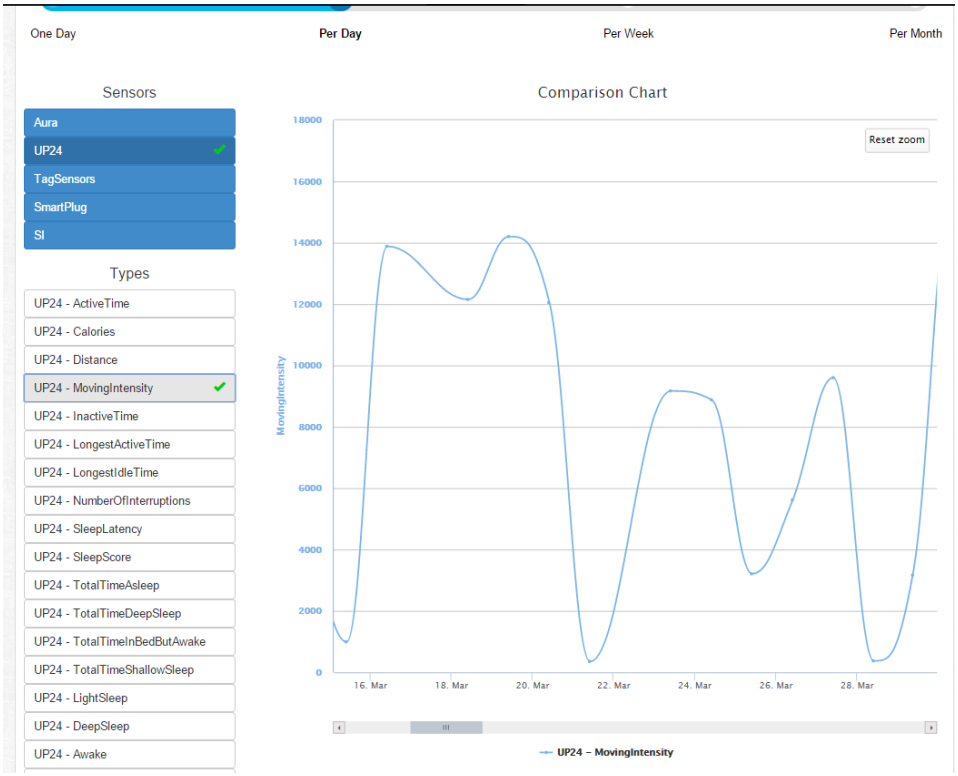


Figure 91. A comparison daily chart information about moving intensity in the beginning of the protocol

Improvement in the middle period-moving intensity: The majority of the values are more than 10000.

Figure 92. A comparison daily chart information about moving intensity in the middle of the protocol

More frequent moving intensity in the final period: The majority of the values are more than 14000.

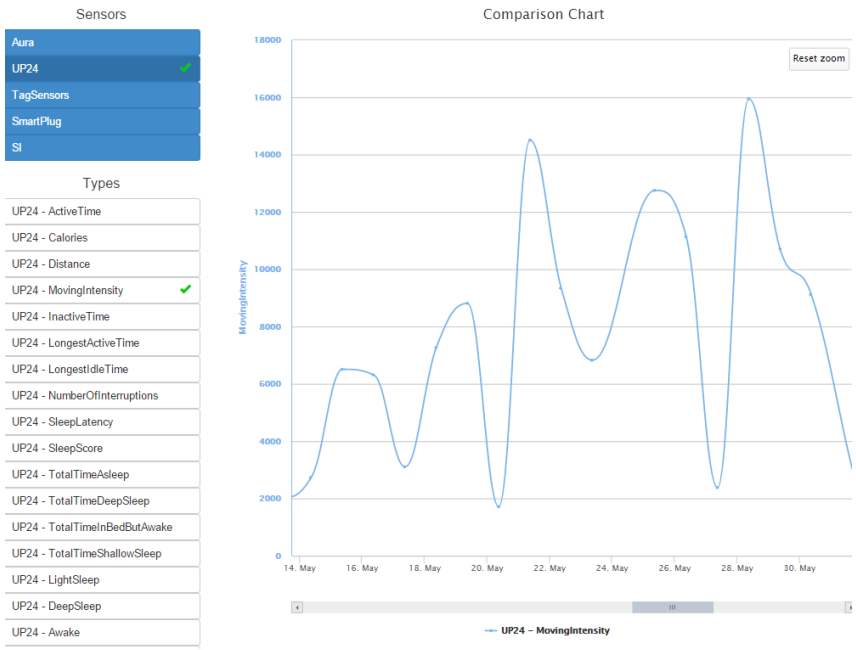


Figure 93. A comparison daily chart information about moving intensity in the end of the protocol

In the following chart the moving intensity affects sleep duration (middle period). This shows from clinical aspect that people who have intense activity during the day have better sleep at night.

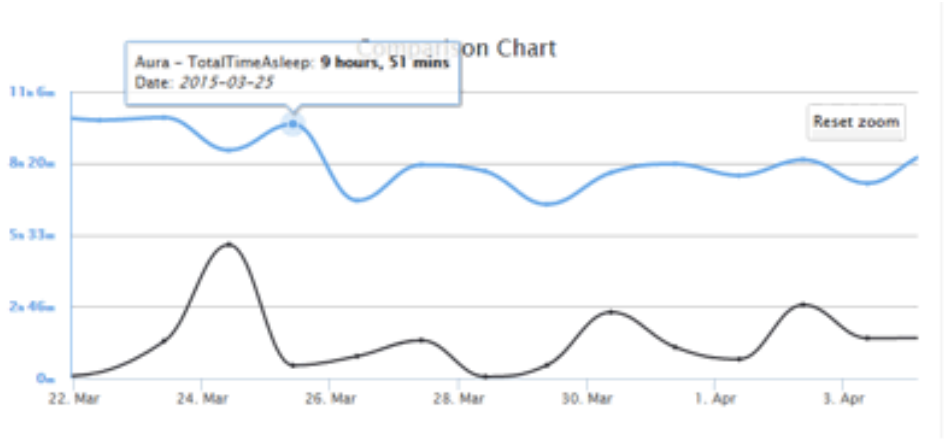


Figure 94. A comparison daily chart with correlation between two activities (otal ttime asleep and moving intensity)

The statistical analysis also confirmed the significant improvement over the time in moving intensity (p=0.04).

7.2.6 Measurements: Daily activity

During the first period, the patient did not do any house works. She did not care about her personal hygiene at all.

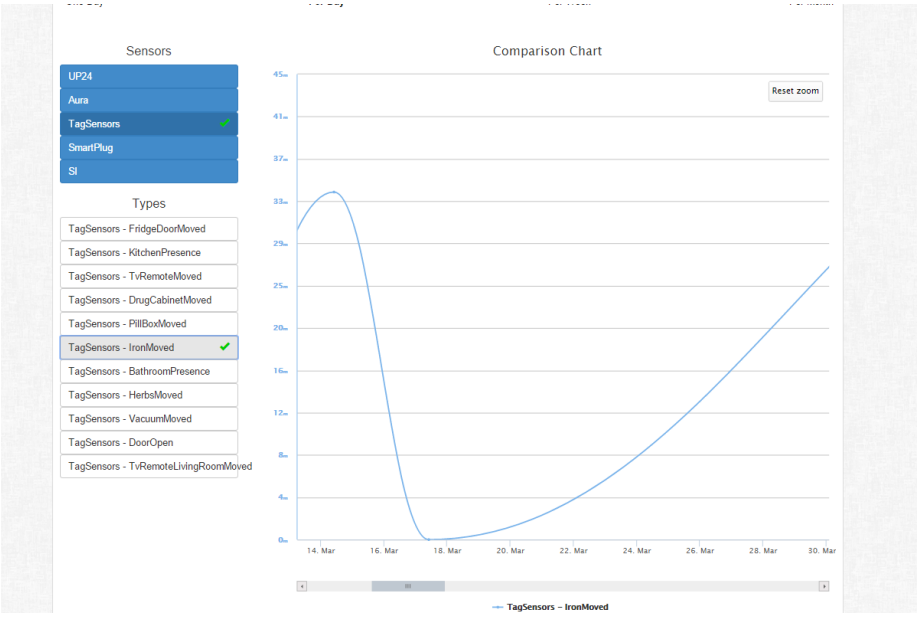


Figure 95. A comparison daily chart information from tag sensors revealed the use of the iron in the beginning of the protocol

After clinical advice and interventions, the patient started be more careful of taking care of the home.

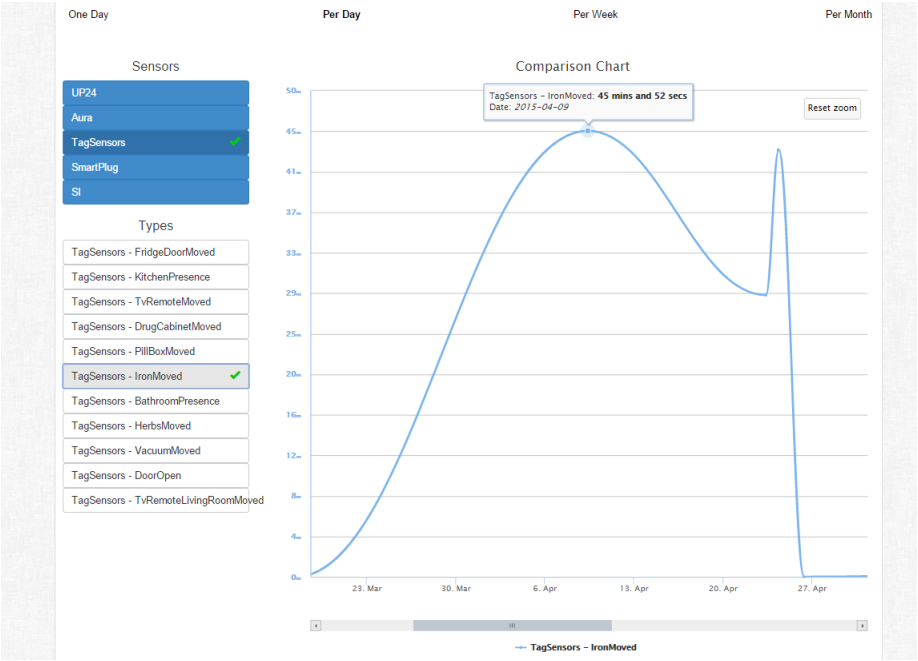


Figure 96. A comparison daily chart information from tag sensors revealed the use of the iron in the middle period of the protocol

During the final period, she was using specific devices at home and taking care of her hygiene more intensively and more frequently.

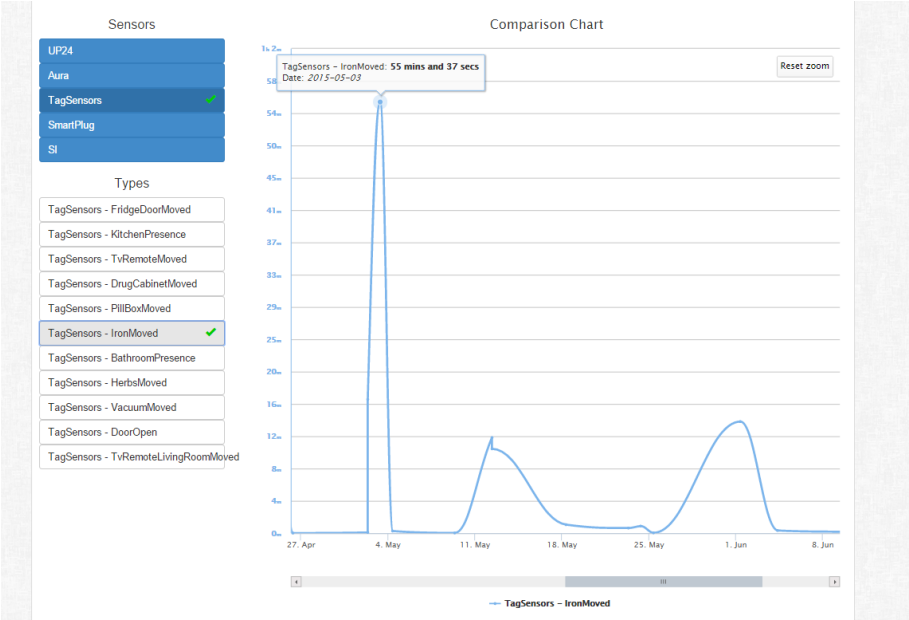


Figure 97. A comparison daily chart information from tag sensors revealed the use of the iron in the final period of the protocol

During the first period the patient preferred to stay at home and not to go out. The clinician detected from the system intense use of TV in the beginning (no social life, many hours in home). However, this status changed and improved over time.

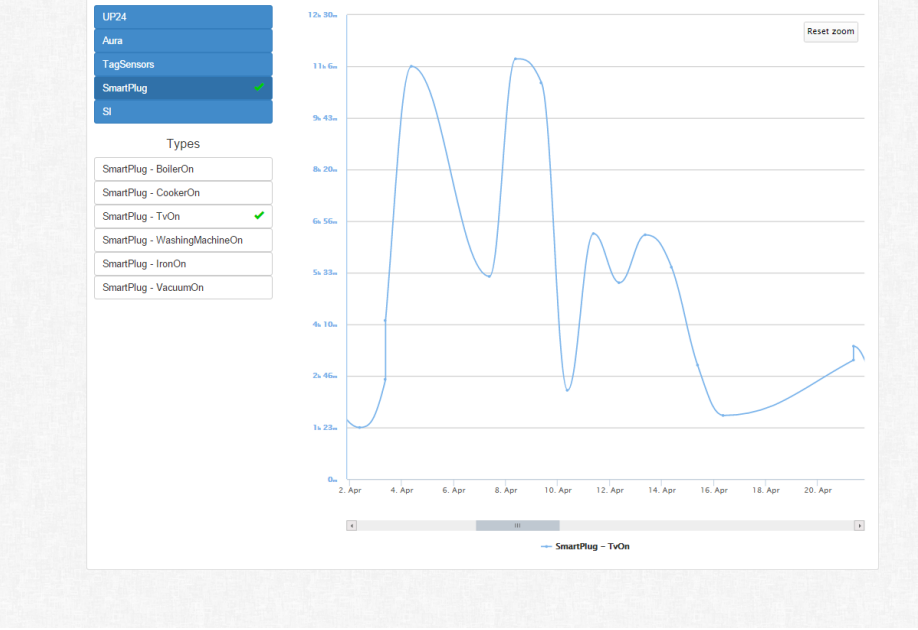


Figure 98. A comparison daily chart information from smart plug revealed the use of the TV in the beginning of the protocol (mean duration was 4 hours and 10 min per day)

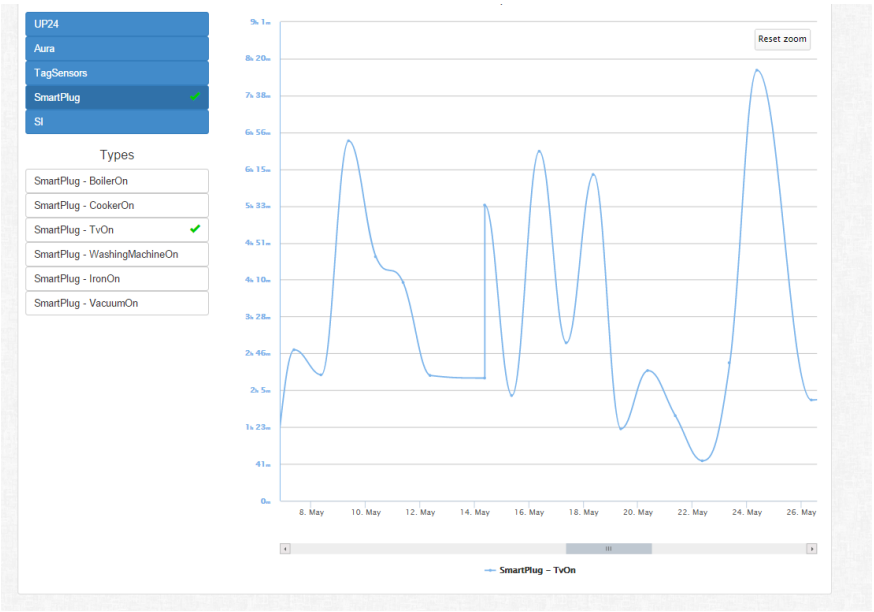


Figure 99. A comparison daily chart information from smart plug revealed the use of the TV in the middle of the protocol (mean duration 3 hours and 33 min)

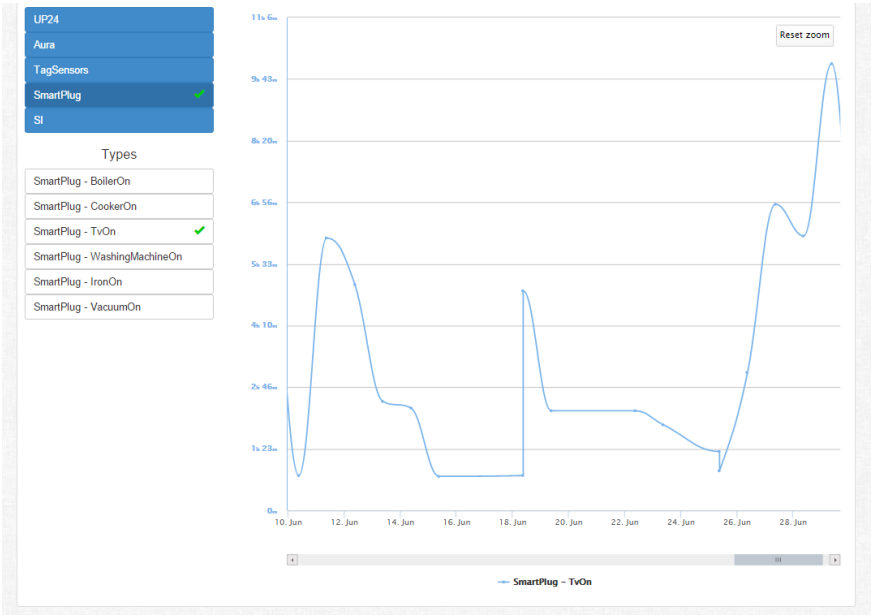


Figure 100. A comparison daily chart information from smart plug revealed the use of the TV in the final period of the protocol

The cause of the peak at the end of June was the political incidents that was happening in Greece during that time. It is important that the system recorded this change.

7.2.7 Measurements: Psychometric

In the following table the three clinical assessments (initial, middle and final) are presented

Table 39. Initial period of neuropsychological assessment

MMSE	29	**RBMT- story direct recall**	16
MoCA	26	**RBMT-story delayed recall**	8.5
CDR	2	**FUCAS**	42
NPI	2	**TRAIL-B**	138
FRSSD	6	**BDI**	10
GDS	1	**QOL**	21
HAMILTON	15	**IADL**	8
PSS	19	**ROCFT-copy**	32
BAI	7	**ROCFT-delayed recall**	14
TEA		**RAVLT**	
Map Search	1st attempt: 15	1st attempt	4
	2nd attempt : 7	5th attempt	(+7)11
Visual Elevator	Correct answers: 9	Total score	48
	Time: 6.97	Delayed recall	(-3) 8
Telephone Search	Total score: 5.73	**FAS**	8

Table 40. Middle neuropsychological assessment

MMSE	30	**RBMT-** story direct recall	10
MoCA	27	**RBMT-**story delayed recall	8
CDR	1	**FUCAS**	42
NPI	8	**TRAIL-B**	138

FRSSD	4	**BDI**	6
GDS	6	**QOL**	28
HAMILTON	18	**IADL**	8
PSS	19	**ROCFT**-copy	34
BAI	8	**ROCFT**-delayed recall	22
TEA		**RAVLT**	
Map Search	1st attempt: 19	1st attempt	6
	2nd attempt : 39	5th attempt	14
Visual Elevator	Correct answers:9	Total score	45
	Time: 6.32	Delayed recall	(-3)11
Telephone Search	Total score: 6.8	**FAS**	12.3

Table 41. Final neuropsychological assessment

MMSE	30	**RBMT-** story direct recall	17
MoCA	30	**RBMT-**story delayed recall	12.5
CDR	0.5	**FUCAS**	42
NPI	2	**TRAIL-B**	120
FRSSD	1	**BDI**	2
GDS	2	**QOL**	44
HAMILTON	5	**IADL**	8
PSS	10	**ROCFT**-copy	36
BAI	4	**ROCFT**-delayed recall	28
TEA		**RAVLT**	
Map Search	1st attempt: 25	1st attempt	6
	2nd attempt : 26	5th attempt	(+9) 15
Visual Elevator	Correct answers: 9	Total score	61

	Time: 5.52	Delayed recall	(-3) 12
Telephone Search	Total score: 3.2	**FAS**	12.6

The neuropsychological assessment revealed changes almost in all domains of cognition and emotion. Moreover, in the beginning the patient had problems in memory and general cognitive function according to MMSE=29, MoCA=26, CDR=2. Also, low scores detected in tests which assess cognitive processing and speed (TRAIL MAKING part B=138, TEA map search=15/17, visual elevator 9/6.97, telephone search total time= 5.73), episodic memory and long-term memory (RBMT delayed recall of the story=8.5), executive functions and visual-spatial long term memory (ROCFT delayed recall=14) and the ability of storing new knowledge (RAVLT total score=48) and verbal fluency FAS=8. Also she was very anxious and pessimistic as it revealed by specific scales (BDI=10, PSS=19) and low scores in quality of life QoL=21.

After the interventions applied to the patient we saw improvement in specific domains of the patient's daily routine such as sleep and daily activities. This improvement also is obvious to the neuropsychological assessment as well. More specifically, the patient's scores in the final assessment indicate improvement in general cognition and memory (scores of MMSE=30, MoCA=30, CDR=0.5), cognitive processing, attention and speed (TEA map search 25/26, visual elevator 9/5.52, telephone search total time= 3.2 TRAIL MAKING part B=120) which is a sign of normal limits for elders. Also, better performance is obvious in scales of emotion (BDI=2, PSS=10, and Hamilton=5) and quality of life. Furthermore, the ability of new learning and verbal fluency is also improved (FAS=12.6, RAVLT total score=61).

7.2.8 Patient Interface

In the middle period of the protocol, the clinician provided to the participant a mobile tablet device and introduced to her the patient interface. There was repeatedly learning sessions in which the clinician presented to the participant the operation and the information that the patient interface is able to provide. The goals of the participant interface was a) to provide in a simple and understandable way all the needed information in order the participant to be aware of the daily activities performance, b) to remind the participant specific activities (e.g. medication), and c) to allow the clinician to send messages and guidelines to the participant any time of the day. More specifically, the user interface informed the participant regarding sleep duration and interruptions, devices usage and medication. At the end of the protocol the clinician interviewed the participant regarding the usefulness and the usability of the system.

In the following figure the patient is able to see the sleep duration in the last 3 days (15/9-17/9) (blue chart), how many times she woke up during the night (yellow chart) and how many hours she was awake in bed (red chart). Also problems of number of interruptions appear in the red line above the chart, which inform the patient how many interruptions she had *("You had 6 sleep interruptions on 17/09/2015")*

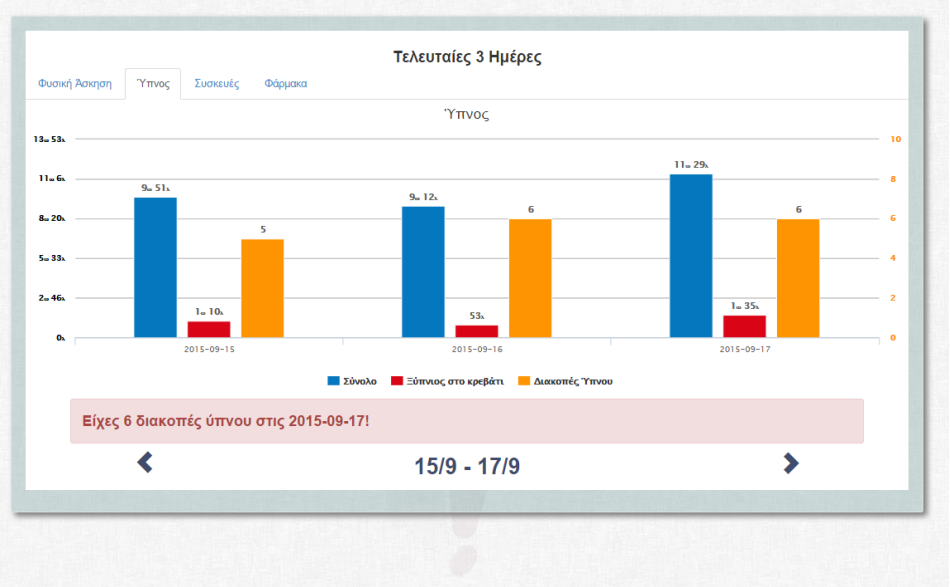


Figure 101. User interface. Sleep information

In this picture the patient can see if she took or not her pills and her herbs during the last 3 selected days (4/7/2015-6/7/2015).

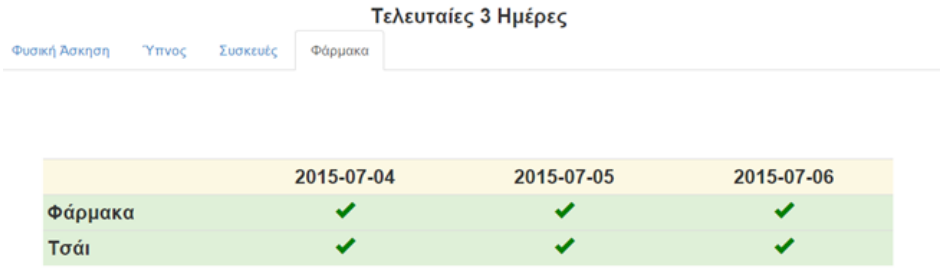


Figure 102. User interface. Medication and herbs information

In this session, se was also able to see the usage of her devices. Duration of TV usage (green chart), cooker (black chart), washing machine (purple chart) or vacuum (orange chart), boiler (blue chart).

Figure 103. User interface. Home devices information

In the following table, the participant's answers and statement to user experience and user evaluation questionnaire is presented.

Table 42. User Evaluation

OVERALL REACTION TO THE SYSTEM	
1. terrible-wonderful	"The system was very good. Actually it was better than I expected "
2. difficult-easy	"When the clinician show me how to use it, it was very difficult and barely could I understand but afterwards it became easier"
3. frustrating-satisfying	"It was very satisfying in my opinion"
4. inadequate power-adequate power	"It is a very good"
5. dull-stimulating	"It is very nice application and very interesting for people who have problems such as me"
6. rigid-flexible	"I think it is actually very flexible"
SCREEN	

7. Reading characters on the screen: hard-easy	" It was very easy to ready what charts included and also to understand the values on them and see specific devices or actions"
8. Highlighting simplifies task: not at all-very much	" All tasks and selections were very much highlighted"
9. Organization of the information: confus-ing-very clear	"I didn't face any problem to understand it and as far as the information is concern it was very well-organized, the graphs were very nice presented"
10. Sequence of screens: confusing-very clear	"The sequence was very clear and understandable"
TERMINOLOGY AND SYSTEM INFORMATION	
11. Use of terms throughout system: incon-sistent-consistent	"It was consistent"
12. Terminology related to task: never-always	"Always. It was very clear what were the button say and what to expect if you select specific options"
13. Position of messages on screen: incon-sistent-consistent	"The position of the messages would be better if they were appearing on desktop not to have to log in so as to see clinician's messages."
14. Prompts for input: confusing-clear	"The prompts were very clear and they help you to shed your attention on problems, which the clinician has detect-ed."
15. Computer informs about its progress: never-always	"Always it was updating. Very few times I couldn't see my recent activities"
16. Error messages: unhelpful-helpful	"the messages were helpful because I can se if I have pro-gress and I have access to my own health"
LEARNING	
17. Learning to operate the system: diffi-cult-easy	"I didn't find it very easy to operate the system on the beginning but after clinician's written instructions I could

	easily see the data"
18. Exploring new features by trial and error: difficult-easy	"It wasn't such a difficult system. I don't know if people who have more problems with their memory can learn how to use it"
19. Remembering names and use of commands: difficult-easy	"Easy. If I had an obstacle I read the written instructions of my clinician"
20. Performing tasks is straightforward: never-always	"Almost always"
21. Help messages on the screen: unhelpful-helpful	"The messages were very helpful and it was very nice to have interaction with my clinician via this tablet"
22. Supplemental reference materials: confusing-clear	"It was very clear"
SYSTEM CAPABILITIES	
23. System speed: too slow-fast enough	"It was very good. The data were loading very fast."
24. System reliability: unreliable-reliable	"I think it was very reliable because I saw that what the system was showing it was true (e.g. I was watching TV for 5 hours yesterday)."
25. System tends to be: noisy-quiet	" It is not noisy"
26. Correcting your mistakes: difficult-easy	"Yes it's very easy'
27. Designed for all levels of users: never-always	"No I think that people with Alzheimer disease cannot use it easily"
USEFULNESS	
28. Using the system in my job would enable me to accomplish tasks more quickly: unlikely-likely	"Yes definitely I was at gym yesterday and the day after I could see how many calories I burned. It was wonderful"

29. Using the system would improve my job performance: unlikely-likely	"I could see what actually helps me and improves my health and my sleep, on which I had a major problem"
30. Using the system in my job would increase my productivity: unlikely-likely	"It enforces you to continue doing what you do because you can see that it helps."
31. Using the system would enhance my effectiveness on the job: unlikely-likely	"I was informed about my progress and I was very interested and happy about that"
32. Using the system would make it easier to do my job: unlikely-likely	"Yes"
33. I would find the system useful in my job: unlikely-likely	"Yes I can detect what helps me. It is like I am the clinician and testing myself every day. It is very nice."
EASE OF USE	
34. Learning to operate the system would be easy for me: unlikely-likely	"The options were very clear after the clinician explain to me how to use it"
35. I would find it easy to get the system to do what I want it to do: unlikely-likely	"Of course cause"
36. My interaction with the system would be clear and understandable: unlikely-likely	"Yes I found it very understandable"
37. I would find the system to be flexible to interact with: unlikely-likely	"Yes it was very flexible"
38. It would be easy for me to become skillful at using the system: unlikely-likely	"Now I know how to use it and what I want to see"
39. I would find the system easy to use: unlikely-likely	"Yes after a long-term of using it"

7.2.9 Conclusions

Our first participant had been diagnosed with mild cognitive impairment and depression. She was fully aware of her memory problems. She accepted that she had depression and started follow the instructions and the interventions the clinician proposed. Dem@Care sensors constant monitoring provided an objective assessment of the initial and following condition and allowed the evaluation and adaptation of the suggested interventions. After 4 months we had great improvement in her cognition, memory, performance of activities of daily living, emotion and sleep.

Based on Dem@Care system output and the relevant statistical analysis, there was significant improvement in the duration and quality of sleep. This is a very important outcome if we consider that sleeping problems are very common in elders and more specifically in patients with cognitive impairments.

Moreover, the correlations between sleep improvements and other activities of daily living that the system was providing, allowed clinician to estimate the effects of specific advices and interventions. The system also provided evidence regarding less TV usage, which was a basic goal from the beginning to reduce TV usage and increase patient's social interaction and activity. Finally, at the end of the intervention there was improvement in various tests and especially in Hamilton and MMSE.

This pilot demonstrates that non drug, psychosocial interventions can be delivered to people dementia. Personalizing such interventions in order to meet individual needs and preferences is key to their success. As this study illustrates, advanced technology can contribute to personalization in many ways by collecting and using personal facts and information. Technology-based interventions can truly live up to patient's potential and make chronic conditions management available with ease.

Chronic disease such as cognitive impairment will never be easy, but disease management can become easier with the help of smart technology. We found that the participant with MCI was very interested in the possibilities of technology and could be tested using it for short as well as extended periods of time. Technology adoption was excellent as reflected in post implementation questionnaire responses and there was a request to keep the sleep sensor after the official trial had ended. This suggests that personal motivation and curiosity are important.

Patient's statements in the final interview with the clinician:

"I feel that after all these procedure I can face my problems in a better way. I am more optimistic about the future and I feel more energetic of beginning new activities hobbies and take care of myself."

"My major problem was my sleep. I didn't feel restful after a night sleep. I was waking up at night and I thought than I couldn't breathe. After all I could sleep better I was tracking my sleep via the tablet and I am starting thinking why this is happening I have to fix it and with relaxation exercises I was seeing improvement and this made me feel I can control my emotions now."

"I can manage the negative feeling when someone insults me and when people tell be something bad. I can control my emotional reaction better than ever"

"I don't forget numbers and names now. I can organize my schedule and use prompts as you advised me to do and it works very nice. It is very useful to have a program in my life"

-"If you can describe the whole protocol you took part with only one sentence how would you describe that?"[Clinician]
-"It is helpful. It changes the way you have used until now to live" [A.]

7.3 Home Pilot 2

7.3.1 Profile

Mr P.K is an 80-year-old man with a diagnosis of mild dementia. He had complex physical and cognitive limitations. His score on the MMSE was 23 of 30, MoCA was 18 of 30, FUCAS 60 and FRSSD 5 indicating problems with various daily activities. He was living alone for almost 10 years. He has two sons, both of them are teachers and one daughter who is not working.

The participant had 6 years of education and a 3-year history of progressive memory problems, which started approximately 5 years after the loss of his wife. His son and his daughter had noticed mild problems with his activities of daily living performance (e.g, the participant forgot to pay bills and had difficulties with his medication). He had a history of hypertension, but his vital signs were normal. He denied any symptom of depression although he stated to the clinician that he was crying sometimes with no specific reason.

The neurologic examination showed mild weakness in his feet. His Mini-Mental State Examination (MMSE) score was 23/30 (2/5 in attention subtests). He failed the clock-drawing test in MoCa, and his verbal fluency for letters starting with X was very poor. Laboratory test results were normal except from vitamin B12 and levels of homocysteine. MRI of his brain showed very mild atrophy of hippocampus, compatible with his age. A comprehensive neuropsychological assessment showed that his executive functions were below the mean for people of his age and education level, and his memory function was between below the mean too. Furthermore, the patient had difficulties in cognitive speed and processing.

The neuropsychological examination showed that his executive function deficits remained stable, but there was progression in his memory deficits, verbal fluency and speed cognitive processing, although they remained below the mean. The neurologist prescribed folic acid and injected vitamin B12 in order to increase levels of the substances.

Patient's and Caregivers' Statements:

"Well I forgot names and places I have been there in the past… I cannot find the correct word when I want to say something it is like my stops working and cannot say what I actually I am thinking. I also confuse words and phrases"

"I am not depressed at all. Ok there are sometimes that I am crying but there isn't anything that has happened. I am just crying… And now while we are talking I think that I can cry"

"It is not the same person. He forgets appointments, he forgets where his keys are, what are his obligations (e.g to pay the bills). We are afraid of leaving the city for more than two days" [son]

"I am calling him every 2-3 hours to reassure that he is ok, that he has taken his medication, to ask him how he slept if he ate his food…It is exhausting to be his shadow. In the end I will need support" [son]

"We are about to hire a woman to take care of him... But first we would like to use your system to see if we will be helped" [son]

Abilities and disabilities in daily living

Such people with difficulties in activities of daily living will generally have mild to moderate dementia and many will be living with a spouse or relative. Difficulties performing activities of daily living at home may trigger the need for personal assistance or relocation to residential care settings. His children were very concerned and they were ready to hire a full time person to take care of him.

Many of the problems the clinician observed are characterized as executive function related errors, such as sequencing problems, omissions, action additions, and difficulty in performing two tasks concurrently. Similarly, the main difficulties observed in the demented patient were found to include item selection and passivity in initiating actions autonomously.

7.3.2 Installation

In the following table, the sensors and the relevant areas or items of the home installation are presented.

Table 43. Sensors and tasks

Sensors	
Presence sensor	- Bathroom
Tag (motion sensor)	- Door - Dug Cabinet - Fridge door - Microwave - Pillbox - Tv remote Living room - Tv remote Bedroom
Activity sensor (Up24)	- Wearable sensor
Sleep sensor (AURA)	- Sleep sensor
Plug sensor	- Microwave - Tv Bedroom - Tv Living Room
IP camera	- Living Room

In the folowing figures various sensors in the home installation are presented.

Figure 104. Plug sensor for the microwave usage

Figure 105. Motion sensor on the box with the medicines

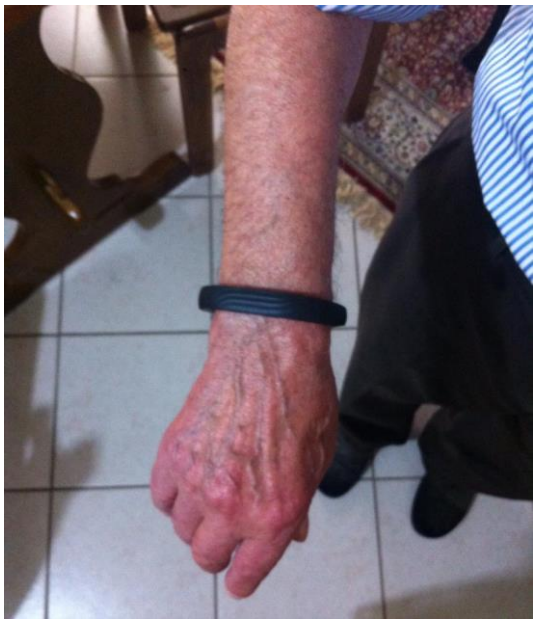


Figure 106. Wearable sensor

Figure 107. Motion Sensor on the TV remote controller

Figure 108. Presence sensor in the bathroom

7.3.3 Interventions

The interventions were based on a) the Dem@Care data analysis that was available to the clinician and b) the participant's preferences and needs after guided advances from clinician.

The need to minimise demand on attentional control is widely acknowledged in cognitive rehabilitation therapy. One approach has been to use procedural memory stimulation, in which the patient with dementia repeatedly performs the sequence of specific tasks in order to learn the specific operational processes.

A number of non-technological interventions have been also suggested. Visual cues such as calendars have been used to help the individual to schedule activities, keep appointments and remember things he/she had to complete. Similarly, training a patient to use a diary was found to be effective in improving schedule keeping.

Based on the initial system monitoring the clinician was able to detect that there were major problems of sleep interruptions and general sleep difficulties. Also there was a specific problem with REM sleep activity. More specific, the patient wasted much time awake in bed and woke up more than 6 times during the night. As he mentioned to the clinician he couldn't sleep at night. During daytime he was feeling very tired and exhausted. He found himself vulnerable to fallings and unstable when he was using the bus. Also he was very anxious for no reason and he worried about his cognition (difficulties to remember names and places). This entire situation frustrated the patient and moreover made him very sad because he had to depend on others and specifically to his son.

Based on the observations from the system, the clinician started visiting the participant twice a week and applied video-imaging exercises to enhance not only his memory but also his emotion via a funny way (by using Greek traditional movies - comedies). Also the clinician advised the patient going out for walking twice a week in his neighbourhood for 20' minutes and writes in a calendar his daily activities. This was expected to improve both activities management and the retrospective memory.

In the middle period the clinician detected from the system that the participant started getting better regarding his cognition. His score in neuropsychological assessment improved as well, together with the social interaction. However, regarding sleep the clinician identified a REM activity during the night. The participant had absolutely absence of REM sleep, a situation which is very common in people with front temporal dementia and parkinsonian syndromes as well. He didn't meet the criteria for frontotemporal dementia (e.g childish behaviour, sweets addiction, abnormal behaviour etc) but the new neurological examination revealed primary parkinsonian syndrome named Primary Supranuclear Palsy (PSP). Thus, his medication changed and Levodopa and decarboxylase inhibitor applied, which enhance dopamine retainment.

Also gymnastics introduced in order to improve his gait and stability. Moreover, personalized psychotherapy with the clinician once a week was also introduced in order to improve his emotional status. After those interventions, different activity of REM sleep behavior (more frequent stages of REM sleep) and increased sleep duration was detected.

In the weekly meetings with the clinician, he stated that he started feeling better. However, he mentioned that he couldn't find the right words when he wanted to say something and he was forgetting to close the door or the light in a room. The clinician introduced a specific semantic memory program with written exercises, as well as Reminiscence therapy to enhance his memory and emotion too. Afterwards, from the Dem@Care interface the clinician detected increased moving intensity. Finally, the participant advised to watch less TV, something that was easily detected from the system.

7.3.4 Measurements: Sleep

Sleep observation-REM sleep

Rapid eye movement sleep behaviour disorder, affects one third of patients with Parkinson disease (PD) [50]. RBD is even more common (80%-90%) in patients with multiple system atrophy, frontotemporal dementia and dementia with Lewy body disease [51] and other neurodegenerative diseases characterized on post-mortem examination, as is PD, by deposit of alpha-synuclein protein in the brain neurons [52]. In addition, as many as one third to two thirds of patients with a diagnosis of idiopathic RBD may, in the subsequent decade after diagnosis, develop signs of parkinsonism [50]. In contrast, REM sleep activity was reported to be rare in a series of patients with Alzheimer disease, Progressive Supranuclear Palsy (PSP), frontotemporal dementia, and corticobasal degeneration [53]. PSP, also known eponymously as Steele-Richardson- Olszewski syndrome, is a rare disease that affects 6.5 per 100 000 subjects, 10 a prevalence 200 times lower than PD. Patients with PSP show a complex range of symptoms, including paralysis of vertical gaze, postural instability and falls [54], frontal cognitive impairment, dysarthria and dysphagia, parkinsonism, and dystonic rigidity of neck and upper trunk. PSP motor symptoms are poorly levodopa responsive. Most patients with PSP complain of insomnia. Polysomnographic studies have reported reduced total sleep time and increased sleep fragmentation early in the course of the disease [55]–[60].

A recent research of Arnulf et al [61] showed that total sleep time was less than 5 hours in 7 PSP patients, in 6 PD patients and in 0 controls but was not significantly different between groups. PSP patients tended to have lower sleep efficiency and had longer duration of wakefulness and interruptions after sleep onset, longer REM sleep latency, higher percentage of

stage 1 sleep, and almost twice as great an arousal index as the PD patients and controls. REM sleep percentage was lower in PSP and PD patients than in controls.

As was discovered from Dem@Care outputs, the participant had short duration of REM sleep, which is a common abnormality in PSP even on the early stages. As REM sleep progressively disappears with the rapid course of the disease, it is possible that RBD will disappear too. This is why RBD has not been previously reported in patients with advanced PSP. Our data suggested that the mechanism underlying excessive daytime sleepiness exists in our PSP patient. REM-sleep executive systems may be too damaged to produce sleep onset in REM periods during daytime and night time's sleeping hours.

At the beginning of the protocol he was spending more than 3 hours awake until he falls asleep.

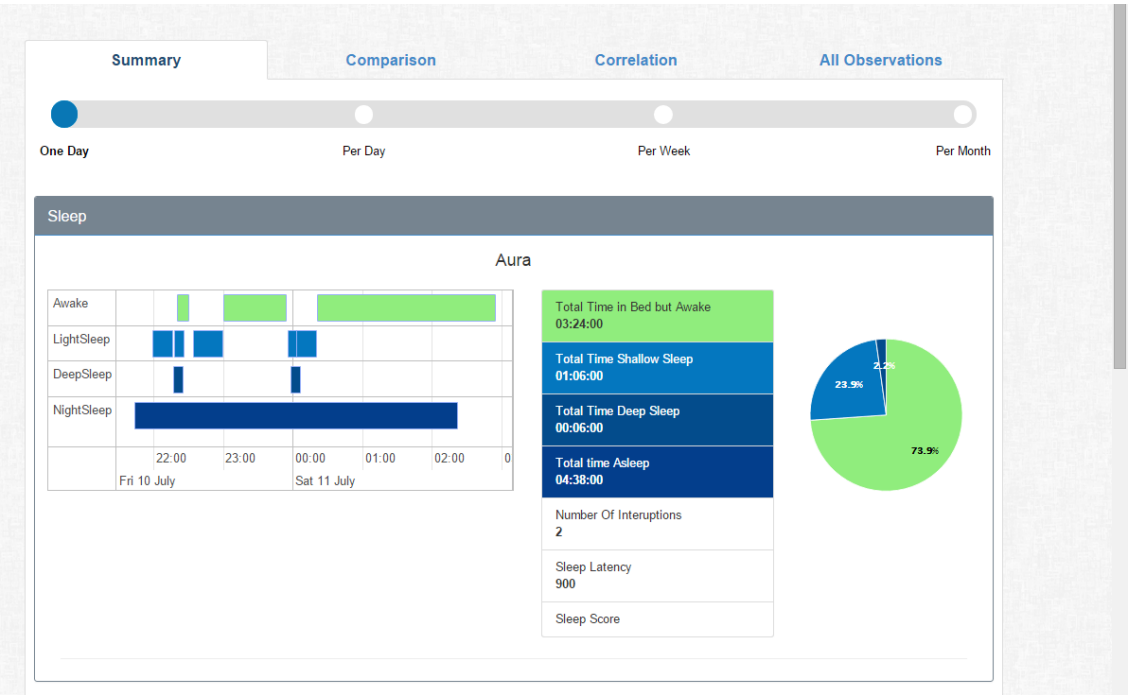


Figure 109. Sleep latency in the beginning of the protocol

In the middle of the protocol, the patient was spending 2 hours awake before sleep. Also, deep sleep duration is more and total time of sleep is also increased.

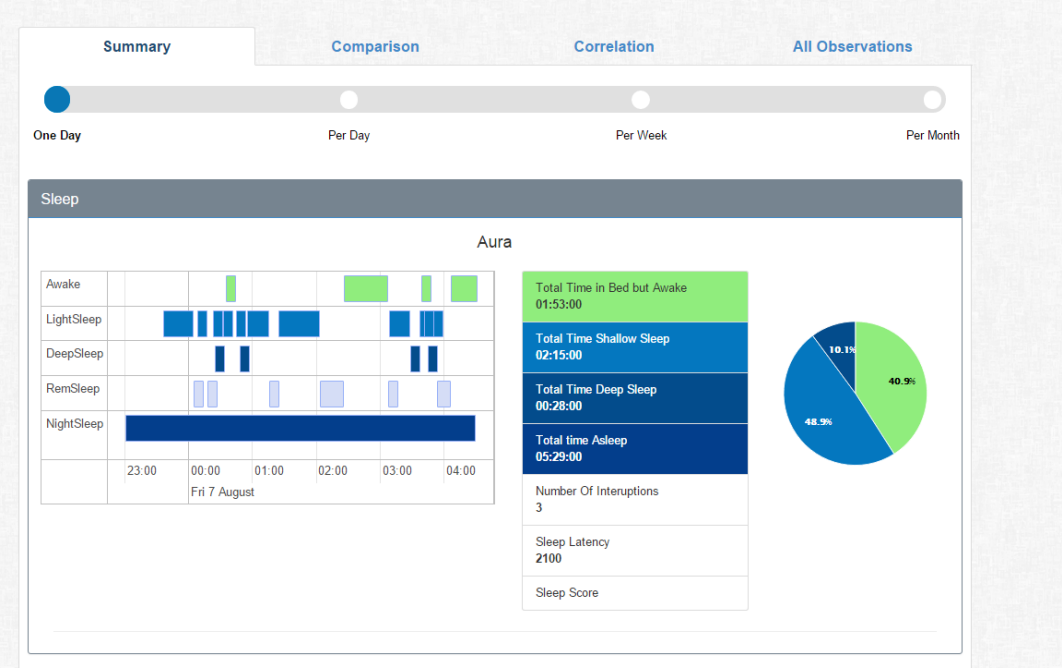


Figure 110. Sleep latency in the middle of the protocol

During the final period of the protocol, the patient was spending less than 2 hours awake before sleep. Also, deep sleep duration is more and total time of sleep is double in contrast with the beginning.

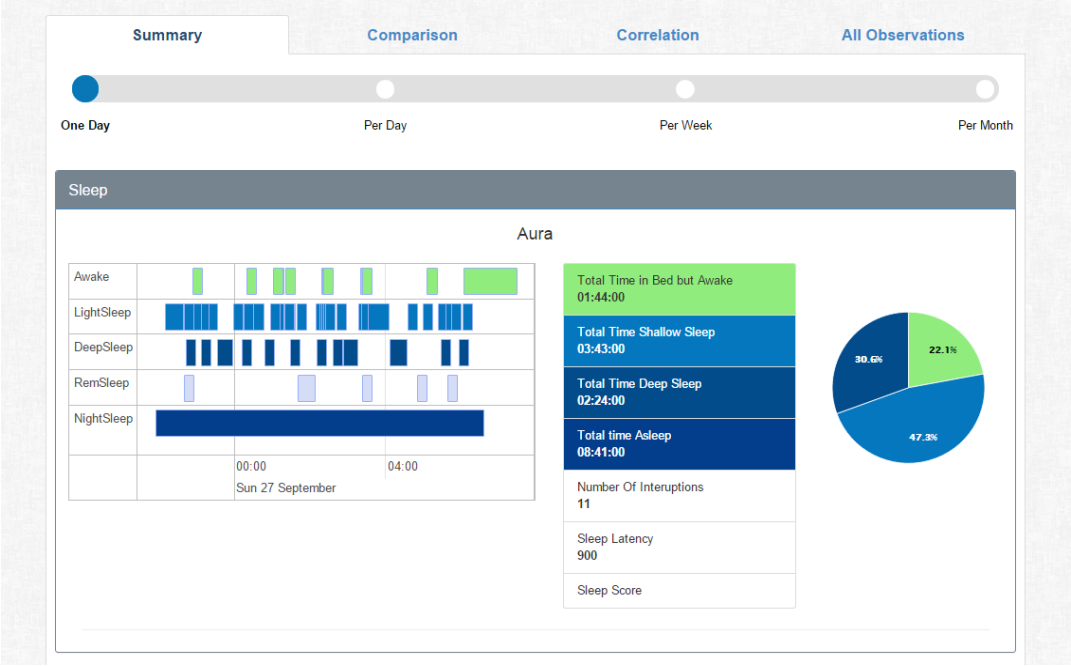


Figure 111. Sleep latency in the end of the protocol

Specific observations of sleep via interface:

Based on the system it was identified that on the beginning of the protocol the participant was more than 3 hours in his bed awake until she falls asleep (Total time in bed awake: 3:24 hrs, 73,9%), though in the majority of adults covers 5-10% of their total time of sleep. His total shallow sleep duration was 1 hour (Total time shallow sleep: 1:06 hrs, 23.9%) while the majority of adults' shallow sleep covers 45-55% of their total time of sleep. Also his deep sleep was extremely low (0:06 hrs, 2.2%), while the total time of deep sleep in adults is an average of 15-25%. His total time of sleep is very low 4:38 hours. Finally, there is absence of REM sleep activity during the night. In the middle period a slightly improvement in the sleep is detected by the clinician, patient spends less time in bed awake (Total time in bed awake: 2:15 hrs, 40.9%). His total shallow sleep duration is more and in normal limits (Total time shallow sleep: 2:15 hrs, 48.5%). Also his deep sleep was increased (0:28 hrs, 19.2%), while the number of interruptions stay almost the same as previously. Regarding REM, his total time of sleep has actually increased 5:29 hours. In the final period the clinician observed significant reduction of total time awake in bed during night time (1:44 hrs, 22.3%), total time of shallow sleep (3:44 hrs, 47.3%), increased duration of total time of deep sleep duration (2:24 hrs, 30.6 %). Moreover, the total time of sleep also increased (from 4 hrs on the beginning to almost 9 hours and a half in the final period). The most important is that there is normal REM activity in his sleep following stages of sleep and the sleep latency is reduced (900 sec). These numbers show that our participant in the last months had normal scores.

Comparison chart total time deep sleep in the beginning of the protocol in Figure 112*:* It is obvious that in the majority of the days the deep sleep duration is very small. The average duration of patient's deep sleep is below 50 minutes (except from two days when the patient went for a trip with his friends and as a result he got more tired and sleep more). The days in circle are those which the patient has changed his daily routine life (mean duration 45' per night).

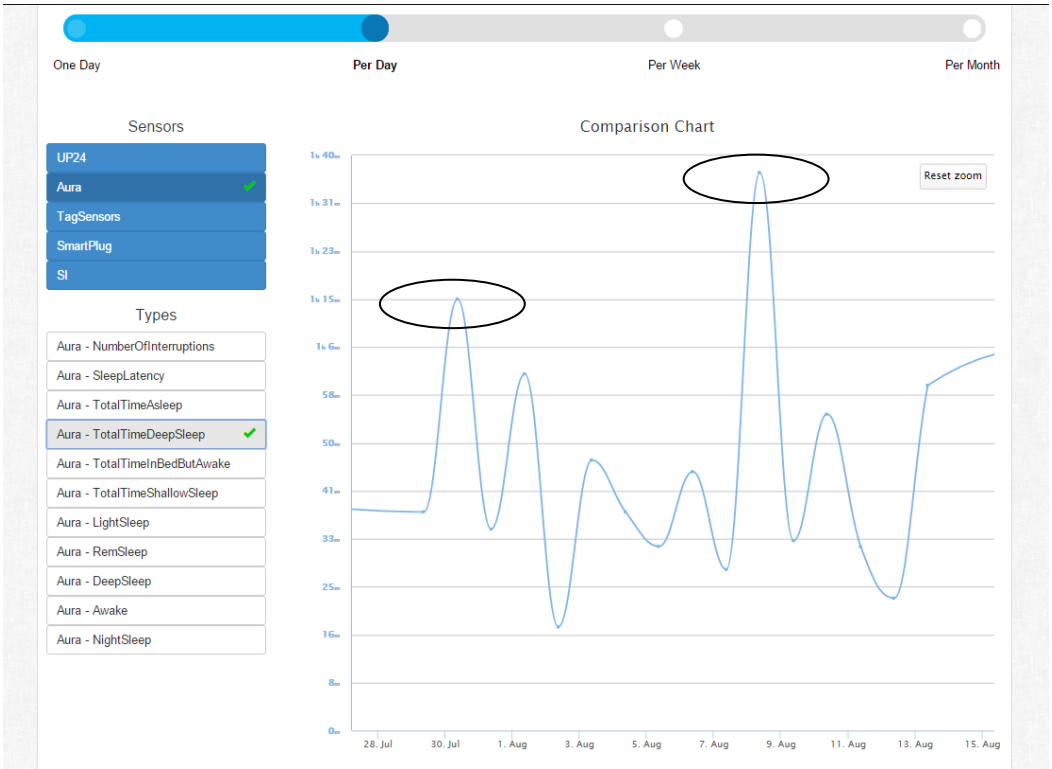


Figure 112. Comparison daily chart, with deep sleep duration of selected days in the beginning of the protocol

Comparison chart total time deep sleep in the middle of the protocol: The majority of the days the deep sleep is increased. The average duration of patient's deep sleep is over 50 minutes. In this graph it seems that our patient has an improvement as considering deep sleep duration.

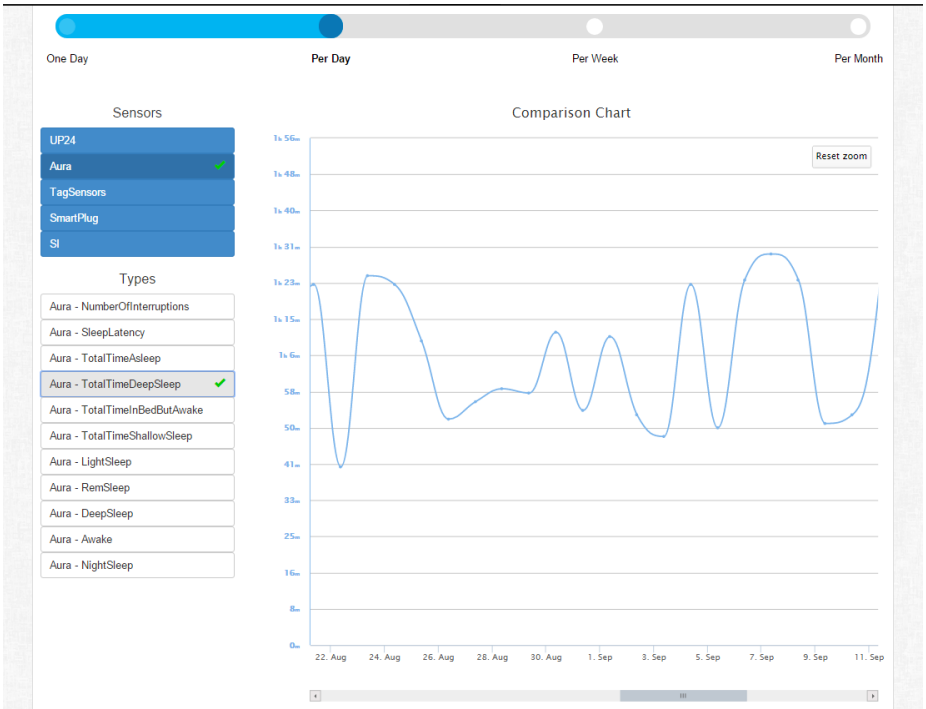


Figure 113. Comparison daily chart, with deep sleep duration of selected days in the middle of the protocol (mean duration 1 hr and 5 min)

Comparison chart total time deep sleep in the end of the protocol: In the majority of the days the deep sleep is increased. The average duration of patient's deep sleep is over 1 hour. An important increase of deep sleep duration is recorded.

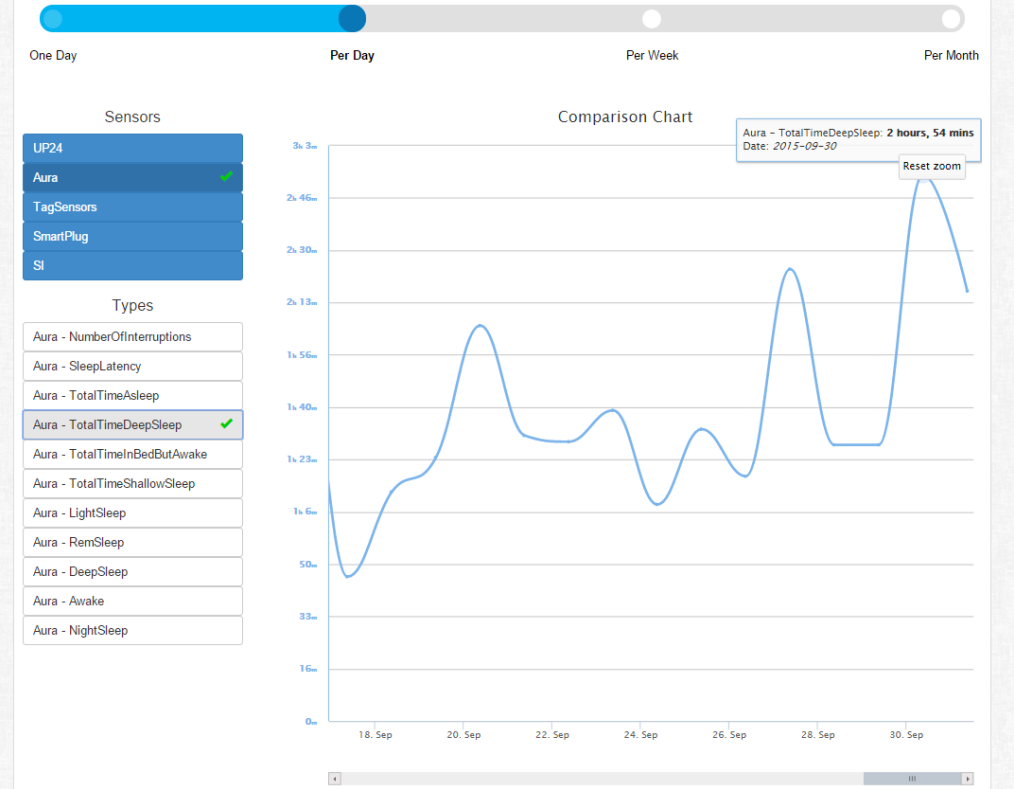


Figure 114. Comparison daily chart, with deep sleep duration of selected days in the final period of the protocol (mean duration 1hr and 38 min per night)

In the following comparison per week chart we can see improvement based on the increased duration of deep sleep per week (this is an important finding, since the deep sleep should cover 30% of total sleep time of an elder person).

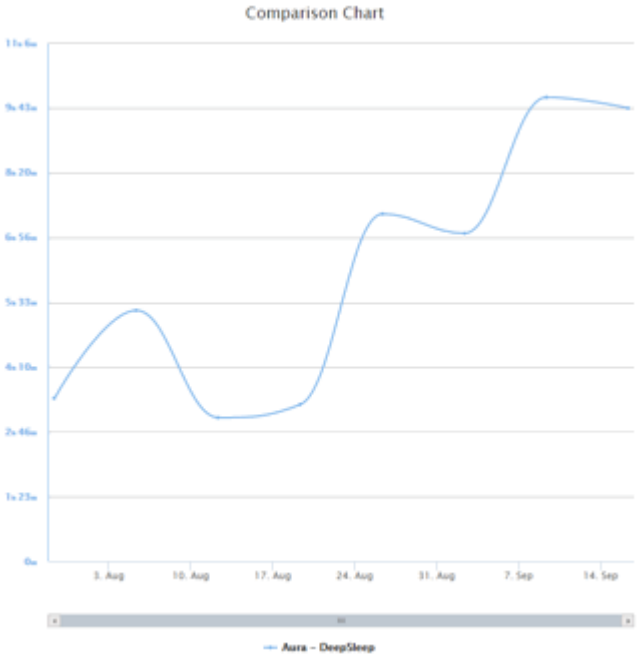


Figure 115. Comparison per Week chart, with deep sleep duration over the whole period of the protocol

REM sleep

In Summar Daily session specific sleep patterns can be detected accurately during the night. In the following figures we can see the REM sleep stages follow deep sleep. In the fist picture (1st period observation) there is almost complete absence of REM sleep activity at night while in the second one there is normal REM activity (final period).

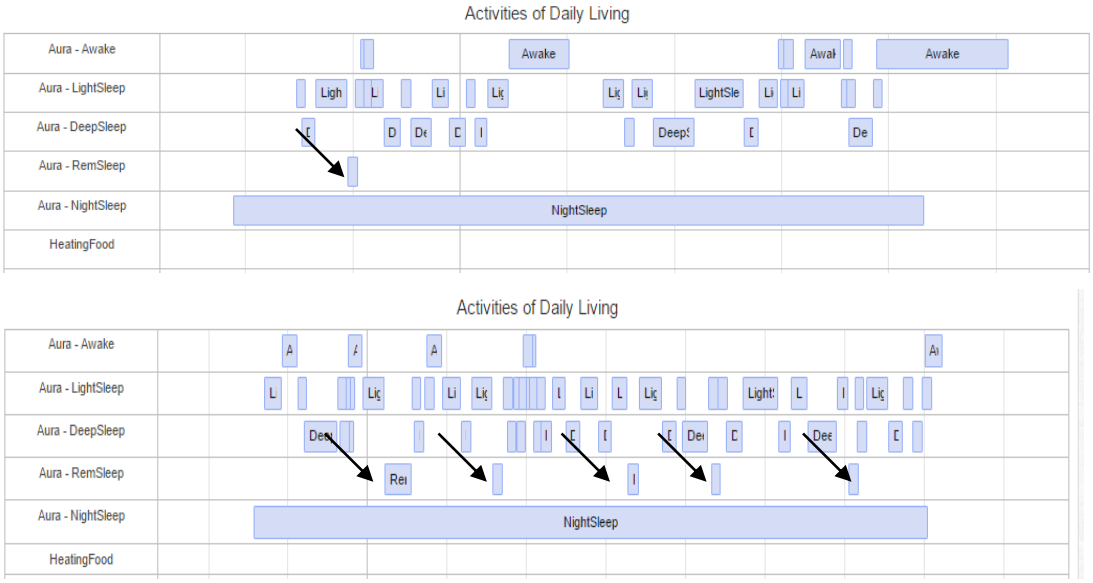


Figure 116. REM sleep activity

Figure 117. Sleepness in daytime recorded from IP camera - a common characteristic of PSP patients.

REM sleep in the beginning of the protocol. The maximum duration of a REM sleep is less than an hour per night while the majority of of REM duration per night is approximately less than 30 minutes.

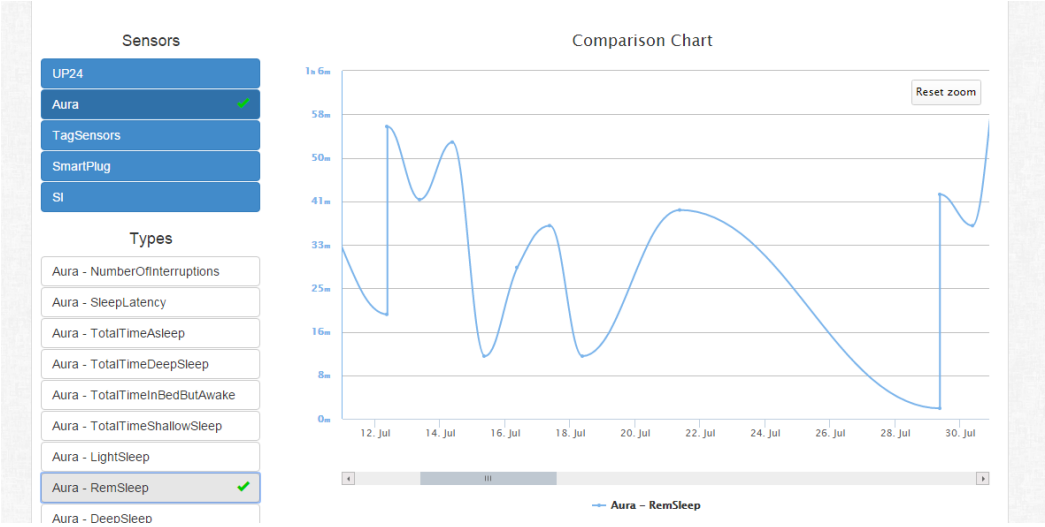


Figure 118. Comparison per day chart. REM sleep duration in selected days in the beginning of the protocol (mean duration 39 minutes per night)

REM sleep activity in the middle of the protocol. REM duration is increased after a follow-up period. The majority of the values are higher than previous ones.

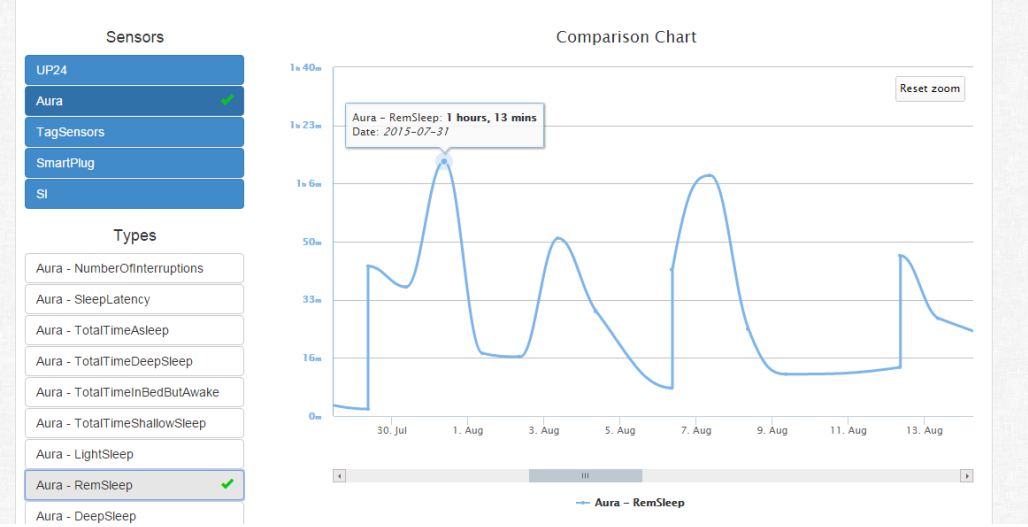


Figure 119. Comparison per day chart - REM sleep duration in selected days in the middle of the protocol (mean duration 36 minutes per night)

REM sleep in the final period of the protocol. Improvement is detected and the duration of REM sleep activity is more than 1 hour.

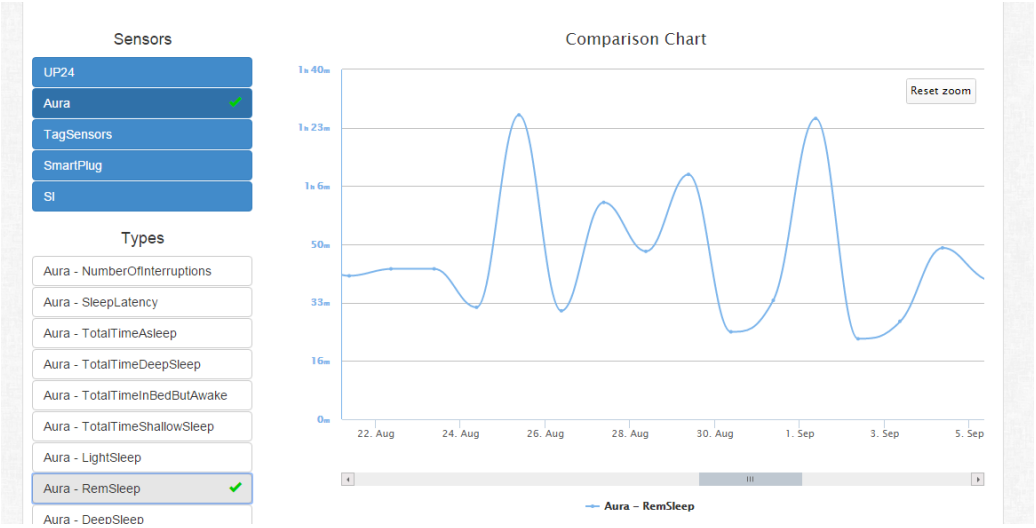


Figure 120. Comparison per day chart - REM sleep duration in selected days in the final period of the protocol (mean duration 48 minutes per night)

In the following comparison chart there is an improvement in the per month REM sleep

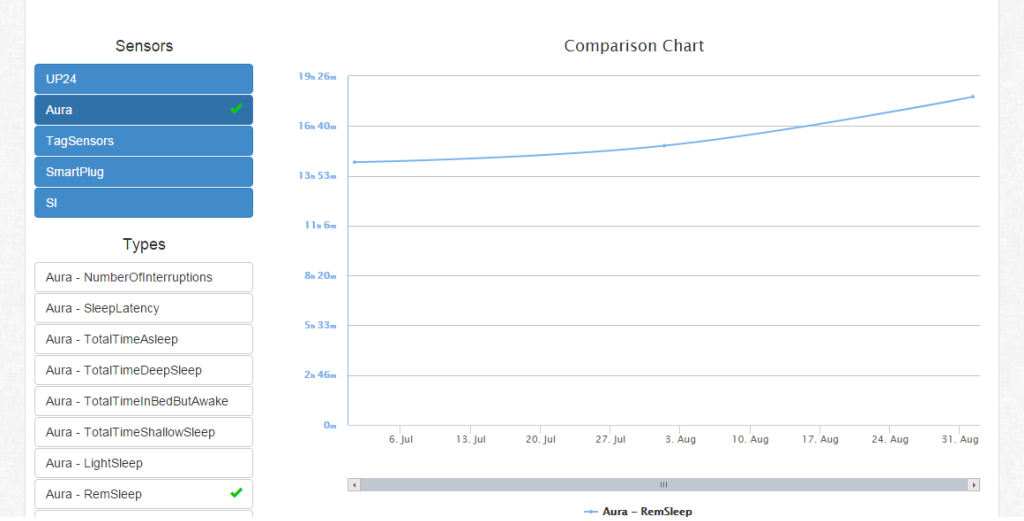


Figure 121. Comparison per Month chart - REM sleep activity over the whole period of the protocol

In the following comparison chart there is an improvement in the per month deep sleep

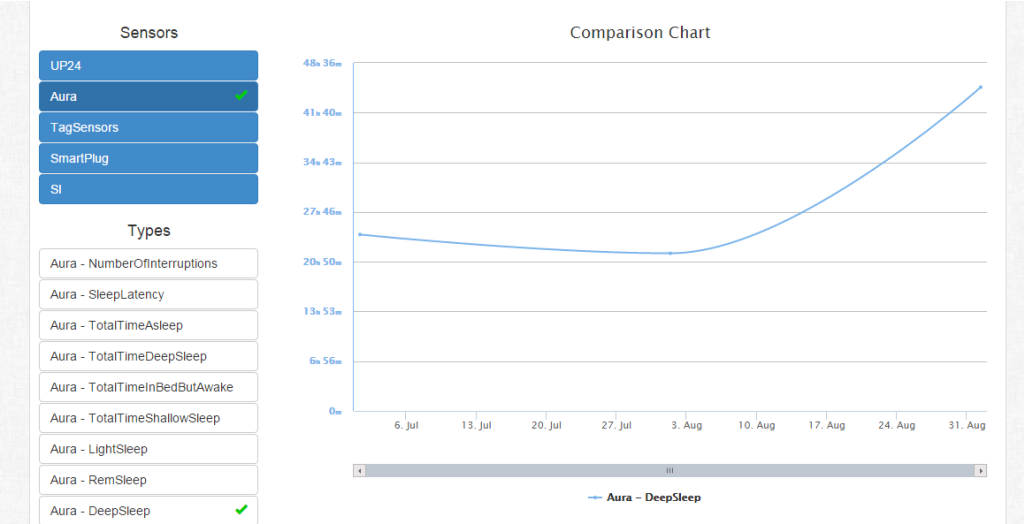


Figure 122. Comparison per Month chart - deep Sleep duration over the whole period of the protocol

Dashboard

The clinician set the following thresholds for specific activities: Sleep Duration: 5 hours, Number of Interruptions: (more than) 4, sleep latency: (more than) 90 minutes, days of reoccuring problem : 4.

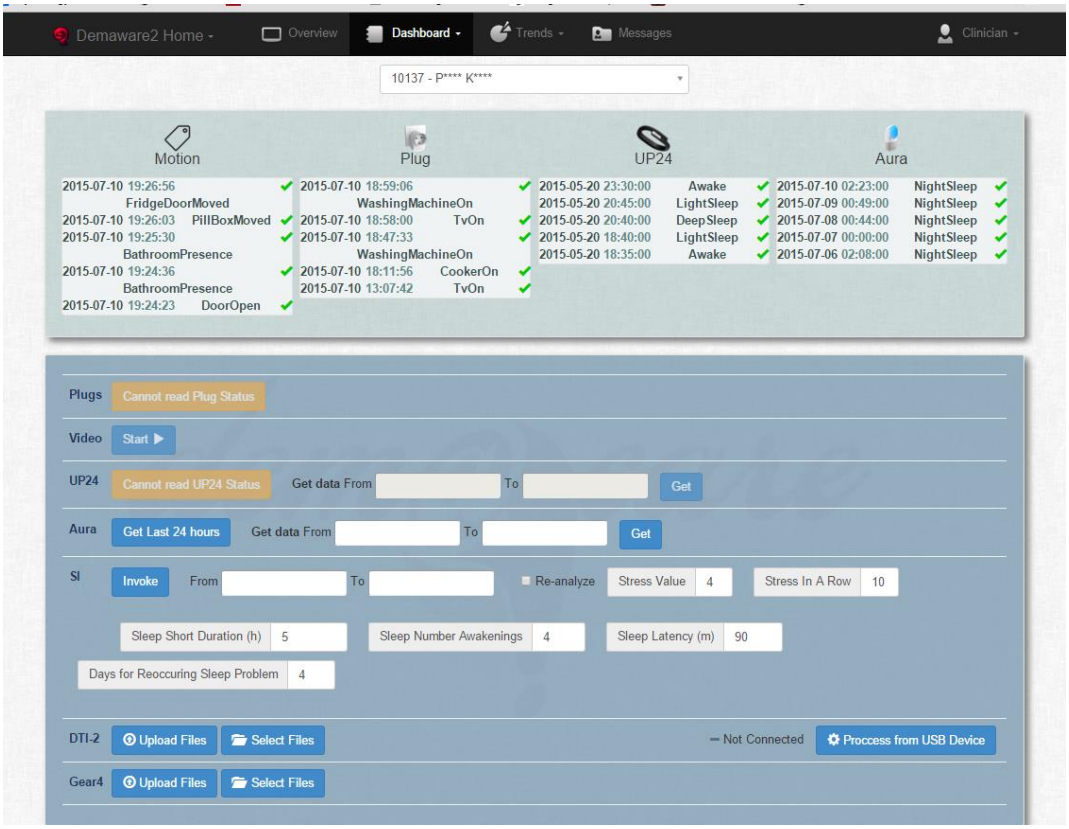


Figure 123. Dashboard

The SI analysis revealed that there is an obvious decrease of Number of interruptions, Short sleep Duration, total time awake in bed (April 99 problems detected, July-August 88 problems detected and September-October 50 problems)

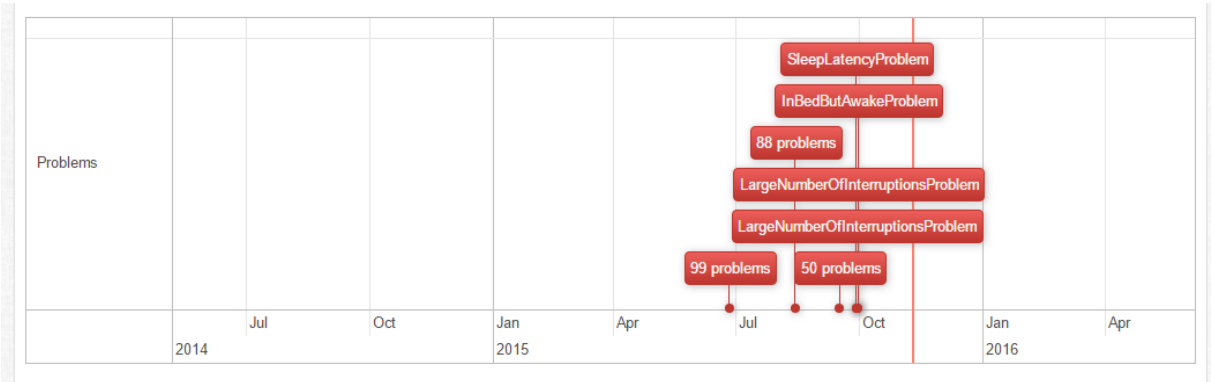


Figure 124. SI output

In the following table a statistical analysis of all the sleep aspects is presented, Moreover, a regression analysis was performed over time for the sleep duration. It can be seen that there is a significant statistical improvement in the various sleep elements. During the protocol period, the patient spends more time asleep at night time, has less number of interruptions during the night and deep sleep duration is more as has to be in normal and healthy elders.

Table 44. Statistical analysis for sleep measurements

	Regression analysis (Sig)
Total time asleep	**0.000*** **
Number of Interruptions	**0.036**
Deep sleep duration	**0.000*** **

***p<001

7.3.5 Measurements: Activity

In one-day summary interface the clinician was able to detect everyday activity and moving intensity of the participant. In the following figures moving intensity values are presenting in three periods of the protocol

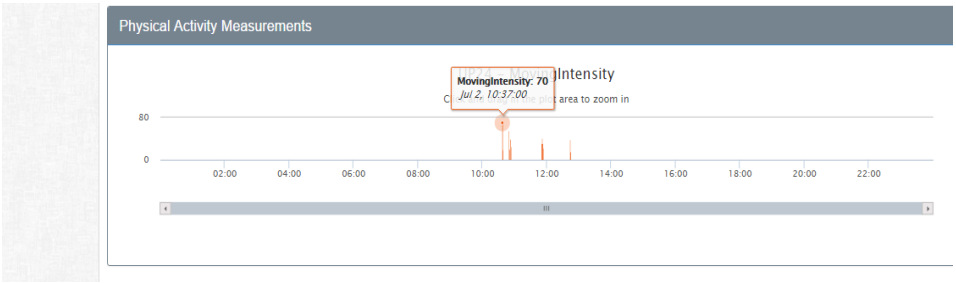


Figure 125. Moving intensity in the beginning of the protocol

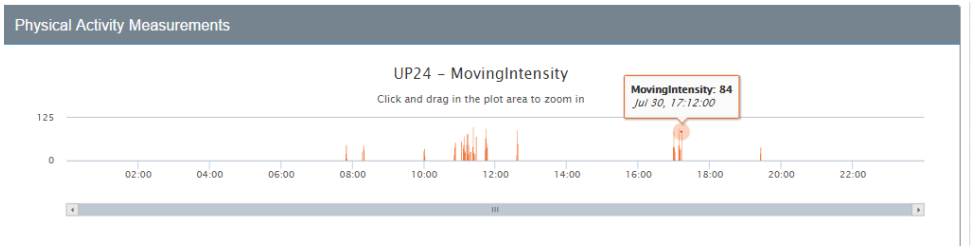


Figure 126. Moving intensity in the middle period of the protocol

During the last phase of the protocol the participant was very active

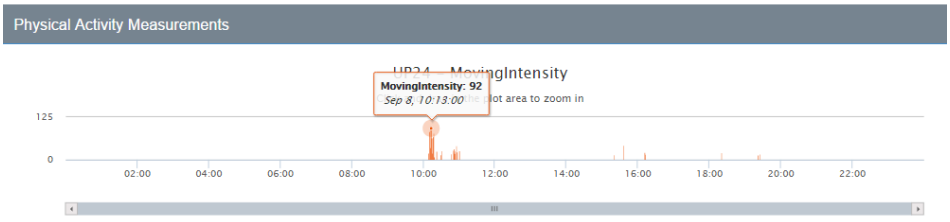


Figure 127. Moving intensity in the final period of the protocol

In Comparison daily chart the clinician could make correlations between specific activities (Sleep and moving intensity)

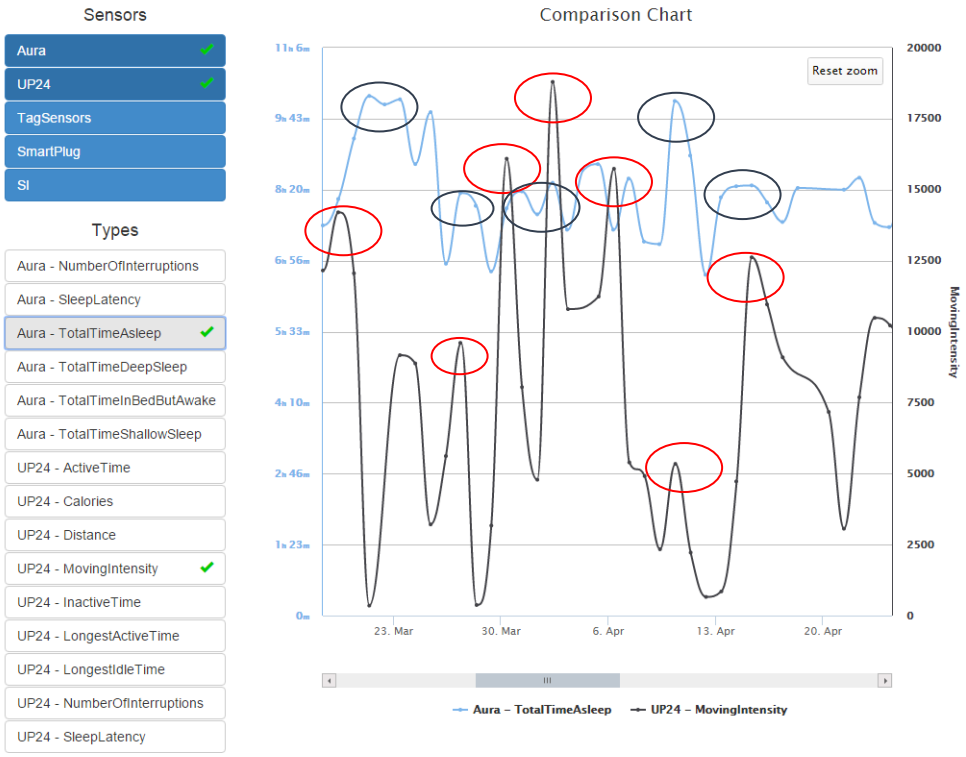


Figure 128. Correlations between sleep and moving intensity

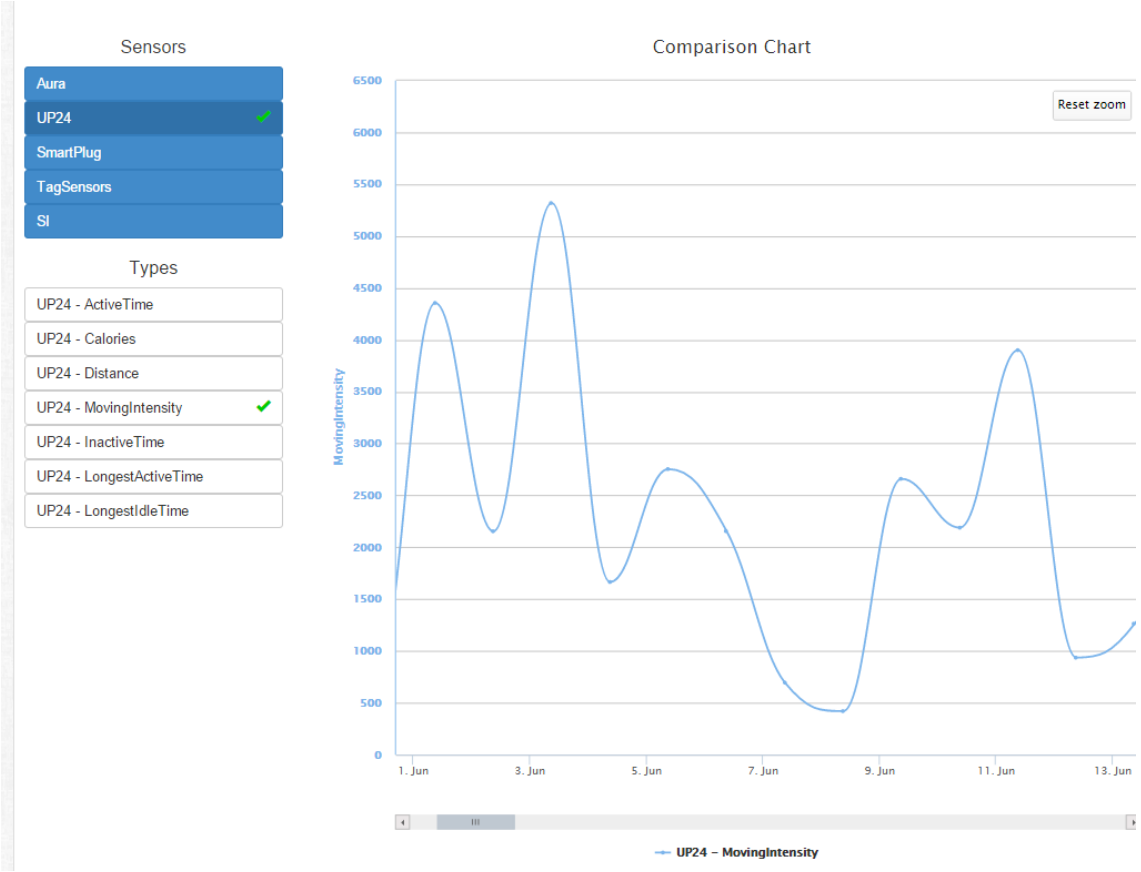


Figure 129. Comparison per Day chart - moving intensity at the beginning of the protocol

Comparison chart-Moving intensity on the final period of the protocol: More frequent and continuous moving intensity of the patient

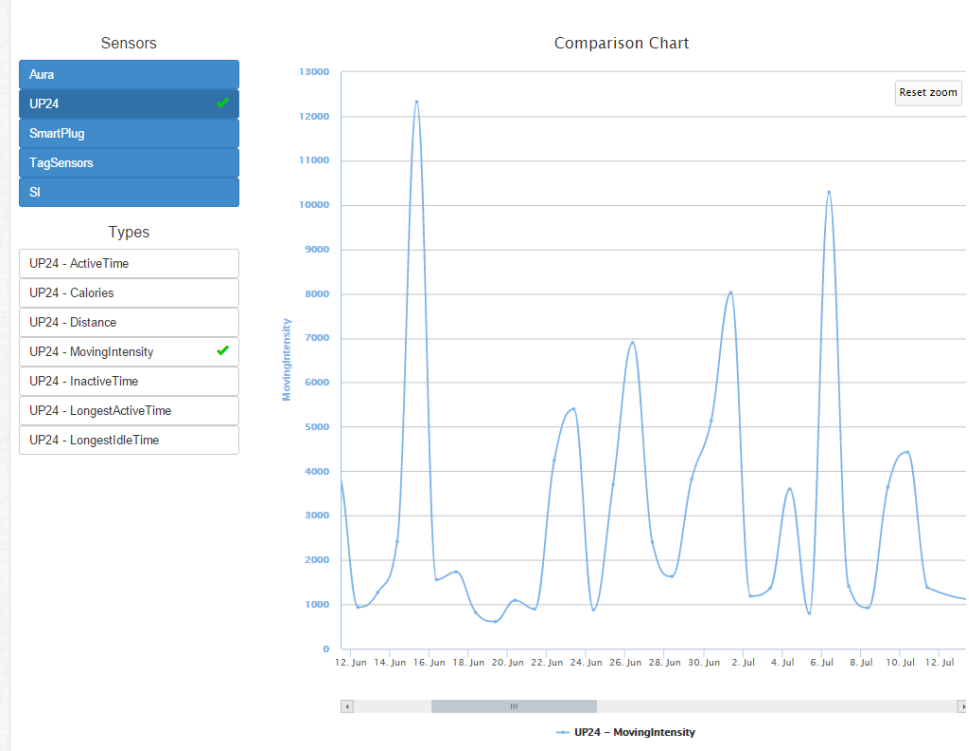


Figure 130. Comparison per Day chart - moving intensity in the final period of the protocol

7.3.6 Measurements: Daily activity

TV usage on the beginning and after specific clinician's advice: In this graph it is clear that the patient was using the TV on a daily basis and many hours on the beginning of the protocol while during the following months and after clinical advices the total watching time reduced and the social interactions increased.

Figure 131. Comparison per Week chart - smart plug information about TV usage in the whole period of the protocol

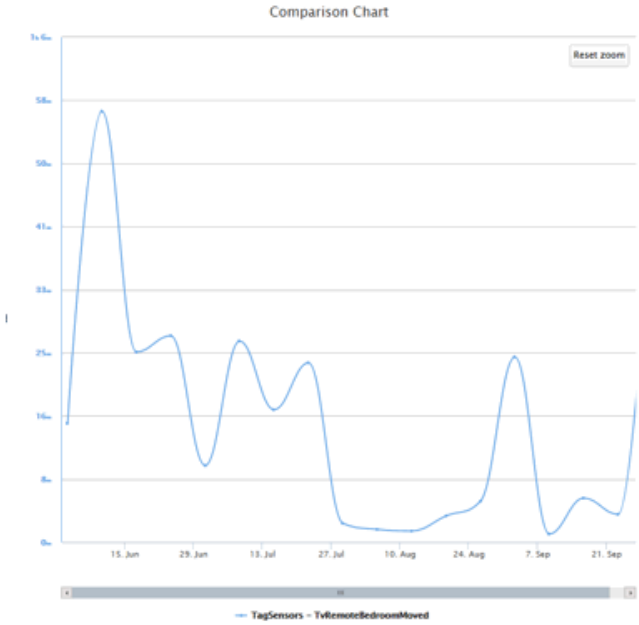


Figure 132. Comparison per Week chart - TV remote tag information about TV usage in the whole period of the protocol

7.3.7 Measurements: Psychometric

In the following table the three clinical assessments (initial, middle and final) are presented

Table 45. Cognitive Scores in 1st Cognitive Assessment

MMSE	23	**RBMT- story direct recall**	5
MoCA	18	**RBMT-story delayed recall**	3.5
CDR	3	**FUCAS**	60
NPI	2	**ROFT-**copy	12
FRSSD	3	**ROCFT-**delayed recall	2
GDS	3	**TRAIL-B**	0
HAMILTON	7	**BDI**	4
PSS	3	**QOL**	26
BAI	0	**IADL**	9
TEA		**RAVLT**	
Map Search	1st attempt: 3	1st attempt	2

	2nd attempt 4	5th attempt	(+4)6
Visual Elevator	Correct answers:2	Total score	20
	Time: 2.02	Delayed recall	(-2)4
Telephone Search	Total score:26.7	**FAS**	**7.6**

Table 46. Cognitive Scores of 2nd Assessment

MMSE	28	**RBMT-** story direct recall	5.5
MoCA	26	**RBMT-**story delayed recall	3
CDR	1	**FUCAS**	50
NPI	0	**ROCFT-**copy	4.5
FRSSD	5	**ROCFT-**delayed recall	0
GDS	2	**TRAIL-B**	0
HAMILTON	6	**BDI**	1
PSS	1	**QOL**	32
BAI	9	**IADL**	8
TEA		**RAVLT**	
Map Search	1st attempt: 7	1st attempt	3
	2nd attempt :8	5th attempt	(0) 3
Visual Elevator	Correct answers:5	Total score	15
	Time: 23.06	Delayed recall	2
Telephone Search	Total score:26.15	**FAS**	12.6

Table 47. Cognitive Scores of 3rd Assessment

MMSE	27	**RBMT- story direct recall**	7
MoCA	25	**RBMT-story**	6.5

		delayed recall	
CDR	1	**FUCAS**	47
NPI	0	**ROCFT-**copy	12
FRSSD	3	**ROCFT-**delayed recall	2
GDS	1	**TRAIL-B**	410
HAMILTON	3	**BDI**	2
PSS	3	**QOL**	34
BAI	4	**IADL**	8
TEA		**RAVLT**	
Map Search	1st attempt:8	1st attempt	2
	2nd attempt:21	5th attempt	(+6) 8
Visual Elevator	Correct answers:5	Total score	23
	Time:11	Delayed recall	(0) 8
Telephone Search	Total score: 10.1	**FAS**	12.3

The neuropsychological assessment revealed changes almost in all domains of cognition and emotion. Moreover, in the beginning the patient had problems in memory and general cognitive and executive function according to MMSE=23, MoCA=18, CDR=3. Also, low scores detected in tests which assess cognitive processing and speed (TRAIL MAKING part B= 0, TEA map search 3/3, visual elevator 2/2.02, telephone search total score 26.7), episodic memory and long-term memory (RBMT delayed recall of the story=3.5), executive functions (ROCFT copy=12) and visual-spatial long term memory (ROCFT delayed recall=2) and the ability of storing new knowledge and learning new things (RAVLT 5th attempt=+4, RAVLT test total score=20). Also he had problems with Activities of daily living and functionality (Frssd=3, Fucas=60).

After the interventions applied to the patient we saw improvement in specific domains of the patient's daily routine such as sleep and daily activities. This improvement also is obvious to the neuropsychological assessment as well. More specifically, the patient's scores in the final assessment indicate improvement in general cognition and memory (scores of MMSE=27, MoCA=25, CDR=1), cognitive processing, attention and speed (TEA map search8= 8/21, visual elevator= 5/11, telephone search total time 10.1, TRAIL MAKING part B=410). Also, better performance is detected in quality of life (QoL=34) and functionality (FUCAS=47, FRSSD=3). Furthermore, the ability of new learning and verbal fluency is also improved (FAS=12.3, RAVLT total score=23, delayed recall=0), which means that every word he learned he could retrieve it after 20 minutes without forget anything. It is worth to be mentioned that slow speed processing is a common characteristic of people with PSP so we didn't expect significant changes but even in this way we can see improvement in comparison with the first assessment.

7.3.8 Caregiver User Interface

In the second pilot the user interface was used by the caregiver (the son). Similarly to the first pilot, the clinician introduced to the caregiver the patient interface (He already had a mobile tablet device). There was repeatedly learning sessions in which the clinician presented the operation and the information that the caregiver interface is able to provide. The caregiver interface provided information regarding the daily steps and total spend calories of the participant, the sleep duration and interruptions, the devices usage and medication. At the end of the protocol the clinician interviewed the caregiver regarding the usefulness and the usability of the system.

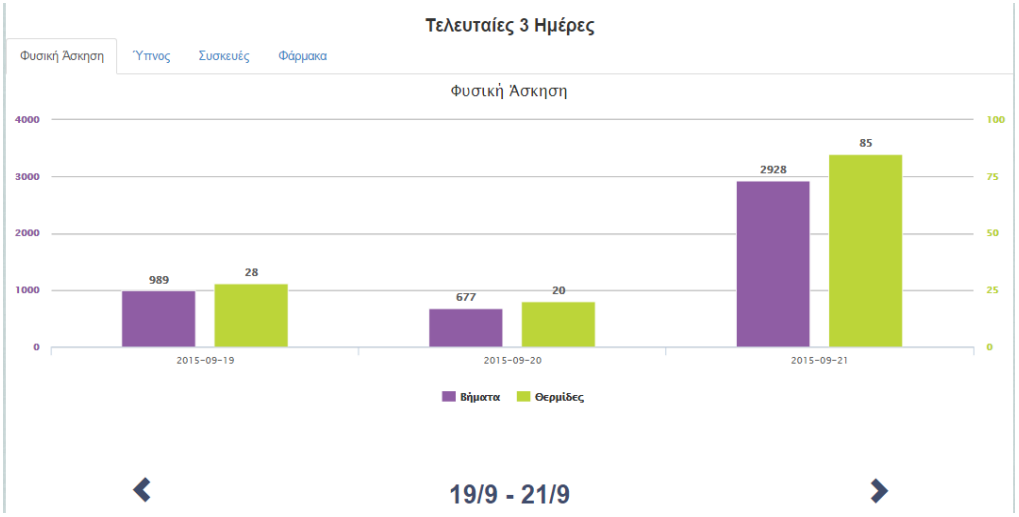


Figure 133. Caregiver UI – steps and calories

In the following figure the caregiver was able to see how many hours the last 3 days (13/9-15/9) he slept (blue chart), how many times he woke up during the night (yellow chart) and how many hours was awake in bed (red chart). Also problems of number of interruptions appear in the red line above the chart, which inform the patient how many interruptions she had *("You had 5 sleep interruptions on 17/09/2015")*

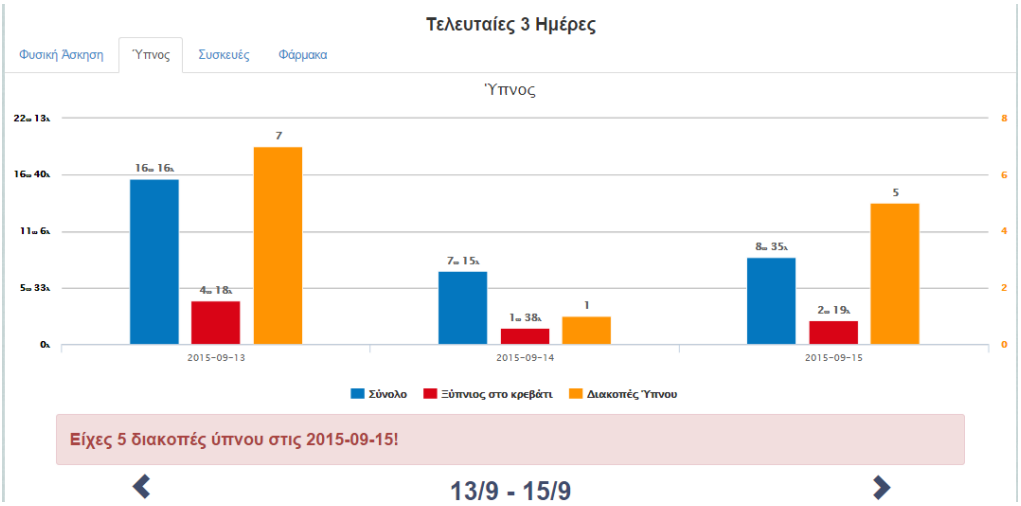


Figure 134. Caregiver UI – sleep quality

Data from devices in Home. In this session the caregiver was able to see the usage of the devices. Duration of TV usage (green chart), cooker (black chart), washing machine (purple chart) or vacuum (orange chart), boiler (blue chart).

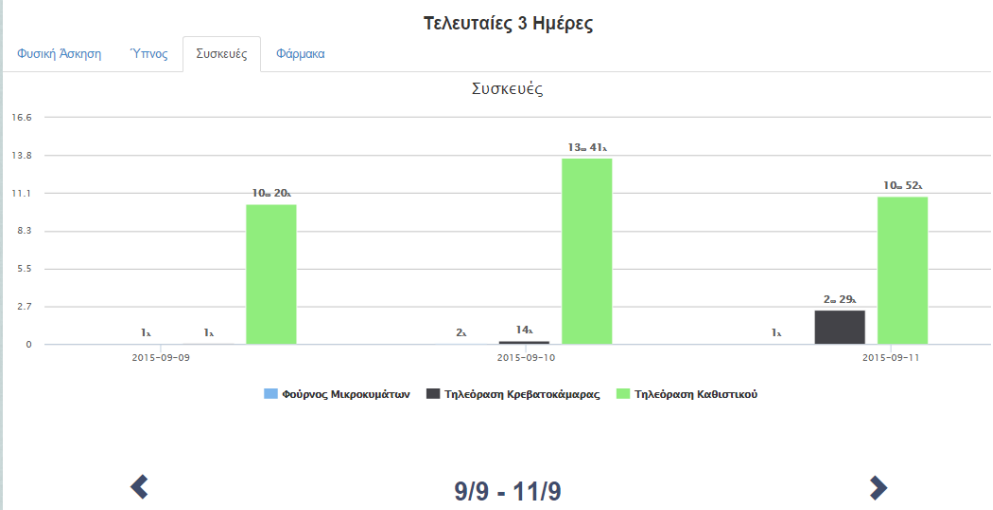


Figure 135. Caregiver UI – devices usage

In the following figure the caregiver was able to see if the participant took his pills or not in the last 3 selected days (8/9/2015-10/9/2015). Also warnings in the red line if he forgot to take them appear on the screen to *("Yesterday you didn't take your medication")*

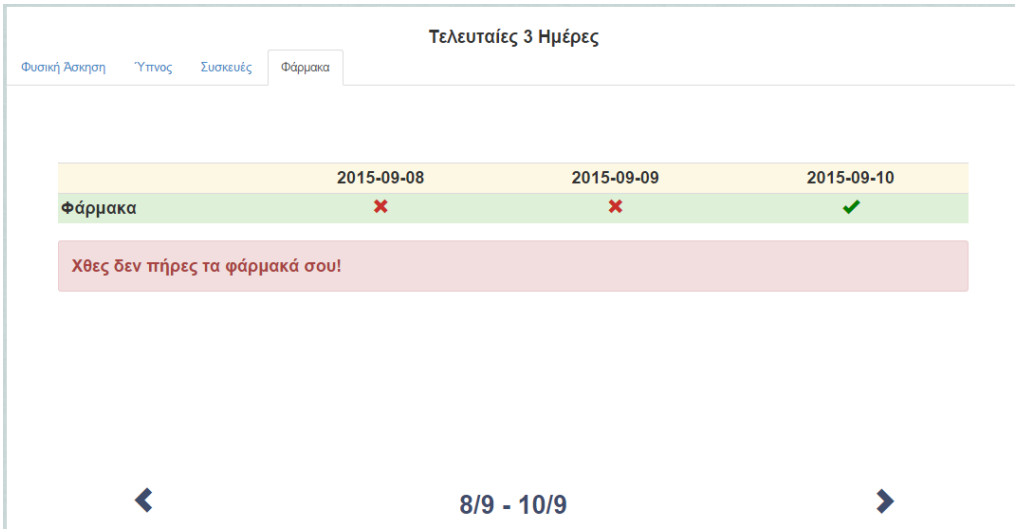


Figure 136. Caregiver UI - Information for medication.

Messages from Clinician. The clinician is able to send messages and information she thinks important to the patient or the caregiver. In the following picture the clinician informs the caregiver that his father sleeps very well at night and he must force him to continue the interventions so as to have improvement.

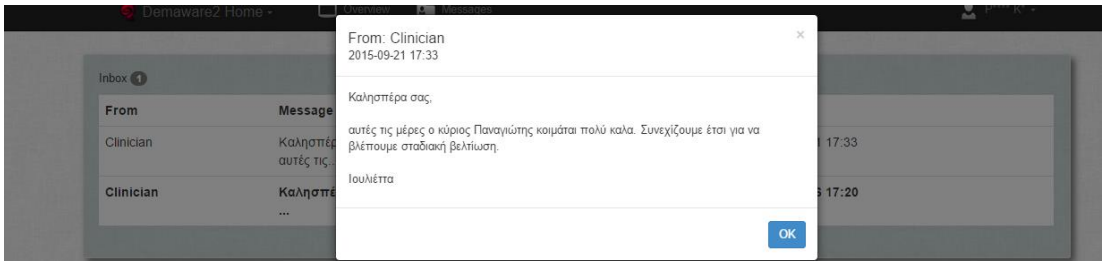


Figure 137. Messages from Clinician ("*Good evening, Mr. P is sleeping very well the last days. We should continue this way*")

Table 48. Assessment of the Caregiver for user interface.

OVERALL REACTION TO THE SYSTEM	
1. terrible-wonderful	"I found the system very well-organized and helpful"
2. difficult-easy	"At the begging was a bit difficult but afterwards it became easy to use"
3. frustrating-satisfying	"It was not frustrating, I found it very interesting and smart"
4. inadequate power-adequate power	"IT is a very powerful system"
5. dull-stimulating	"Very nice application for caregivers of people with Dementia"
6. rigid-flexible	"very flexible for using"
SCREEN	
7. Reading characters on the screen: hard-easy	" It was very easy to ready what charts included and also to understand specific devices represented with specific colors"
8. Highlighting simplifies task: not at all-very much	" All tasks were very good highlighted"
9. Organization of the information: confusing-very clear	"The information was very clear, the graphs were very good presented"
10. Sequence of screens: confusing-very clear	"The sequence was very clear too"

TERMINOLOGY AND SYSTEM INFORMATION	
11. Use of terms throughout system: inconsistent-consistent	"It was very consistent"
12. Terminology related to task: never-always	"Always. It was very clear what were the options"
13. Position of messages on screen: inconsistent-consistent	"The position of the messages would be better if they were appearing on desktop not to have to log in so as to see clinician's messages but it wasn't big deal I was watching data twice a day."
14. Prompts for input: confusing-clear	"The prompts were very clear"
15. Computer informs about its progress: never-always	"Always it was updating"
16. Error messages: unhelpful-helpful	"Very helpful because I can se if we have progress or if he follows your and our instructions, e.g too many interruptions during sleep"
LEARNING	
17. Learning to operate the system: difficult-easy	"I found it very easy to operate the system cause I have interaction with technology but as for a person with dementia this could be more difficult"
18. Exploring new features by trial and error: difficult-easy	"It wasn't a difficult system. It has been developed very well even for people who have no interaction with technology"
19. Remembering names and use of commands: difficult-easy	"Very easy"
20. Performing tasks is straightforward: never-always	"The majority of times"
21. Help messages on the screen: unhelpful-helpful	"The messages were very helpful"
22. Supplemental reference materials: confusing-clear	"I didn't face any problem. It was very clear"
SYSTEM CAPABILITIES	
23. System speed: too slow-fast enough	"This was depended from the internet connection. When I had

	good connection the loading of data was very fast."
24. System reliability: unreliable-reliable	"Only one or two times I found that it was unreliable and I informed you. Otherwise I think it was very reliable because I tested it too."
25. System tends to be: noisy-quiet	" No its not noisy"
26. Correcting your mistakes: difficult-easy	"It is not allowed you to get confused and make mistakes but if you mean to skip a date and I want to see another activity yes its very easy'
27. Designed for all levels of users: never-always	"No I think that people with severe or moderate dementia cannot use it"
PUEU	
USEFULNESS	
28. Using the system in my job would enable me to accomplish tasks more quickly: unlikely-likely	" Yes definitely I was at work and at the same moment I could see if my father took his medication yesterday or how well he was. Its great"
29. Using the system would improve my job performance: unlikely-likely	"Definitely we could see what actually helps or not, what he has to do better or stop doing"
30. Using the system in my job would increase my productivity: unlikely-likely	"I could be less anxious about my father with the system"
31. Using the system would enhance my effectiveness on the job: unlikely-likely	"Definitely as my father told me because I was informing him about his progress and he was very interested about what he did or not"
32. Using the system would make it easier to do my job: unlikely-likely	"Yes of course. When you don't have to be aware about a person and the system gives you this opportunity is totally a very innovative and helpful for every carer"
33. I would find the system useful in my job: unlikely-likely	" Yes it is useful not only for me as a caregiver, but also for my father too because we could see which intervention actually helps him or not"

EASE OF USE	
34. Learning to operate the system would be easy for me: unlikely-likely	"I found it very easy to operate the system. The options are very clear"
35. I would find it easy to get the system to do what I want it to do: unlikely-likely	"Of course cause I could see what I actually want in separate sessions"
36. My interaction with the system would be clear and understandable: unlikely-likely	"Yes I found very smart and easy and very accurate"
37. I would find the system to be flexible to interact with: unlikely-likely	"Yes it was very flexible"
38. It would be easy for me to become skillful at using the system: unlikely-likely	"Now I know how to use it and its very helpful"
39. I would find the system easy to use: unlikely-likely	"Definitely yes"

7.3.9 Conclusions

The second participant has been diagnosed with mild dementia. After the installation and the first monitoring of the system outcomes, the clinician introduced new exercises to enhance his memory and cognitive functions via a memory exercises program. During the interventions these initial exercises were updated or adapted based on the everyday monitoring by the clinician through the Dem@Care system.

Also the clinician found abnormal activity of REM sleep, which helped the clinician and an expert neurologist to find out the early onset of PSP. More specifically the clinician identified through the outputs of the sleep sensor the absence of REM activity. After the specific non-pharmacological interventions, guidelines and specific levodopa treatment, significant improvement in his sleep quality and duration and sequence of sleep stages was detected.

Through reminiscence therapy the participant started to manage his emotion of loneliness and improve his memory of remembering incidents from the past. Furthermore, specific clinical advices and strategies made him more active.

His sons and his family in general noticed improvement in his emotion and cognition and they were impressed from how the system can actually work in such a way, informing them about their father condition without being concerned all day. In the cognitive tests there was significant improvement, something that the participant also stated to the clinician.

In conclusion the most important outcome with this participant was that clinician's observations through the system helped to understand why there were problems with his sleep (ab-

sence of REM). The final diagnosis was based on sleep sensor data and the medication treatment was the most accurate and right for this disease.

Patient's and his caregiver's statements to clinician

"Well I couldn't imagine that I can wake up after 8 o'clock in the morning. I used to wake up before 5 o 'clock. I am impressed that you can solve and find out my problem via this thing under my bed"

"I am more stable now and I can walk with very high speed after gym"

"I was very happy now. I have friends and things to plan. I have a schedule with specific programs to attend"

"I am excited with all this technology. I was updated all the time about my father health. I wasn't anymore aware if he has taken his medication. I was very interested to see his progress after the diagnosis of PSP and the changed medication and I could see that his sleep duration increased" [son]

"How would you describe the whole procedure and the whole protocol?" [Clinician]

"Basically on the beginning I couldn't imagine that in a very short period my father's condition would become better. I was about to hire a full-time person to take care of him, but I cannot describe with words exactly the feeling of being in my work in the morning and have full access all day from the tablet and see how he slept what he did if he is ok, if he took his medication etc. It is feeling of safety and relief that every caregiver of an elder person must have" [son]

7.4 Home Pilot 3

7.4.1 Profile

Mrs V.T. is a 69-year-old woman with a diagnosis of mild cognitive impairment and depression. She has recently lost her husband and she faced emotional difficulties (sadness). Mrs V.T was selected because of her complex behavioural and cognitive limitations. Her score on the MMSE was 28 of 30, MoCA was 19 of 30, Hamilton 14 and Beck Depression Inventory was 10 indicating maximum level of memory difficulties and emotion in comparison with her educational level and background. Mrs V.T. has been living in her home alone for almost 1 year. She is a retired physician.

According to her family, she had depression combined with cognitive problems and her husband's death made things even worse. She had depressed mood, anxiety, crying spells, anger which was based on grief and mourning suicidal ideation, insomnia, lack of appetite, sweet addiction; she had lost 15 pounds in 1 year. She had also short-term memory problems and difficulties in finance and medication management. Blood test didn't show lack of a vitamin or other problems and MRI results didn't indicate structural changes in the brain such as

stroke. During clinical assessment, the participant looked tearful and had minimal bradykinesia. Her Overall, she met the criteria for mild depression.

The National Institute on Aging and Alzheimer's Association (NIA-AA) criteria [62] for MCI were used also in the 3rd participant in order to characterize a syndrome that is most likely associated with AD pathology. The participant presented an abnormal neuropsychological performance associated with other signs and symptoms:

(1) Complaints of cognitive deficits (or awareness of cognitive problems)

(2) Deficits in memory or other cognitive domain function demonstrable by testing

(3) Mild problems in instrumental activities of daily living could be present. A certain level of concern about their cognitive problems should be present in these patients, which in turn motivates the visit to a memory clinic.

Patient's and Caregiver's Statement:

"*You think that I have Alzheimer's… No I don't have this disease... Well I am physician and I know what I have. I forget things but I have not lost my mind yet. I have lost my husband. Do you know what is this? It is worse than losing your mind"*

"I think my children avoiding me... I think that nobody wants a widow for company. I used to have many friends with my husband going out for a walk or planning trips all together. Now I am only me and my apartment"

"Sometimes if I don't take down notes I forget what I have to do later… I don't remember appointments"

"My mother is very different since my father's death. She is lost in her thoughts. She forgets things she has planned. She has stopped cooking. She doesn't care about house works. She is very different"

7.4.2 Installation

In the following table, the sensors and the relevant areas or items of the home installation are presented.

Table 49. Installation

Sensors	
Presence sensor	- Bathroom - Kitchen
Tag sensor	- Door - Dug Cabinet - Fridge door - Microwave - Tv remote Living room
Activity Sensor (Microsoft band)	- Wearable sensor
AURA	- Sleep sensor
Plug sensor	- Microwave - Washing machine - Tv Living room
IP Camera	- Living room

In the following figures various sensors in the home installation are presented.

Figure 138. Motion sensor on the refrigerator

Figure 139. Motion sensor on the microwave

Figure 140. Activity sensor

7.4.3 Interventions

The interventions were based on a) the Dem@Care data analysis that was available to the clinician and b) the participant's preferences and needs after guided advances from clinician.

More specific, the patient was spending much time awake in bed and had more than 5 sleep interruptions. She had mentioned to the clinician that she could not relax or sleep at all. Similarly to the other pilots, this situation (bad sleep quality, tiredness feeling) made her anxious and without will to accomplish any daily activity (e.g. cleaning or cooking).

Based on the above observations the clinician started personalized psychotherapy with the participant in order to understand better the causes of the depression and relaxation exercises to help the participant's anxiety management. These approaches were based on Cognitive Behavioural Therapy and specifically of Beck's Cognitive Restructuring technique.

Moreover, the clinician noted that the participant avoided leaving home. She had limited social interactions. Based on these observations she proposed dance lessons, twice a week, with other people of the same age in Alzheimer day care center to support both physical and cognitive aspects (e.g. attention, visual-spatial memory). The results from this intervention were obvious through the system: more active, better sleep.

In the middle period of the protocol although there was some progress in sleep, there were still issues with the accomplishment of daily activities. The clinician proposed a specific weekly schedule with house works (e.g ironing, cleaning), combined with computer-based exercises in order to learn how to use applications such as Skype. Afterwards, and through the Dem@Care system the clinician could detect increased moving intensity.

By the end of the intervention Mrs V.T. rated positively her ability to use her iPad and PC and reported that she was extremely satisfied that she was able to communicate with her children through PC applications.

7.4.4 Measurements: Sleep

In the beginning of the protocol, the participant had very intense sleep problems. In the middle period, there was an improvement in all aspects and in the final period there was a clear improvement. Moreover, the patient also spent many hours in bed awake. In the following figures the clinician observed specific measurements of sleep.

In the following figure we can see that the participant has major problems with sleep. She was awake in bed more than 2 hours and the total time of sleep was very low (6 hours). Finally, sleep latency duration is very high (2520 sec)

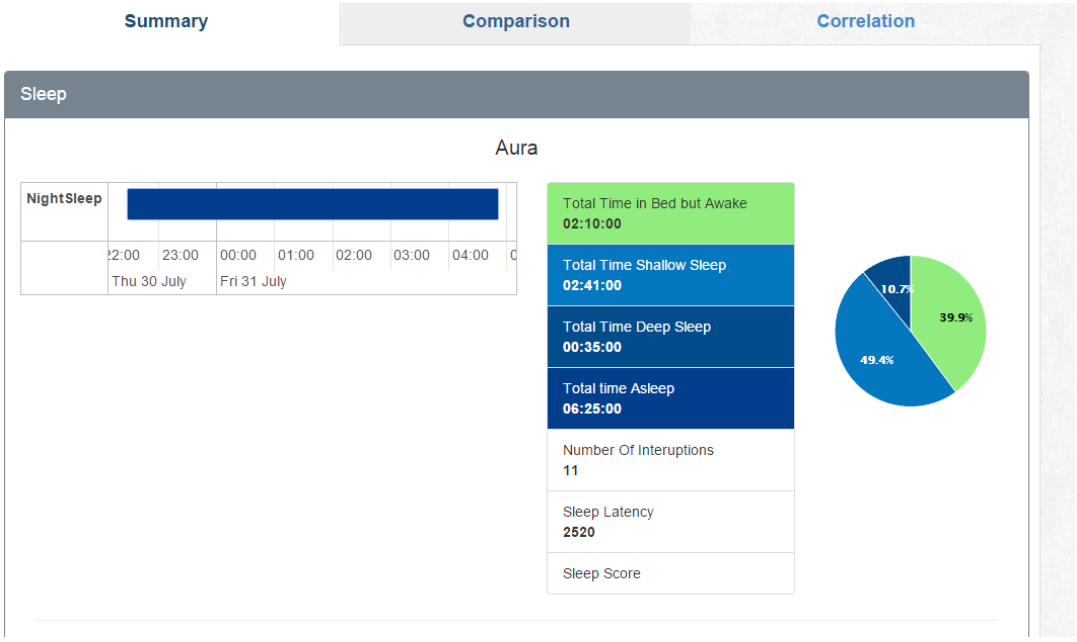


Figure 141. One day Summary, with sleep information in the beginning of the protocol

After one month of interventions the patient showed improvement in all domains of sleep. Less number of interruptions, more deep sleep duration, less total time awake in bed.

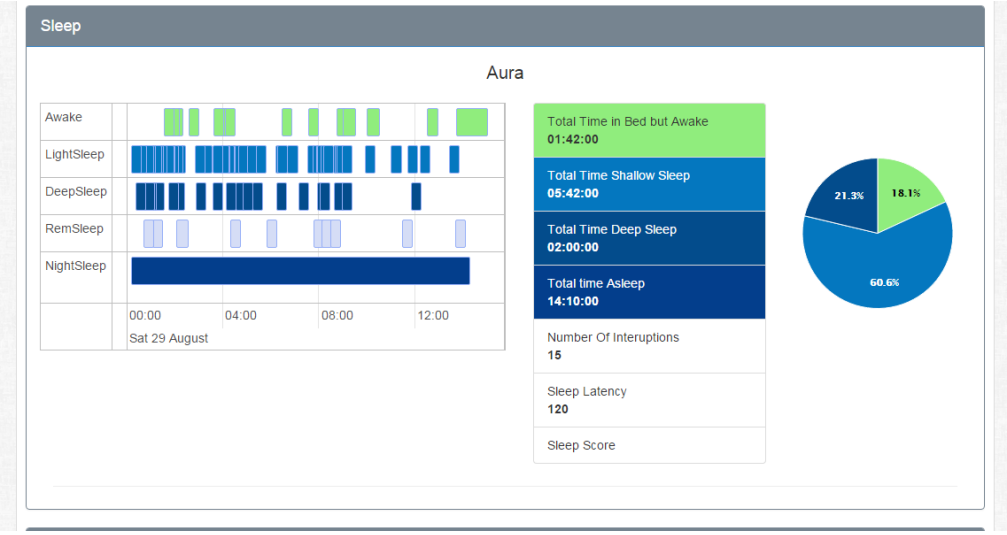


Figure 142. One day summary, with information about sleep in the middle period of the protocol

During the final period there was a clear improvement in sleep latency and increase of deep sleep duration.

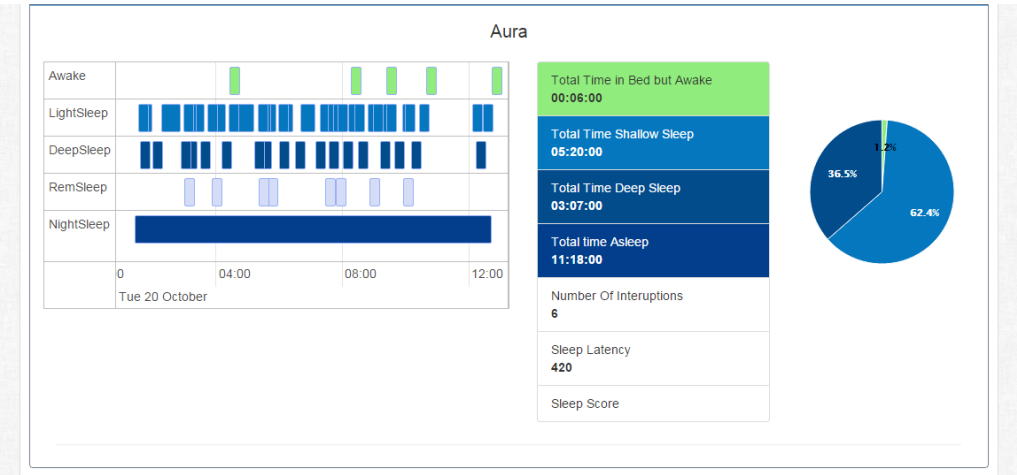


Figure 143. One day summary, with information about sleep in the final period of the protocol

Specific observations of sleep via interface:

At the beginning of the protocol the participant was more than an hour in bed awake before sleep (Total time in bed awake: 2:10 hrs, 39,9%), in contrast with the majority of adults at this stage who covers 5-10% of their total time of sleep awake in bed. Her total shallow sleep duration was in normal limits (Total time shallow sleep: 2:41 hrs, 49,4%). However, the deep sleep was low (0:35 hrs, 10.7%), while the total time of deep sleep in adults is between 15-25%. Sleep latency was extremely high (1:00 hrs). Furthermore, the numbers of interruption were around 11 and total time of sleep was around 6 hours.

In the middle period there was an obvious improvement (Total time in bed awake: 0:55 hrs, 12.2%). Her total shallow sleep duration was reduced (Total time shallow sleep: 3:55 hrs, 52.1 %) her deep sleep was increased (2:41 hrs, 35.7 %), while the number of interruptions

were around 4. The total time of sleep was around 9 hours. Sleep latency was also reduced (0:30 hrs).

In the final period the clinician observed significant reduction of total time awake in bed during night time (0:35 hrs, 8.4%), total time of shallow sleep (4:09 hrs, 59.7%), increased duration of total time of deep sleep duration (2:13 hrs, 31.5%). Moreover, the total time of sleep also increased (from 6 hrs on the beginning to almost 9 hours in the final period) and number of interruptions decreased (N=2). Sleep latency was also reduced too (0:17 hrs).

In comparison per week Chart the clinician observed reduction of total time awake in bed. In the first graph 1st period of observation is presented while in the second graph later observations are presenting.

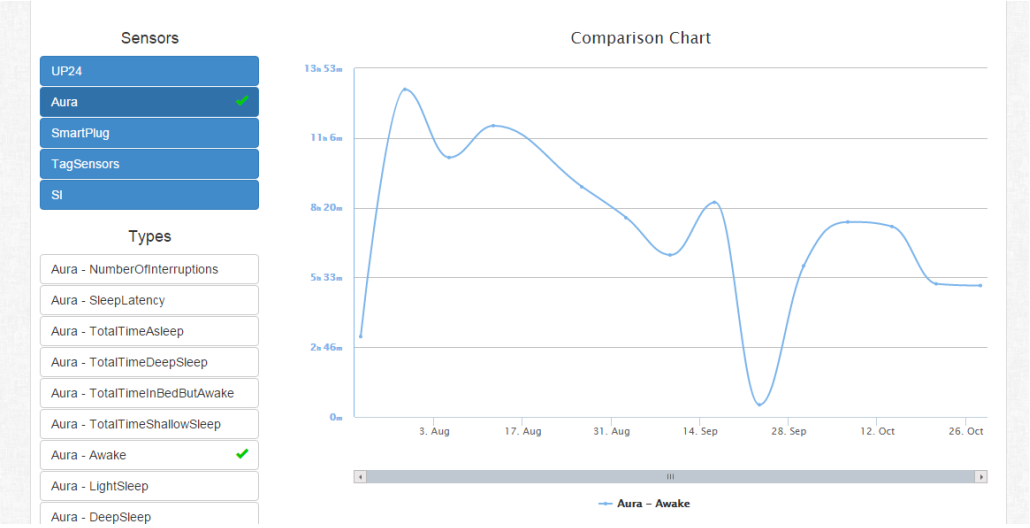


Figure 144. Comparison per Week chart, with total time awake during night sleep of the whole period of the protocol

Figure 145. Comparison per Week chart, with total time awake in bed at night during the whole period of the protocol

The statistical analysis (Linear regression) revealed significant improvement regarding the number of sleep interruptions (p=0.000)

7.4.5 Measurements: Activity

During the beginning the patient had very moving intensity during daytime, while in the middle and in the final period there was clear improvement.

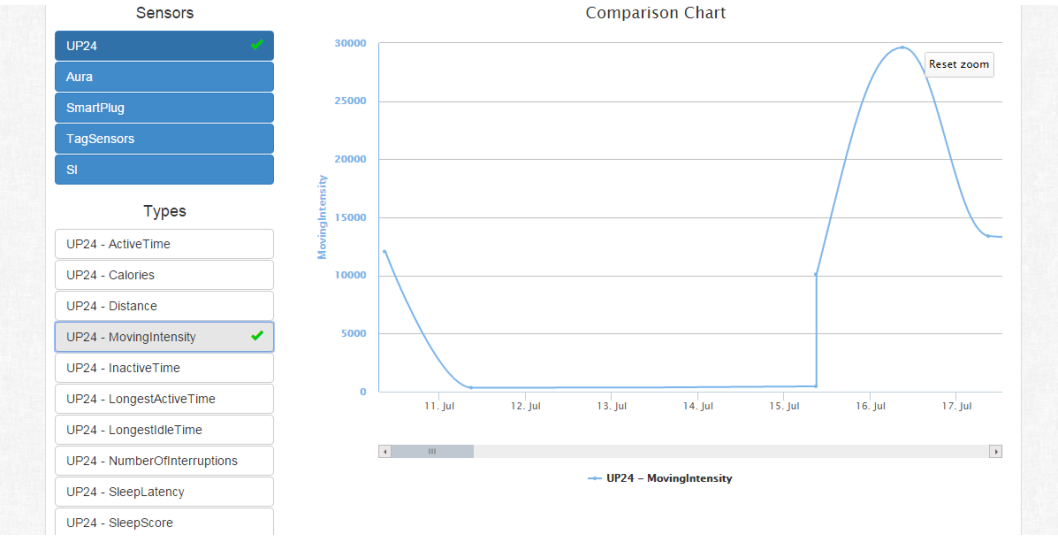


Figure 146. Comparison per Day chart of specific days moving intensity in the beginning of the protocol

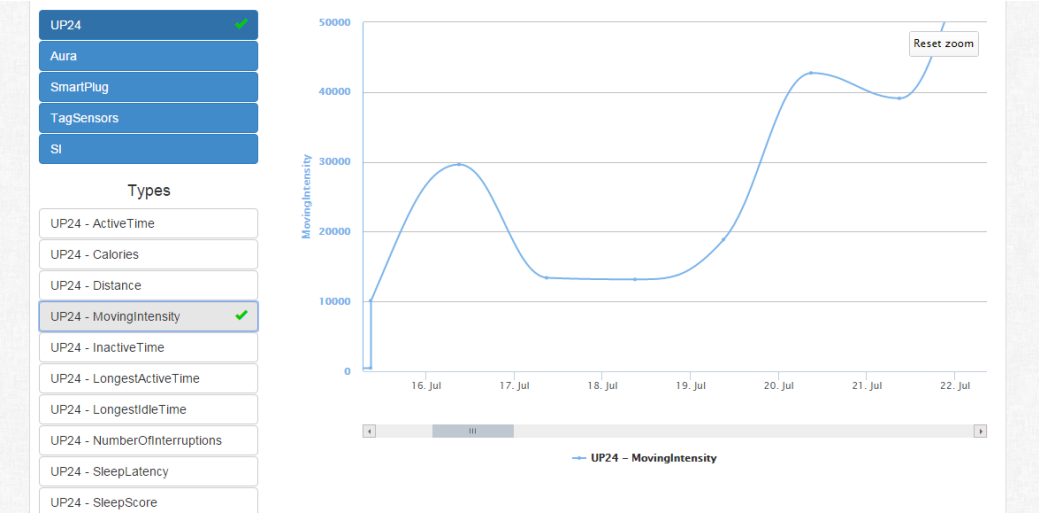


Figure 147. Comparison per Day chart of specific days moving intensity in the middle period of the protocol

The majority of the values in the final period were more than 4000 and the frequency is higher than in the first period.

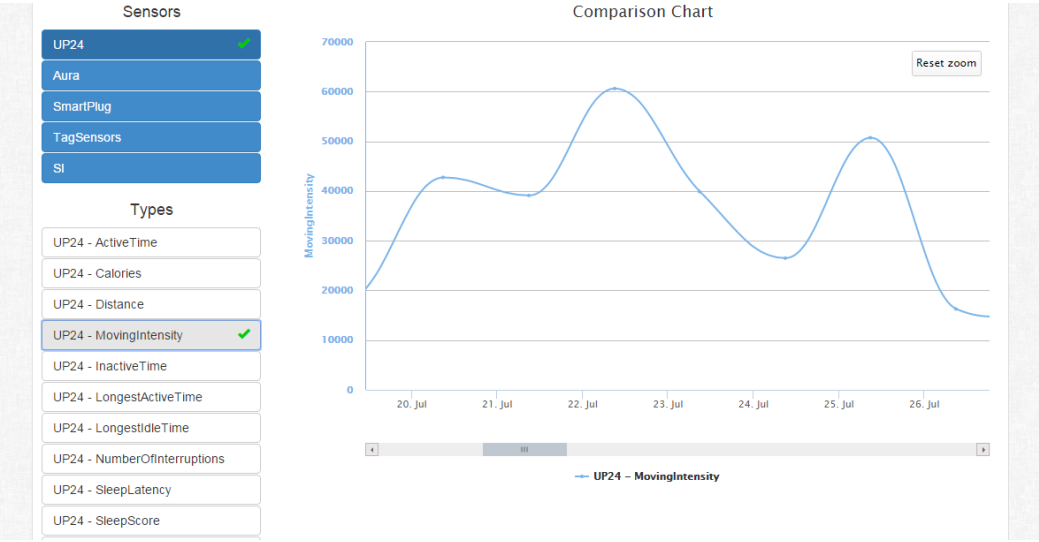


Figure 148. Comparison per Day chart of specific days moving intensity in the final period of the protocol

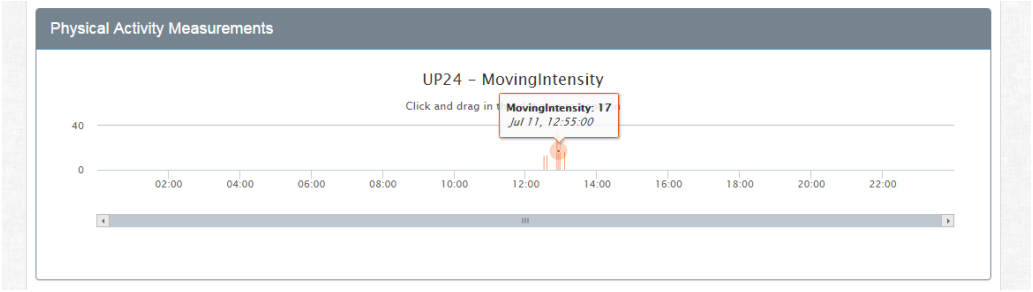


Figure 149. One-day Summary information about moving intensity from the Up24 bracelet in the beginning of the protocol

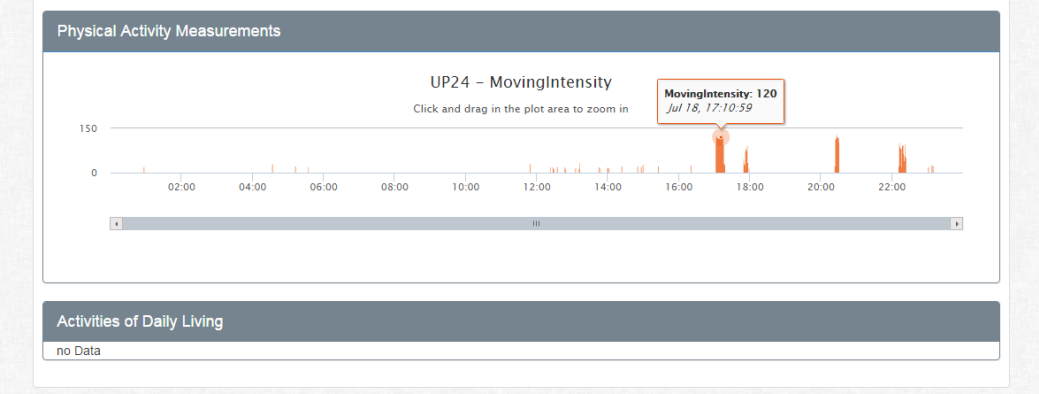


Figure 150. One-day Summary information about moving intensity from the Up24 bracelet in the middle period of the protocol

During the last phase of the protocol the participant was very active. Intense moving intensity can be observed in the one day section summary of the interface.

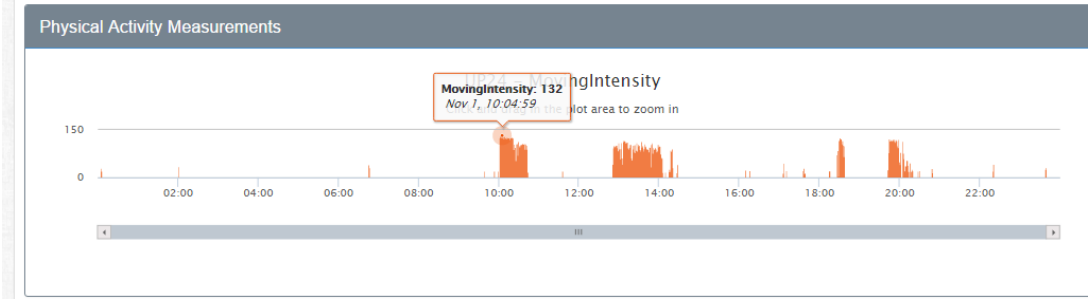


Figure 151. One-day Summary information about moving intensity from the Up24 bracelet in the final period of the protocol

7.4.6 Measurements: Daily activity

At the beginning of the protocol, the participant didn't want to cook or prepare her lunch and denied to take part in house cleaning. After the clinician's advices and specific tasks noted down in the calendar the participant started involving in more house works during the day.

Microwave usage.

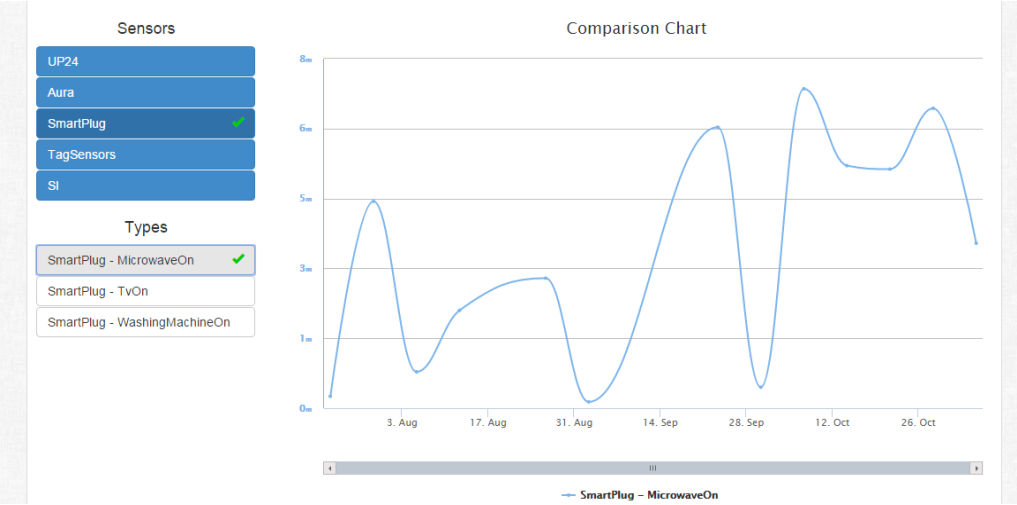


Figure 152. Comparison per Month chart showing increased involvement in house works and more frequent use of microwave during the whole period of the protocol

Washing machine usage

Figure 153. Comparison per Week chart showing decreased involvement in house works and less frequent use of washing machine during the first period of the protocol.

In the final period of the protocol the patient was more aware of her hygiene and house works.

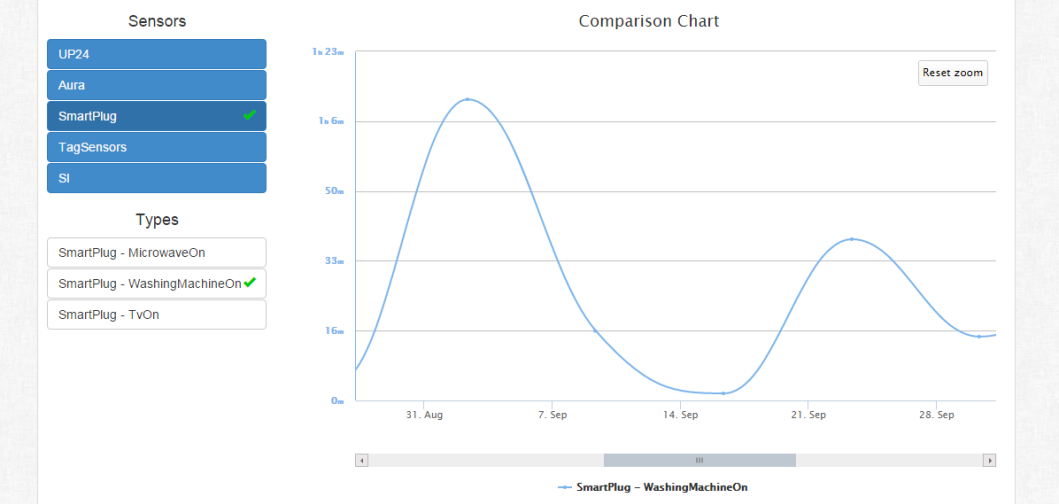


Figure 154. Comparison per Week chart showing increased involvement in house works and more frequent use of washing machine during the final period of the protocol

7.4.7 Measurements: Psychometric

In the following table the three clinical assessments (initial, middle and final) are presented

Table 50. 1st Neuropsychological Assessment

MMSE	28	**RBMT- story direct recall**	11
MoCA	19	**RBMT-story delayed recall**	7.5
CDR	1	**FUCAS**	42
NPI	2	**ROCFT**-copy	36
FRSSD	3	**ROCFT**-delayed recall	25
GDS	2	**TRAIL-B**	171
HAMILTON	14	**BDI**	10
PSS	3	**QOL**	26
BAI	4	**IADL**	10
TEA		**RAVLT**	
Map Search	1st attempt: 25	1st attempt	6

	2nd attempt 26	5th attempt	(+6) 12
Visual Elevator	Correct answers: 7	Total score	48
	Time: 4.51	Delayed recall	(-4)7
Telephone Search	Total score:3	**FAS**	12

Table 51. 2nd Neuropsychological Assessment

MMSE	29	**RBMT- story direct recall**	11.5
MoCA	23	**RBMT-story delayed recall**	8.5
CDR	1	**FUCAS**	42
NPI	4	**ROCFT**-copy	34
FRSSD	3	**ROCFT**-delayed recall	21
GDS	2	**TRAIL-B**	220
HAMILTON	12	**BDI**	11
PSS	4	**QOL**	29
BAI	4	**IADL**	9
TEA		**RAVLT**	
Map Search	1st attempt: 23	1st attempt	8
	2nd attempt: 28	5th attempt	(+4) 12
Visual Elevator	Correct answers: 8	Total score	50
	Time: 4.51	Delayed recall	(-4)8
Telephone Search	Total score:2.53	**FAS**	12.3

Table 52. Final Cognitive Assessment 3rd Neuropsychological Assessment

MMSE	30	**RBMT- story direct recall**	12
MoCA	24	**RBMT-story delayed recall**	8.5
CDR	0.5	**FUCAS**	42
NPI	0	**ROCFT**-copy	31.5
FRSSD	2	**ROCFT**-delayed recall	13
GDS	2	**TRAIL-B**	210
HAMILTON	7	**BDI**	3
PSS	2	**QOL**	30
BAI	2	**IADL**	8
TEA		**RAVLT**	
Map Search	1st attempt: 27	1st attempt	8
	2nd attempt: 56	5th attempt	(+5) 13
Visual Elevator	Correct answers: 9	Total score	54
	Time: 4.5	Delayed recall	9
Telephone Search	Total score:2.42	**FAS**	10.3

The neuropsychological assessment revealed changes in almost all domains of cognition and emotion. Moreover, in the beginning the patient had problems in memory and in general cognitive and executive function according to MMSE=28, MoCA=19, CDR=1. Also, low scores detected in tests which assess cognitive processing and speed (TRAIL MAKING part B= 171, TEA map search= 25/26, correct answers= 7/4.51, telephone search total time score=3), epi-

sodic memory and long-term memory (RBMT delayed recall of the story=7.5) visual-spatial long term memory (ROCFT delayed recall=7.5) and the ability of storing new knowledge and learning new things (RAVLT test delayed recall=-4, total score=48). Also she had problems with Activities of daily living (IADL=10) and quality of life. Moreover she met the criteria for mild depression (Hamilton=10, BDI=10).

After the applied interventions the participant's scores in the final assessment indicate improvement in general cognition and memory (scores of MMSE=30, MoCA=24, CDR=0.5), cognitive processing, attention and speed (TEA map search 27/56, visual elevator 9/4.5, telephone search total time score=2.42, TRAIL MAKING part B=210), within normal limits. Also, better performance is detected in quality of life (QoL=30) and activities of daily living (IADL=8). Furthermore, the ability of new learning and verbal fluency is also improved (FAS=10.3, RAVLT total score=54).

7.4.8 Patient User Interface

Similarly to the first participant, in the middle period of the protocol, the clinician provided to the third participant a mobile tablet device and introduced to her the patient interface. There was repeatedly learning sessions in which the clinician presented to the participant the operation and the information that the patient interface is able to provide. The goals were the same with the first participant: a) to provide in a simple and understandable way all the needed information in order the participant to be aware of the daily activities performance, b) to remind the participant specific activities (e.g. medication), and c) to allow the clinician to send messages and guidelines to the participant any time of the day. More specifically, the user interface informed the participant regarding daily steps and calories, sleep duration and interruptions, devices usage and medication. At the end of the protocol the clinician interviewed the participant regarding the usefulness and the usability of the system.

In the following figure, information about steps (purple chart) and burned calories (green chart) in specific dates 2/11/-4/11/2015 is presented.

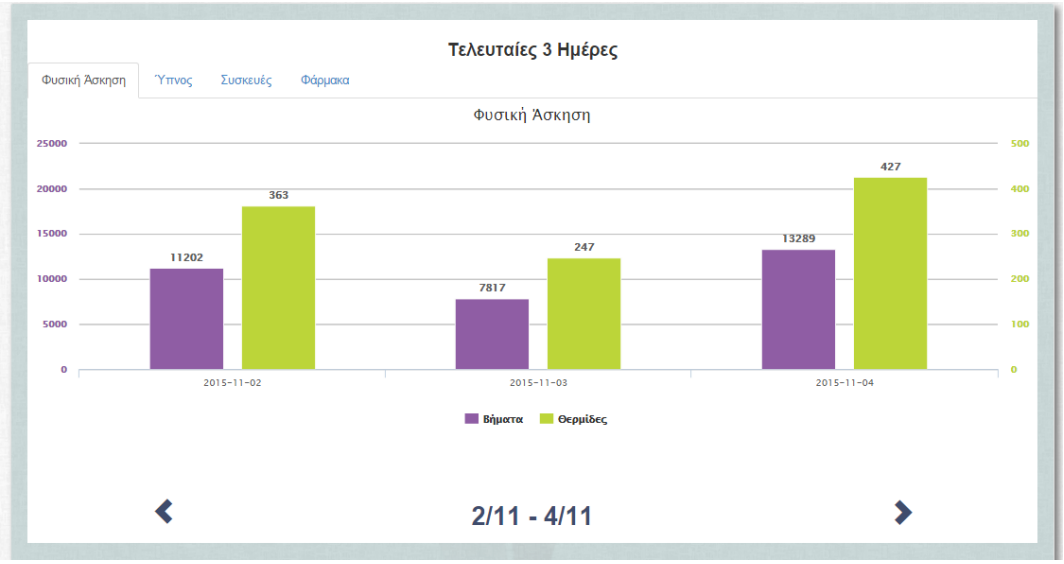


Figure 155. Information about patient's activity

In this figure the patient can see how many hours the last 3 days (2/11-4/11) she slept (blue chart), how many times she woke up during the night (yellow chart) and how many hours was awake in bed (red chart). Also problems of number of interruptions appear in the red line above the chart, which inform the patient how many interruptions she had during a night *("You had 5 sleep interruptions on 4/11/2015")*. This sleep interruption indication proved beneficial for the participant because she was from one hand to think for the causes of these interruptions and from the other to discuss with the clinician these problems. Of course, the third participant was MCI and was able to manage and reflect on these results.

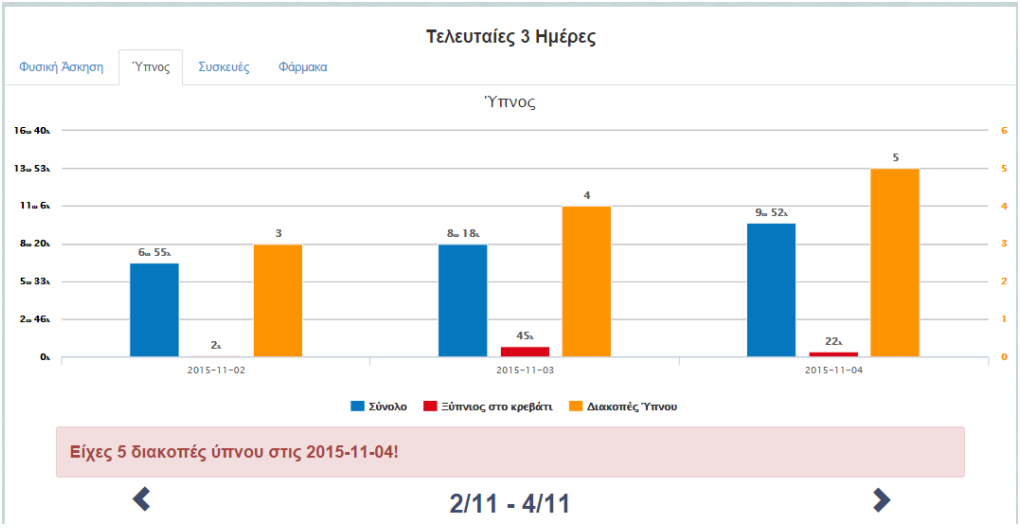


Figure 156. Information about patient's sleep quality and duration

Data from devices in Home. In this session also the participant can see the usage of her devices. Duration of TV usage (black chart), cooker (blue chart), washing machine (green chart).

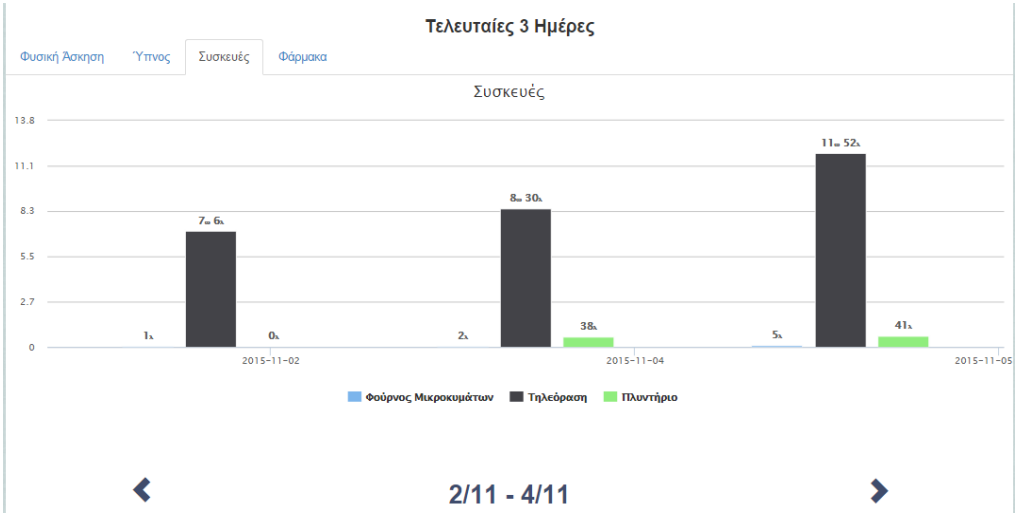


Figure 157. Information about usage of devices in the home

Information for medication: In this picture the patient can see if she took or not his pills the last 3 selected days (3/11/2015-5/11/2015).

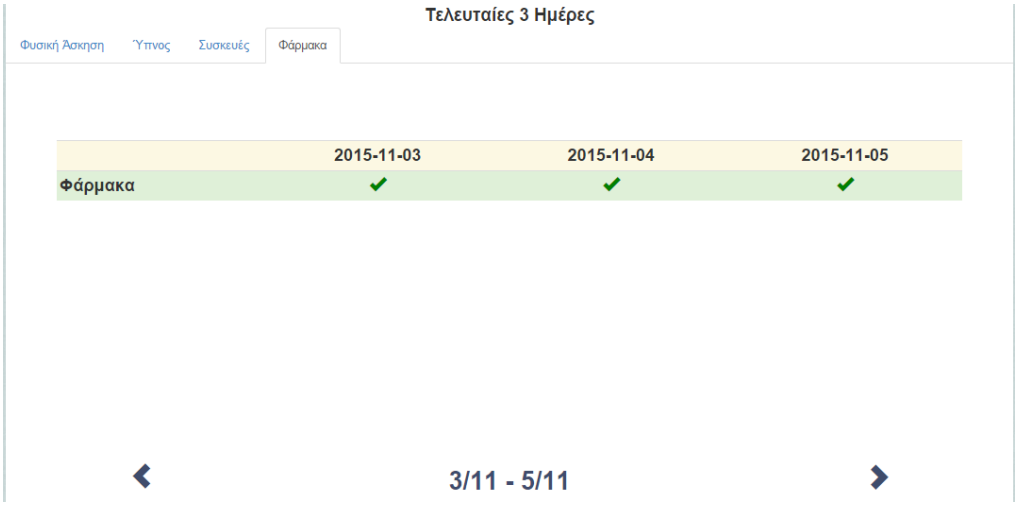


Figure 158. Information about medication

In the following table the user evaluation regarding the system is presented.

Table 53. User evaluation

OVERALL REACTION TO THE SYSTEM	
1. terrible-wonderful	"Terrible? No no terrible I wouldn't say that. It was a good system"

2. difficult-easy	"Well it isn't the easiest thing in the world but ok when you showed me how to use it I think It became easier"
3. frustrating-satisfying	"For a person like me I think it was not frustrating"
4. inadequate power-adequate power	"I cannot answer to that question I don't know. I think it is good"
5. dull-stimulating	"It is very stimulating. I am the doctor of myself. Every morning I wake up and I open the table to see what has happened"
6. rigid-flexible	"It is flexible"
SCREEN	
7. Reading characters on the screen: hard-easy	"It was easy. I could read the characters very well"
8. Highlighting simplifies task: not at all-very much	" Everything you saw or everything you wanted to do it was very ell-highlighted"
9. Organization of the information: confusing-very clear	" It was very clear"
10. Sequence of screens: confusing-very clear	"Very clear too"
TERMINOLOGY AND SYSTEM INFORMATION	
11. Use of terms throughout system: inconsistent-consistent	"It was consistent"
12. Terminology related to task: never-always	"Always. This is for sure. I wanted to look at my sleep and it was clear what I was watching"
13. Position of messages on screen: inconsistent-consistent	"The messages were very good. I liked them. My clinician sent me about my progress. Encourages me more to continue my interventions and not to give up"
14. Prompts for input: confusing-clear	"Prompts were very clear. But I was becoming a bit nervous when I saw for example that yesterday I woke up 7 times. I said "Oh my God" I have major problem"
15. Computer informs about its progress: never-always	" It was always informed and updated"

16. Error messages: unhelpful-helpful	"they were very helpfult. They guide you what to do next"
LEARNING	
17. Learning to operate the system: difficult-easy	"It was very difficult on the begging but after practice it wasn't so difficult"
18. Exploring new features by trial and error: difficult-easy	"It was easy"
19. Remembering names and use of commands: difficult-easy	" No I remember names and demands very well"
20. Performing tasks is straightforward: never-always	"Always. Whatever I wanted to see it was very clear"
21. Help messages on the screen: unhelpful-helpful	"Messages were very very very helpful indeed. The clinician reminded me what I had to do "
22. Supplemental reference materials: confusing-clear	"It was very clear"
SYSTEM CAPABILITIES	
23. System speed: too slow-fast enough	"I didn't face any problem with speed. I would say that the pages change very well. The system has very good speed"
24. System reliability: unreliable-reliable	"In the beginning I was checking twice to see if it works well. But after testing it was working
25. System tends to be: noisy-quiet	"No it was simple and quiet"
26. Correcting your mistakes: difficult-easy	"I didn't do any mistake..If you mean to select sleep instead of physical activity ok I did it but then I choose the right one"
27. Designed for all levels of users: never-always	" No I don't think that my friend's husband who has Alzheimer's disease would use it"
PUEU	
USEFULNESS	
28. Using the system in my job would enable me to accomplish tasks more quickly: unlike-	"Yes it gave the opportunity to accomplish my everyday tasks more easily"

ly-likely	
29. Using the system would improve my job performance: unlikely-likely	"I am not working now but I think yes. If I see to the system that the day before I moved more and I slept better this gives me feedback to continue doing what I have to do more successfully"
30. Using the system in my job would increase my productivity: unlikely-likely	"Yes it gives you more power to continue what you do. You see the results by yourself"
31. Using the system would enhance my effectiveness on the job: unlikely-likely	"I agree."
32. Using the system would make it easier to do my job: unlikely-likely	"Actually it helps you to do your job because you can see that if you do this it affects the other and if you don't do this you get better to the other and so on…."
33. I would find the system useful in my job: unlikely-likely	" Probable yes"
EASE OF USE	
34. Learning to operate the system would be easy for me: unlikely-likely	"Yes now I can say that to learn how to use it would be very easy for me."
35. I would find it easy to get the system to do what I want it to do: unlikely-likely	"Yes"
36. My interaction with the system would be clear and understandable: unlikely-likely	"Of course. It was very nice to want see something the system show it to me with this easy way"
37. I would find the system to be flexible to interact with: unlikely-likely	"Yes sure"
38. It would be easy for me to become skillful at using the system: unlikely-likely	" I became skillful even from the second week of course if I have more time to use it I would become more skillful"
39. I would find the system easy to use: unlikely-likely	"I think that in the end it is very useful and easy to use."

7.4.9 Conclusions

The third participant has been diagnosed with mild cognitive impairment and depression. During the first days of monitoring, the clinician identified that the participant had minimum engagement in daily activities such as cooking and cleaning. A weekly schedule was proposed combined with computer based cognitive exercises. Increased moving intensity was also detected after specific interventions (such as dance lessons).

As said before, the participant had depressed symptoms mainly because of the lost if her husband. The patient was in denial of doing everything, she was all the time declaring that she in not ready to face the reality. The intense emotion was deflected from the vulnerable core, redirected and expressed as anger. Her anger aimed at inanimate objects, complete strangers, friends or family. Before the interventions, her son was worried about his mother. Thus the clinician introduced relaxation therapy exercises based on Cognitive behavioural approaches of Aaron Beck and Albert Ellis. After carefully selection of the interventions, her son noticed improvement in her emotional reactions.

After the interventions and the guidelines from the system, the participant improved her sleep quality and anxiety management. She also started taking part in more activities of daily living at home (e.g. cooking, cleaning) and became more sensitive about personal and house hygiene. Furthermore, she started being more sensitive about other people such as her grandchildren and she offered to take care of them when her daughter in-law was at work.

Patient's Statement in the clinician

"Well I couldn't imagine that I can manage to feel happy sometimes and have friends, get out of home and meet people and feel good. Well I feel that I am important for my family and my children"

"My involving in this program came the exact time when I need help because I started having important problems with my memory. I was afraid that I have lost my mind. Now I am very good I was tracking my progress by myself via the tablet"]

"Now I can talk with my children via tablet. I have learned modern things and my grandchildren admire me and beg me to show them things I have learned in tablet"

-"Mrs Vicky how would you describe your experience with this project?"[Clinician]

-"I used to be a doctor but I couldn't imagine that I will take part in my own health and treatment without drugs actually. This works. I feel better after the interventions with you I can live normal" [Patient]

7.5 Home Pilot 4

7.5.1 Profile

Mrs V.Z. is a 74-years-old woman with a diagnosis of Alzheimer disease and depression. She has lost her husband and faces complex physical and cognitive limitations. Her score on the MMSE was 21 of 30, MoCA was 14 of 30, fucas 59, frssd 7 which indicates major problems in memory and activities of daily living. Mrs V.Z. has been living alone for the last 15 years. She was previously a house cleaner. She has two sons who are aware of their mother's medication (they mentioned that she is taking more pills than she should).

The NIA–AA diagnostic criteria, published in 2011, asymptomatic (preclinical AD), predementia (MCI due to AD), and dementia (due to AD) used to determine the diagnosis of our participant [63]. The NIA–AA diagnostic framework provides different levels of probabilistic probability (high, intermediate, or unlikely) based on biomarker information of Magnetic

Reasoning Image. The participant's MRI showed hippocampal atrophy in the brain with cognitive neuropsychological measures. According to these criteria, our participant diagnosed with Alzheimer disease in moderate stage and the suggested treatment medication with donepezil and non-pharmacological interventions from our clinician.

Even though we did not expect improvement in cognition during the observation period we wanted to support the caregivers' awareness about patient's medication and alertness. Her caregiver mentioned the following issues:

(1) memory deficits,

(2) difficulties in Activities of Daily Living,

(3) social contact,

(4) health monitoring and safety.

Patient's statement

"I am doing all house works alone. I forget sometimes but ok everyone forgets things.. you know..Generally I don't forget important things. I am going to the supermarket I prepare my food alone. You know I am doing all house works alone."

"I have problems with sleep. All night I sleep maximum three hours. I am not sleeping all day and night. The last 10 years I cannot sleep at all"

Table 54. Specific complaints from caregivers

Routine	*''If you have a strict enough routine, you don't have to remember. Because one thing leads on to the other. She wakes-up in the morning. She knows she must go to the bathroom. She knows that she must do something with my face, wash her teeth. Whatever it may be, it follows one from the other. But if you change her routine she is stressed''*
Forget to do things	*''Well there's so much she needs reminding about things she has to do. When we have an appointment I call her and remind her that I will pick her up at 17.00"*
Television	*"She has a television in the living room. And she forgets to switch that off. TV is always and all day turned on''*
Appointments	*"On Tuesday we arrange a new appointment for Thursday but she was persistent on telling me that we didn't have an appointment but she didn't know what day it was really actually.''*
Cleaning	*''Well she doesn't do anything really, if you tell her that the house need to*

	be cleaned she gets upset.'' *"She will wash up some plates and glasses, but she cannot remember where the pots and cutlery goes—sometimes she can. But otherwise I say leave them out and I put them where they've got to go."*
Using the Telephone	*''I think it's a dislike to doing it. But if she's on her own, it has to be done and she picks up the phone.''*
Orientation to time	*''Knowing what time of day it is can be very difficult. At winter time when it gets dark early, people will think its night time … also remembering what time of the week it is, is it the weekend, or during the week.''*
Preparation of meal	*"As with preparing a meal, problems in making a hot drink were associated with difficulties in planning and sequencing required actions: She may not do all sorts of variations on how she would actually structure the tasks. But she insists on doing and preparing her lunch alone without assistance"* *"Generally speaking she gets the coffee out. And she'll take the top of the jar. And she'll look at it and think, ''well what am I taking this off for?'' And I would say, ''we're having a cup of coffee''.* *"I am very afraid when she uses gas to cook..I think one day she will blow up the house"*
Sleep	*"She is sleeping more than 10 hours at night. And I imagine that she is sleeping during day time too. She is lounging in the couch and she is sleeping"*
Forget to do things	*''I suppose the major problem is memory. Anything that requires memory, what ever that might be. So remembering to go to an appointment or if she has already taken her pills.''*

7.5.2 Installation

In the following table, the sensors and the relevant areas or items of the home installation are presented.

Table 55. Installation

Sensors	
Presence sensor	- Bathroom

Tag (motion sensor)	- Door - Pill Box - Fridge door - Phone - Tv remote Living room
Up24	- Wearable sensor
AURA	- Sleep sensor
Plug sensor	- Tv Living room
IP camera	- Living room

Figure 159. Withings Aura sleep sensor

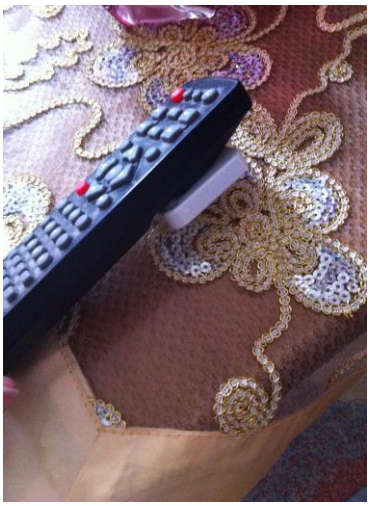


Figure 160. Motion sensor on the TV remote controller

Figure 161. Activity wearable sensor

Figure 162. Motion sensor on the drawer with the pills

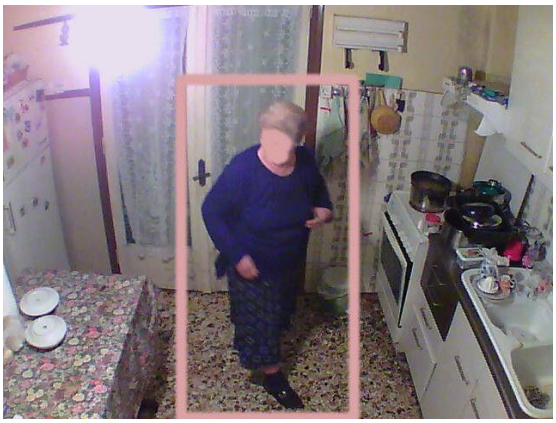


Figure 163. IP camera in the kitchen area

7.5.3 Interventions

Medication management has been recognised as a problem for people with cognitive decline and there are numerous products designed to help. However, medication is also acknowledged as a particularly difficult problem for people with more serious cognitive problems, as our participant with moderate stage of dementia. Caregivers were very anxious about that because

they couldn't control her while they were away. The Dem@Care system provided all the necessary information regarding the medication management (e.g. when she took her medication)

Specific prompts and aids were used as a medication reminder for the participant. Moreover, through the caregiver UI the caregivers were able to see if the participant took the medication or not (specific alerts were used).

Preparing food and kitchen cleaning was one of the main issues for the fourth participant. One of the main problems is safety (leave the oven turned on etc). In order to deal with this problem, we introduced a table with specific tasks that the participant has to do when she was about to start cooking. She had to mark Yes or No in every step.

In the weekly meetings, the clinician introduced reminiscence therapy to enhance her memory deficits and emotion. From the Dem@Care interface the clinician was able to detect increased activity and moving intensity after suggested gymnastic program for elders in Alzheimer's center.

Table 56. Specific clinical directions and guidelines for the patient with dementia when she was preparing a meal

Date:……/……/…… **Instruction for Preparation of Food**		
1.	Turn on the cooker	Yes/No
2.	Note down what time you begin to prepare your food ……..	Yes/No
3.	Prepare your Food CAREFULLY!	Yes/No
4.	Check your food if it is ready	Yes/No
5.	Turn off the cooker	Yes/No
6.	Check again if you have turned off the cooker	Yes/No
7.	Clean your kitchen	Yes/No
CONGRATULATIONS!!!		

7.5.4 Measurements: Sleep

Improvement of the shallow sleep during the protocol

During the first period the participant was sleeping many hours during the night and the duration of shallow sleep was high. Other sleep patterns and naps also were detected by the clinician in this section as well.

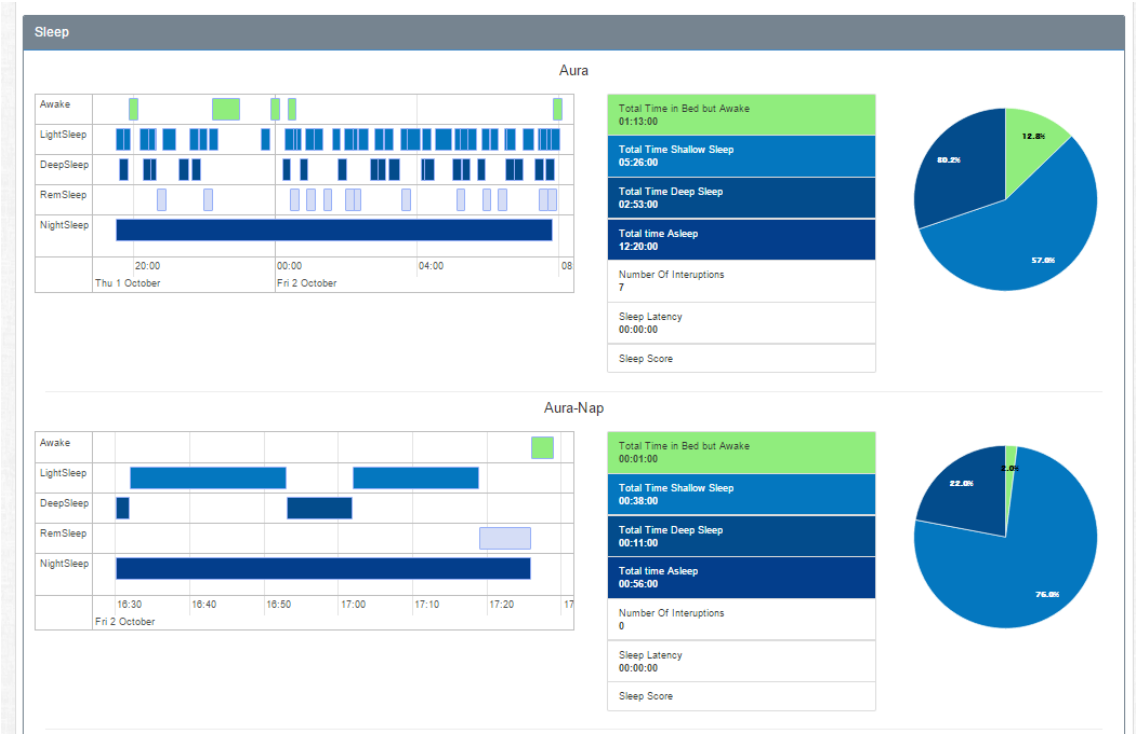


Figure 164. One day Summary graph, with naps detected during the day

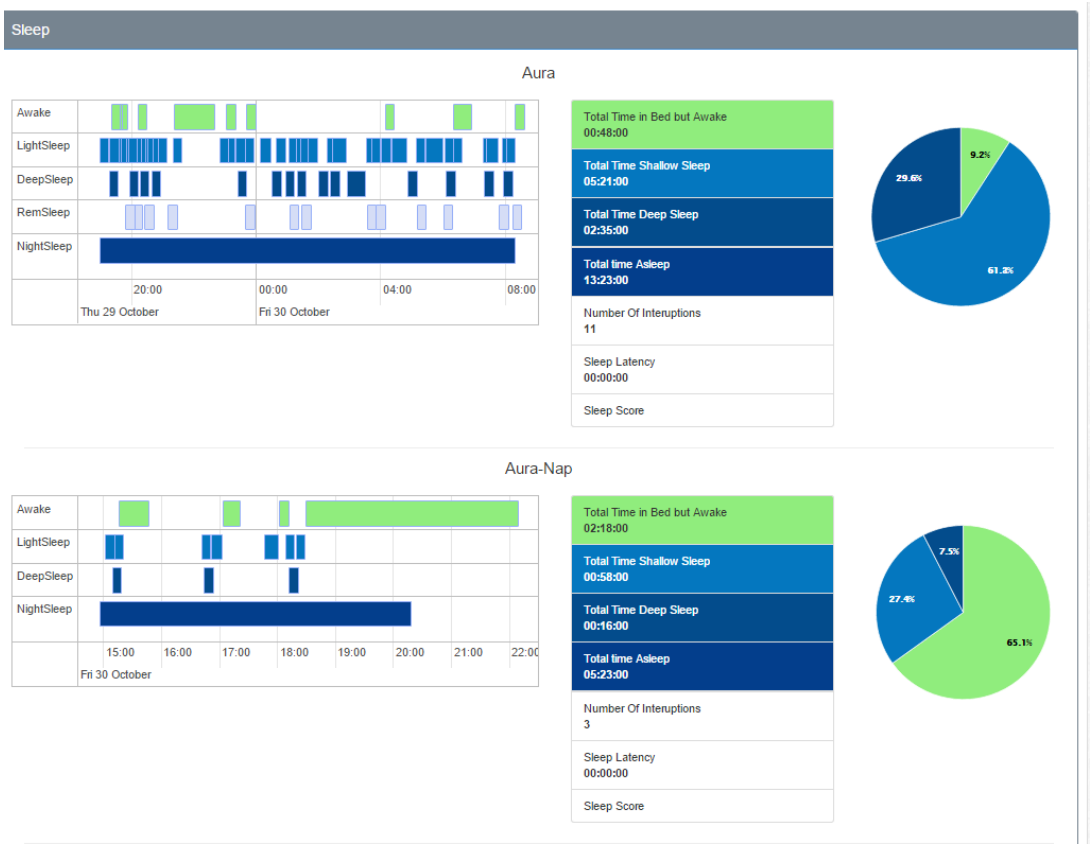


Figure 165. One day summary, with increase in total time of sleep, decreased shallow sleep, and naps detected during the day

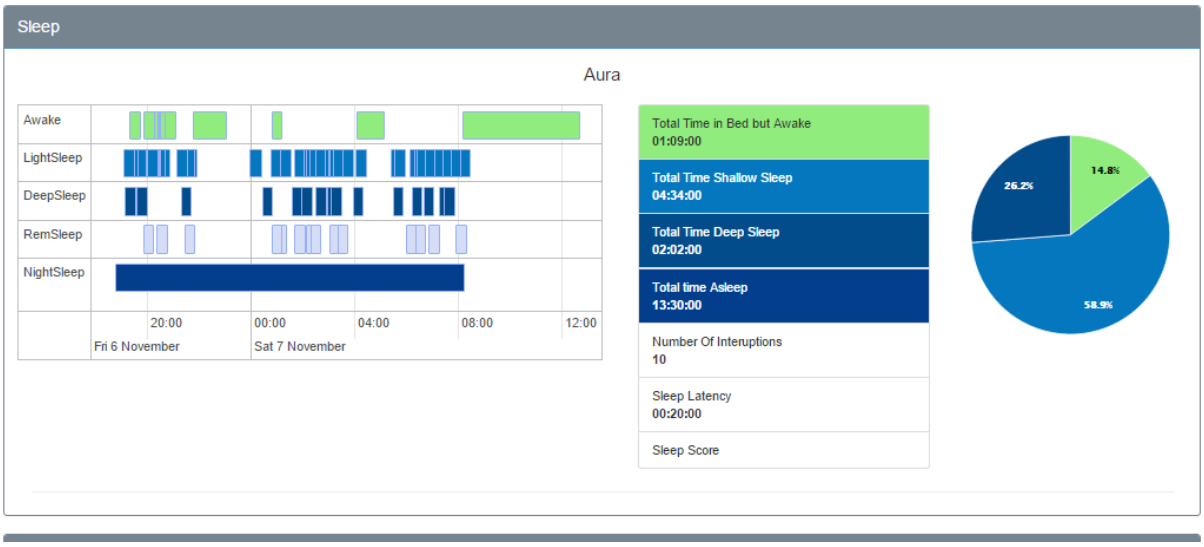


Figure 166. One day Summary, with decreased duration of Shallow sleepm and absence of naps during the day after clinician's advice

Specific observations of sleep via interface:

From the system, it is identified that in the beginning of the protocol the patient total shallow sleep duration was more than 5 hours (Total time shallow sleep: 5:26 hrs, 57,4%) while the majority of adults' shallow sleep covers 45-55% of their total sleep time. Her total sleep time was high while she was sleeping during daytime for one hour too (Nap total time asleep: 0:56). Furthermore, the numbers of interruptions were round 7.

During the middle period a slightly improvement in the sleep was detected by the clinician (Total time in bed awake: 0:56 hrs, 9.2 %) (Total time shallow sleep: 5:21 hrs, 61.5%). The deep sleep was increased (2:35hrs, 29.2%), while the number of interruptions were around 3.

In the final period the clinician observed significant reduction of total time of shallow sleep (4:34 hrs, 58.5 %), increased duration of total time deep sleep (2:02 hrs, 26.2 %). The total time of sleep remained stable the same. The most important finding was that the participant had limited naps during daytime and she was more active during the day.

In Comparison Chart the clinician is able to make correlations between specific variables such as activity (UP24) and sleep patterns (AURA). Moreover, in the following figure, correlations between Deep sleep duration and moving intensity are presented. It is clear that after an intensive activity the duration of sleep was increased as well. Colors of circles represent the correlation between the dates. Furthermore, when there is a reduced moving intensity the duration of deep sleep is also low (arrows).

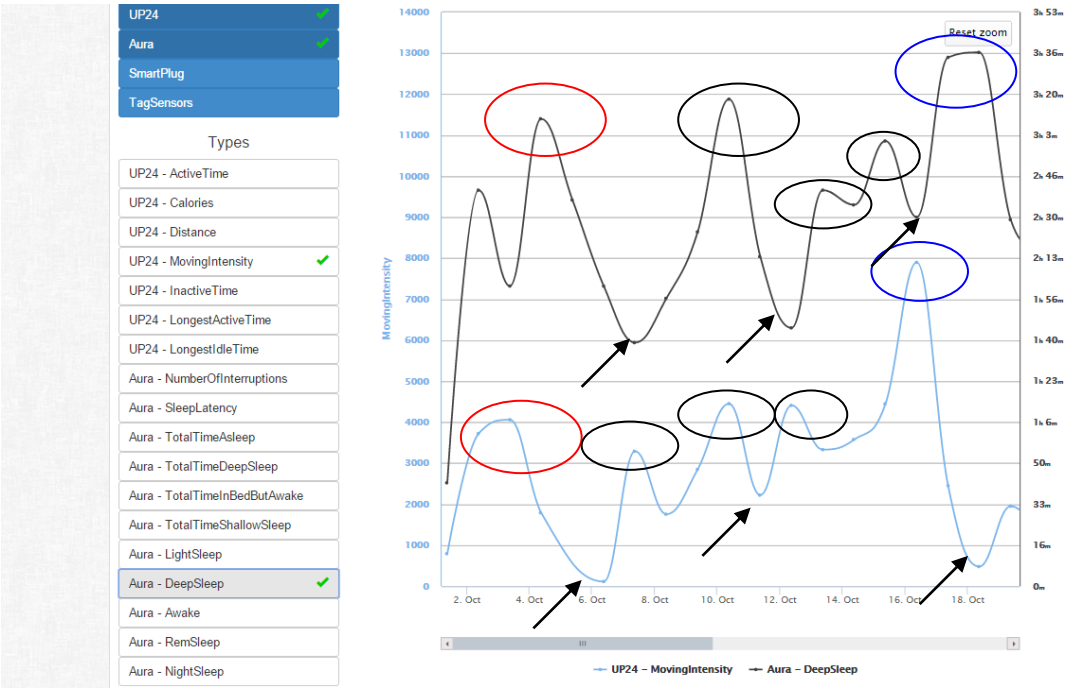


Figure 167. Comparison per Day chart, with correlation between two measures: Deep sleep duration and moving intensity

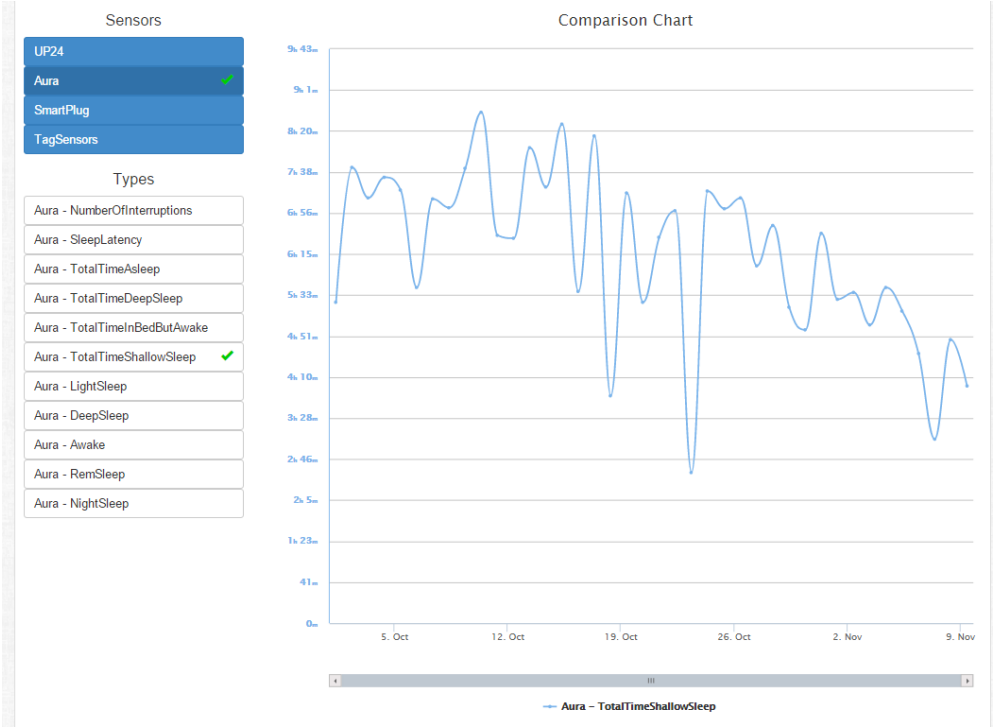


Figure 168. Comparison per Day chart, with reduced shallow sleep information of the whole period of the protocol. Reduction of sallow sleep is detected from the interface.

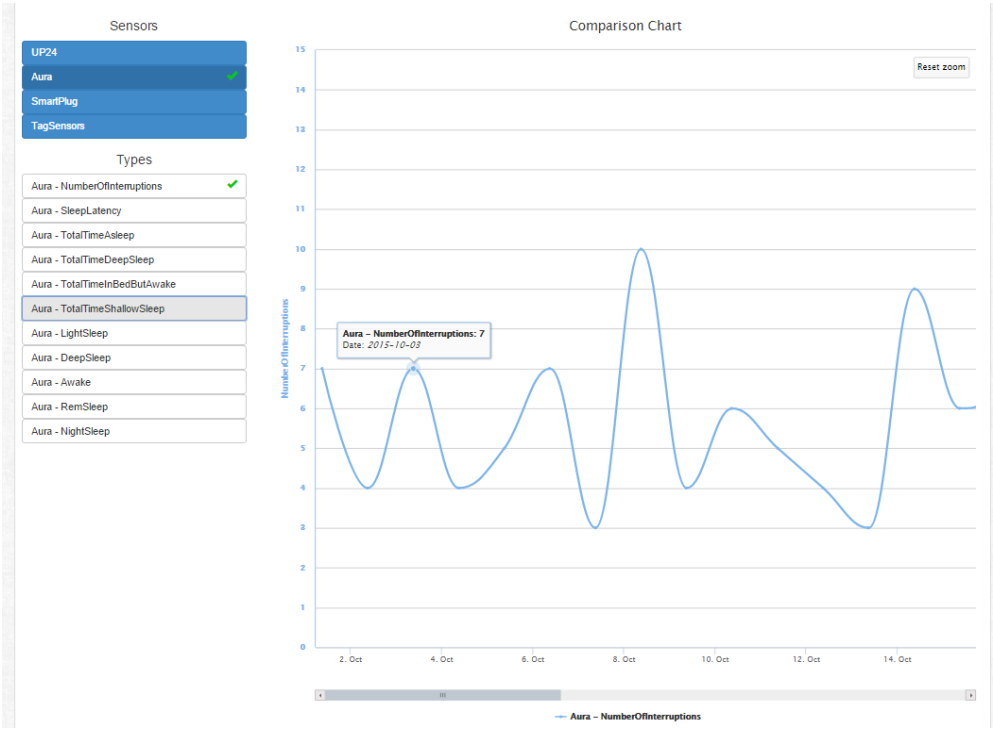


Figure 169. Comparison per Day chart, with number of interruptions in the beginning of the protocol (mean number of interruptions was 6 per night).

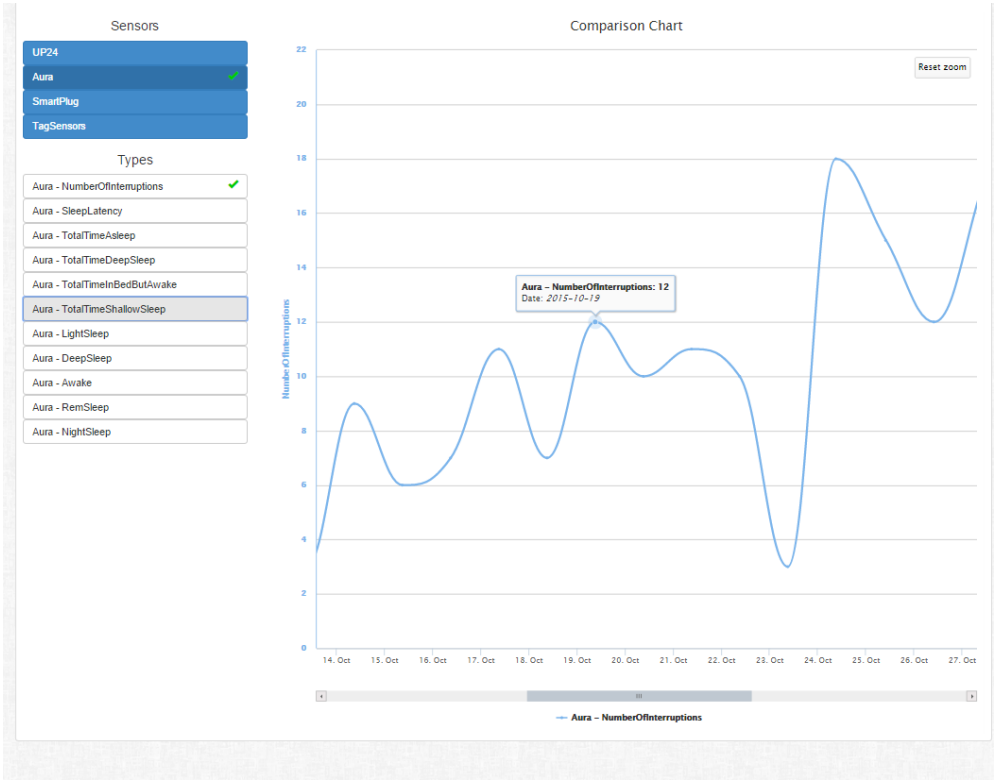


Figure 170. Comparison per Day chart, with increased number of interruptions in the middle period of the protocol (mean number of interruptions per night was 10).

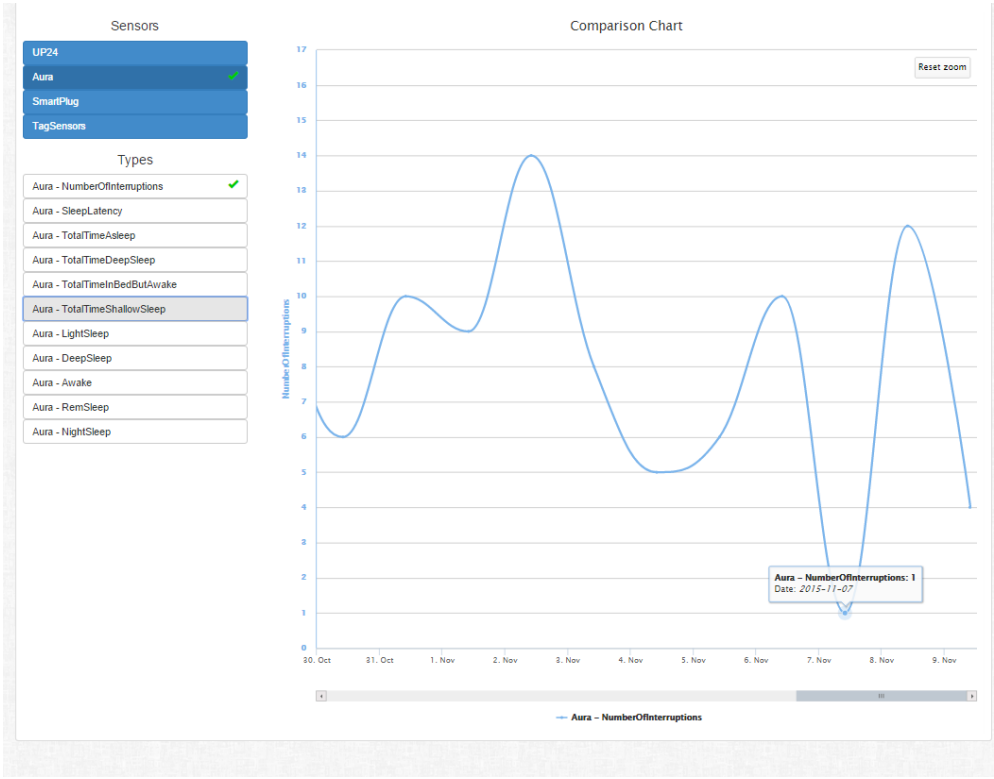


Figure 171. Comparison per Day chart, with number of interruption decreased (mean number of interruptions per night was 8)

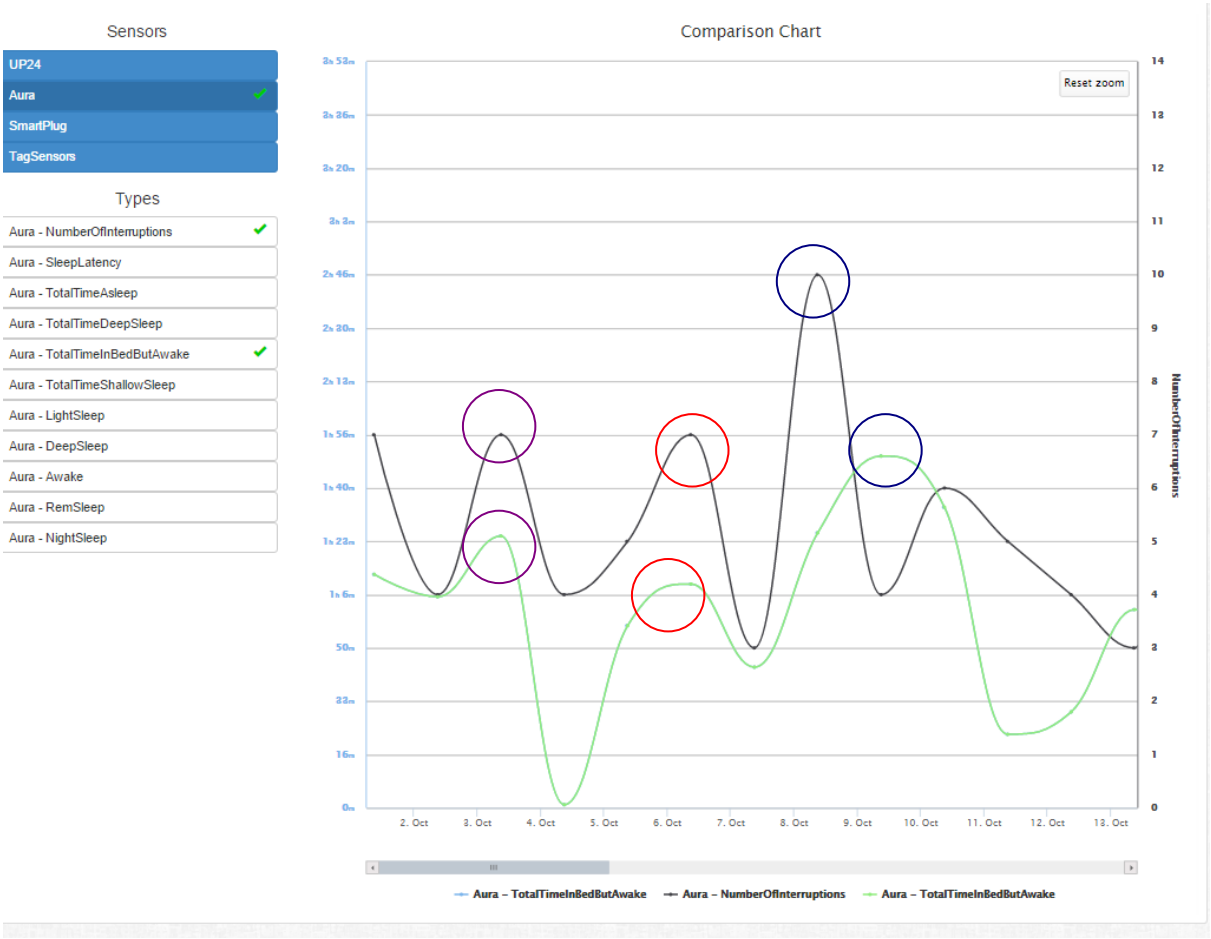


Figure 172. Comparison chart, with correlations between Number of interruptions and Total time in bed Awake. Different colours represent the impact of one variable to the other (same color)

Moreover, the statistical analysis (Linear regression) revealed significant improvement over the time of the intervention in total time asleep (p=0.000).

7.5.5 Measurements: Activity

In Summary of One-Day the clinician was able to detect everyday activity and moving intensity of the patient. In the following pictures moving intensity values are presented in three periods of the protocol

Moving intensity in the beginning of the protocol: The patient is less active during daytime.

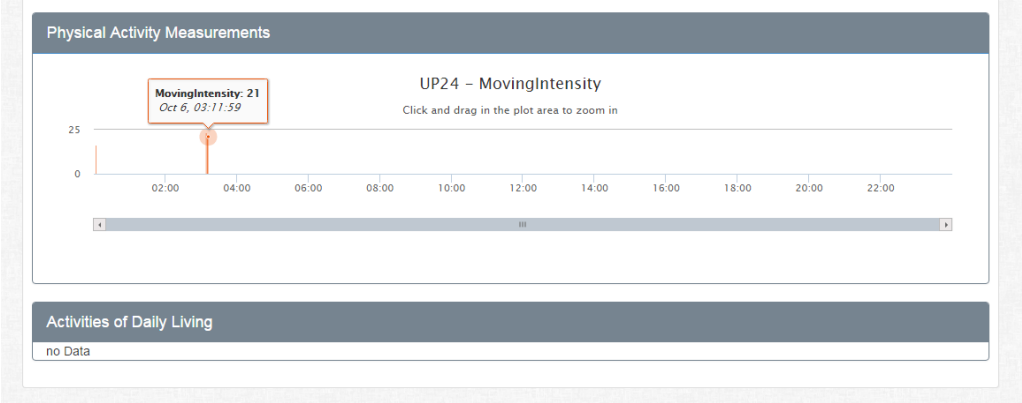


Figure 173. One-day Summary information about moving intensity from the Up24 bracelet in the beginning of the protocol

Moving intensity in the middle period: After specific interventions (gymnastic) the patient started being more active during the day.

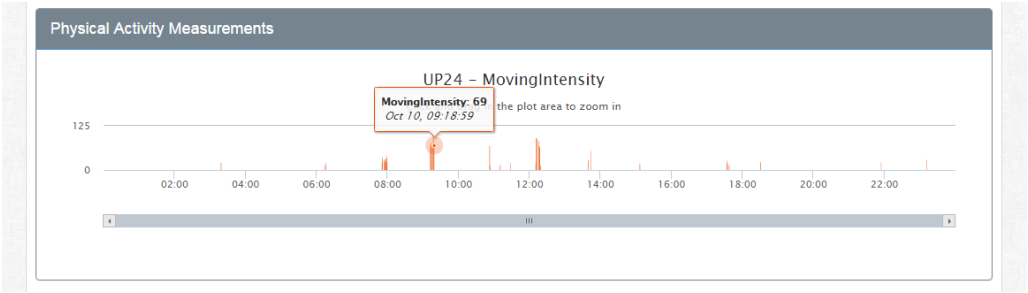


Figure 174. One-day Summary information about moving intensity from the Up24 bracelet in the middle of the protocol

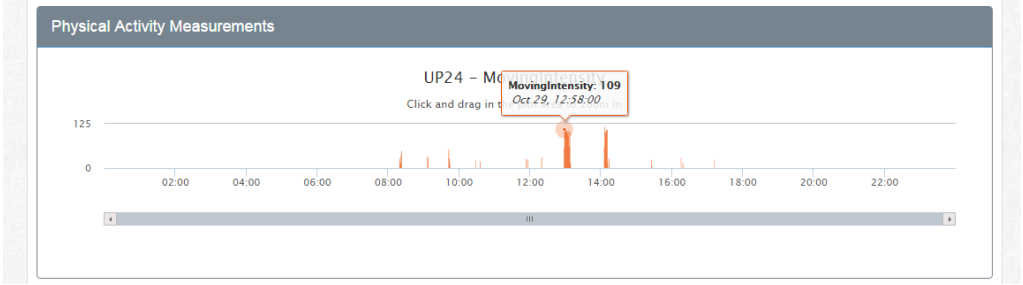


Figure 175. One-day Summary information about moving intensity from the Up24 bracelet in the final period of the protocol

7.5.6 Measurements: Daily activity

The patient didn't use the majority of the electrical devices. In comparison Chart the clinician could monitor the TV usage for specific days.

The patient was using the TV a lot despite clinical advice

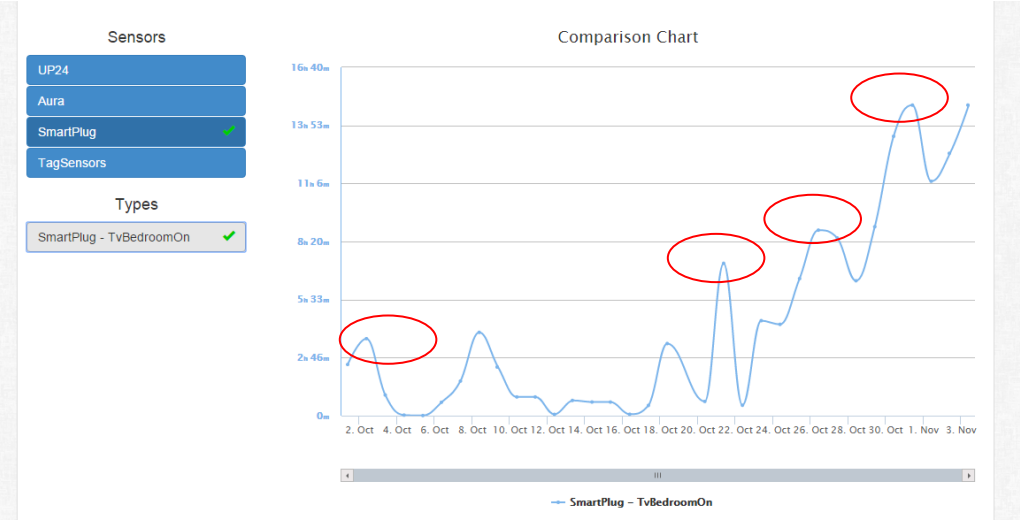


Figure 176 Comparison per day chart - TV usage

The patient didn't take her medication on a daily regular basis. The clinician detected from the system that she forgot medication repeatedly.

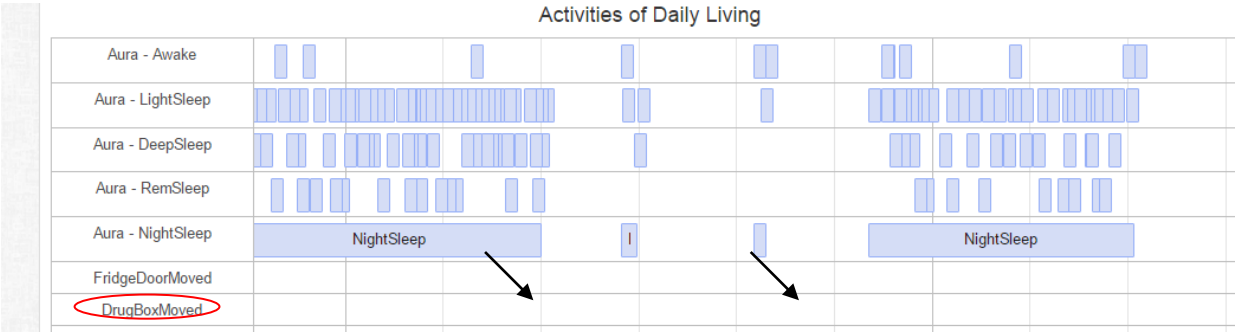


Figure 177. A Summary per day session in the beginning of the protocol, with a tag sensor on the drug box

After prompts placed in specific places in house and user-interface messages to caregiver's interface the situation improved with more regular and proper medication taking.

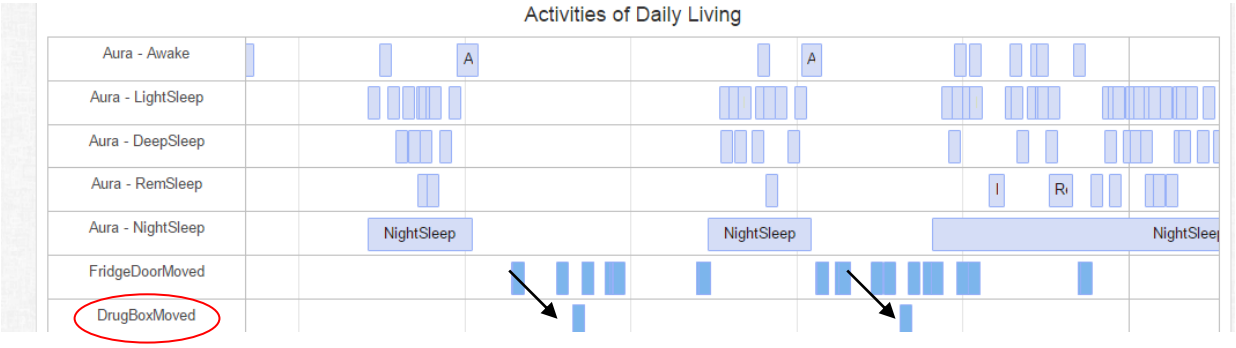


Figure 178. A Summary per day session in the middle of the protocol after intervention exercise, with a tag sensor on the drug box

7.5.7 Measurements: Psychometric

In the following table the two clinical assessments (initial and final) are presented

Table 57. 1st Neuropsychological Assessment

MMSE	21	**RBMT-** story direct recall	7
MoCA	14	**RBMT-**story delayed recall	5
CDR	2.5	**FUCAS**	59
NPI	2	**ROCFT-**copy	1.5
FRSSD	7	**ROCFT-**delayed recall	0
GDS	2	**TRAIL-B**	0
HAMILTON	8	**BDI**	0
PSS	0	**QOL**	25
BAI	1	**IADL**	10
TEA		**RAVLT**	
Map Search	1st attempt: 0	1st attempt	5
	2nd attempt :4	5th attempt	(0) 5
Visual Elevator	Correct answers: 0	Total score	23
	Time: 0	Delayed recall	(-5)0
Telephone Search	Total score:53.3	**FAS**	6.6

Table 58. 2nd Neuropsychological Assessment

MMSE	26	**RBMT-** story direct recall	7.5

MoCA	19	**RBMT-**story delayed recall	2.5
CDR	1.5	**FUCAS**	47
NPI	3	**ROCFT-**copy	14.5
FRSSD	4	**ROCFT-**delayed recall	2
GDS	2	**TRAIL-B**	0
HAMILTON	2	**BDI**	4
PSS	9	**QOL**	32
BAI	3	**IADL**	8
TEA		**RAVLT**	
Map Search	1st attempt: 4	1st attempt	3
	2nd attempt :10	5th attempt	(+6) 9
Visual Elevator	Correct answers: 4	Total score	30
	Time: 11.23	Delayed recall	(-6) 2
Telephone Search	Total score: 27.45	**FAS**	6

In the beginning of the protocol, the participant patient had problems in memory and general cognitive and executive function according to MMSE=21, MoCA=14, CDR=2.5. Also, low scores detected in tests which assess cognitive processing, speed and measures of selective attention, sustained attention and attentional switching (TRAIL MAKING part B=0, TEA map search=0/4, visual elevator 0/0, telephone search total score=53.3), episodic memory and long-term memory (RBMT delayed recall of the story=5), executive functions (ROCFT copy=1.5) ,visual-spatial long term memory (ROCFT delayed recall=0) and the ability of storing new knowledge and learning new things (RAVLT test total score=23, delayed recall=-5). Finally, she had problems with Activities of daily living and functionality (Frssd=7, Fucas=59).

After the applied interventions, there was a more stable situation: the scores in the final assessment indicated improvement in general cognition and memory (total scores of MMSE=26, MoCA=19, CDR=1.5), cognitive processing, attention and speed (TEA map search=4/0, visual elevator=4/11.23, telephone search=27.45, TRAIL MAKING part B=0). Also, better performance is detected in quality of life and functionality (QoL=32, Frssd=4,

FUCAS=47). Furthermore, the ability of new learning, verbal fluency and episodic memory was stable (FAS=6, RAVLT total score=30, RBMT story direct recall=7.5). It is worth to be mentioned that the incapability of learning and episodic memory deterioration is a common characteristic of people with Alzheimer's disease but our participant improvement in comparison with the first assessment in other cognitive tests and remains stable in these measures.

7.5.8 Caregiver User Interface

Similarly to the second pilot, the user interface was used by the caregiver (the son). The clinician introduced to the caregiver the patient interface (He already had a mobile tablet device). There was repeatedly learning sessions in which the clinician presented the operation and the information that the caregiver interface is able to provide. The caregiver interface provided information regarding the daily steps and total spend calories of the participant, the sleep duration and interruptions, the devices usage and medication. At the end of the protocol the clinician interviewed the caregiver regarding the usefulness and the usability of the system.

Before the prompting exercise the participant was forgetting to take her pills. The user interface informed the caregivers if the participant took her medication

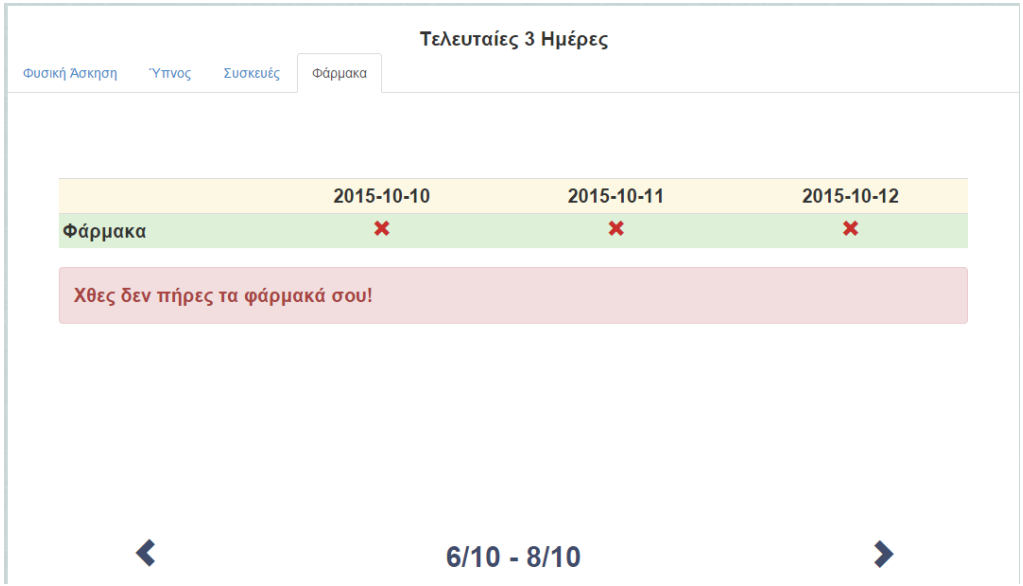


Figure 179. User interface - Information about medication

After specific intervention and prompting exercises the participant remembered to take her medication on a daily basis.

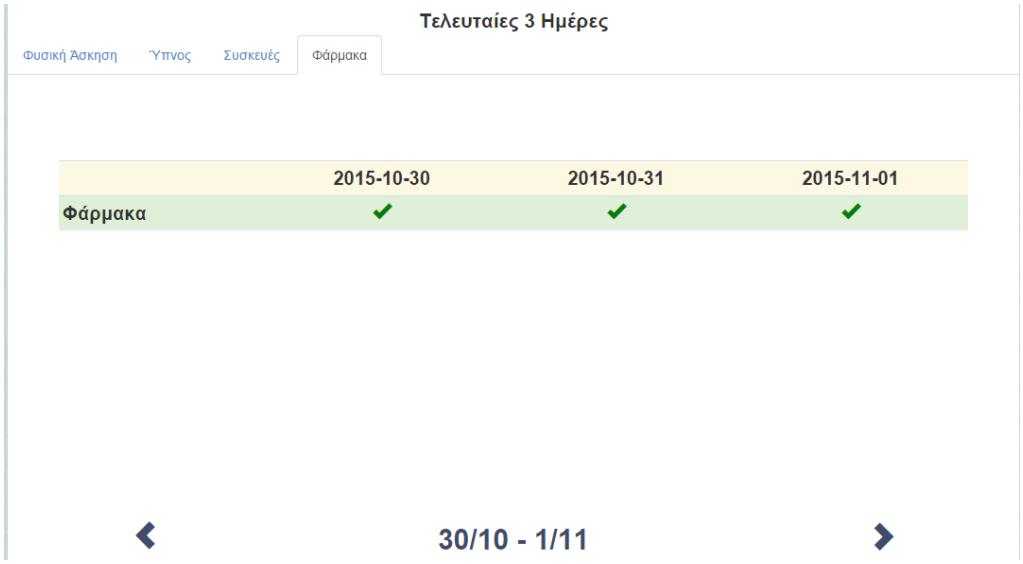


Figure 180. User interface - Information about medication

The caregiver app informed the caregiver about the usage of devices. In this figure the use of TV is presented

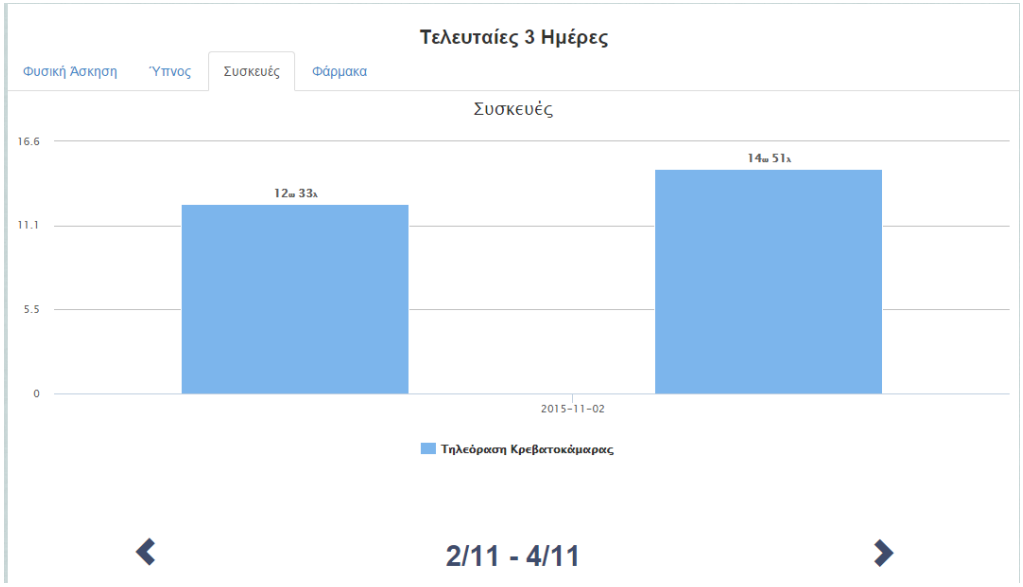


Figure 181. User interface - Information about TV use.

Table 59. Evaluation of the user interface by the caregiver

OVERALL REACTION TO THE SYSTEM	
1. terrible-wonderful	"I found the system astonishing! It is very innovative and very good"
2. difficult-easy	" It is very easy. Actually I was watching it with my son and we found it very easy."

3. frustrating-satisfying	"No. no frustrating at all."
4. inadequate power-adequate power	"It is very powerful I think you must put it on the market. The majority of people who have patient with dementia will buy this. If your rating scale had 10 instead of 9 I would choose this score"
5. dull-stimulating	"It is very stimulating. Dull? Not at all!"
6. rigid-flexible	"I found it very flexible even for me who I am not very skillful with technology"
SCREEN	
7. Reading characters on the screen: hard-easy	"It was very easy"
8. Highlighting simplifies task: not at all-very much	" Everything I wanted to do was very well-highlighted"
9. Organization of the information: confusing-very clear	"The organization was very clear. Everything I want-ed to do was very clear"
10. Sequence of screens: confusing-very clear	"It was very clear too. I didn't find any difficulty"
TERMINOLOGY AND SYSTEM INFORMATION	
11. Use of terms throughout system: inconsistent-consistent	"It was very fixed and consistent. I didn't meet any difficulty"
12. Terminology related to task: never-always	" Always"
13. Position of messages on screen: inconsistent-consistent	"I would prefer messages appear as pop-ups not in front of the screen. Like other applications do. But even in this way they were very consistent"
14. Prompts for input: confusing-clear	"Very clear and very helpful"
15. Computer informs about its progress: never-always	"It was always informed about my mother's progress. It was the first time that I could see things happening in real times and observe many patterns"
16. Error messages: unhelpful-helpful	"This was the most important of all. To see specific messages which shows problems"
LEARNING	
17. Learning to operate the system: difficult-easy	"For me it was very easy. But even for my brother

	who doesn't interact with computers and technology was very easy"
18. Exploring new features by trial and error: difficult-easy	"It was easy"
19. Remembering names and use of commands: difficult-easy	"Very easy. Very well-presented very simple"
20. Performing tasks is straightforward: never-always	" Absolutely always"
21. Help messages on the screen: unhelpful-helpful	" Messages form the clinician were very helpful and the best thing is like you have someone who keeps you update about the patient."
22. Supplemental reference materials: confusing-clear	" It was very clear"
SYSTEM CAPABILITIES	
23. System speed: too slow-fast enough	"Its speed was very good.I didn't face any problem"
24. System reliability: unreliable-reliable	" In the beginning I was double checking. For example I was checking as you told me her pills then I saw from the system that she didn't took them I found that this would help me very much to solve this problem. Then you forced her to follow specific instructions and she actually started taking them"
25. System tends to be: noisy-quiet	" No it wasn't noisy"
26. Correcting your mistakes: difficult-easy	"I found it very easy to correct any mistake"
27. Designed for all levels of users: never-always	"I think it is easy for the majority of the users. Only people on the late stages of Alzheimer disease will not understand how to use it"
PUEU	
USEFULNESS	
28. Using the system in my job would enable me to accomplish tasks more quickly: unlikely-likely	"Definitely yes"
29. Using the system would improve my job performance: unlikely-likely	"Being not all the time concerned about your mother it gives you the opportunity

30. Using the system in my job would increase my productivity: unlikely-likely	" Yes I am less worry about her now"
31. Using the system would enhance my effectiveness on the job: unlikely-likely	"If your mind is clear from awareness you can work more effectively "
32. Using the system would make it easier to do my job: unlikely-likely	"Yes I agree. It happens indeed"
33. I would find the system useful in my job: unlikely-likely	" Yes of course"
EASE OF USE	
34. Learning to operate the system would be easy for me: unlikely-likely	" Yes it was very easy for me"
35. I would find it easy to get the system to do what I want it to do: unlikely-likely	"Yes of course. Whatever I wanted to see it was easy"
36. My interaction with the system would be clear and understandable: unlikely-likely	"It was very clear. I didn't need second time to show this to me. I understand it and I teach my brother how to use it also."
37. I would find the system to be flexible to interact with: unlikely-likely	"I didn't met any problem during my interaction with the system"
38. It would be easy for me to become skillful at using the system: unlikely-likely	"From the first hour actually"
39. I would find the system easy to use: unlikely-likely	"I will miss it when you will stop the program. I used to it"

7.5.9 Conclusions

Our fourth participant has been diagnosed with moderate dementia according to specific clinical and psychological criteria. The Dem@Care recordings revealed that the AD participant has much less daily activity that the other participants and she forgets to take her medicine on a daily basis. She was not taking care of house works and their children could not trust her about the medication. From the summary per day interface it is obvious that the participant forgot her medication and although she was sleeping more than 10 hours per day the quality of her sleep was not good enough (shallow sleep, high number of interruptions).

We are not expecting as we mentioned to see significant improvement and dramatically cognitive changes in a demented patient. The goal for this fourth participant was to support her to live without high caregivers' concerns and promote her quality of life. Indeed, there was an improvement regarding sleep routine which affected the whole daily life.

Based on their positive user interface evaluation and the statements they had made to the clinician, the caregivers are overwhelmingly positive of the technology. Moreover, for the first time they were able to monitor the actual daily activity of their patient combined with important issues as medication taking.

We found that caregivers of the participant were very interested in the possibilities of technology. Dem@Care system provided all the necessary information in order to have all a clear picture of the participant's condition.

7.6 Expert evaluation

Apart from the participant and the caregiver interface, in order to evaluate the user interface satisfaction and the usefulness of the clinician interface for the home pilots, we conducted expert evaluation with 10 domain experts. These experts are professionally active psychologists working at Alzheimer day centers. None of them was familiar neither with the project, nor the sensor-based technology. The evaluation process lasted 2 days and included three phases:

- Phase 1: in this phase all the experts were present. The researchers presented the goals of the project, protocol, the sensors and the system. There was also a live presentation of the protocol and the system. The experts were free to interrupt and make questions regarding both the protocol and the system functionalities. The duration of this section was 1 hour.
- Phase 2: during the second phase, the experts worked individually and outside the lab. They on their own were able to operate with the system through a demo online environment and to explore all the system's functions. There was no time limit for this phase. The experts were free to interact as much as they like.
- Phase 3: in the last phase the experts had to answer an online questionnaire. The questionnaire consisted of two sections. The first one included the QUIS-short version, a standardized questionnaire for user interface satisfaction [64] and the second one included the PUEU questionnaire regarding the perceived usefulness and ease of use [65]. Both of these questionnaires are well known, valid and reliable.

Table 60. Expert evaluation results for home system

#	**Questions (min: 0, max: 9)**	**Mean n=10**	**SD**
QUIS			
OVERALL REACTION TO THE SYSTEM			
1	terrible-wonderful	8.00	0.89
2	difficult-easy	8.17	0.75
3	frustrating-satisfying	8.33	0.82
4	inadequate power-adequate power	8.50	0.84
5	dull-stimulating	7.67	1.86
6	rigid-flexible	8.17	1.17
SCREEN			

7	Reading characters on the screen: hard-easy	7.50	1.52
8	Highlighting simplifies task: not at all-very much	8.17	1.17
9	Organization of the information: confusing-very clear	6.83	2.32
10	Sequence of screens: confusing-very clear	7.17	2.56
TERMINOLOGY AND SYSTEM INFORMATION			
11	Use of terms throughout system: inconsistent-consistent	8.17	0.75
12	Terminology related to task: never-always	8.83	0.41
13	Position of messages on screen: inconsistent-consistent	7.33	1.63
14	Prompts for input: confusing-clear	7.50	1.52
15	Computer informs about its progress: never-always	7.83	0.98
16	Error messages: unhelpful-helpful	7.67	0.52
LEARNING			
17	Learning to operate the system: difficult-easy	7.50	1.76
18	Exploring new features by trial and error: difficult-easy	7.67	1.21
19	Remembering names and use of commands: difficult-easy	8.67	0.82
20	Performing tasks is straightforward: never-always	8.33	0.82
21	Help messages on the screen: unhelpful-helpful	7.83	0.75
22	Supplemental reference materials: confusing-clear	7.67	1.37
SYSTEM CAPABILITIES			
23	System speed: too slow-fast enough	7.83	0.75
24	System reliability: unreliable-reliable	7.83	1.17
25	System tends to be: noisy-quiet	7.83	0.75
26	Correcting your mistakes: difficult-easy	7.50	2.26
27	Designed for all levels of users: never-always	8.50	0.84
PUEU			
USEFULNESS			
28	Using the system in my job would enable me to accomplish tasks more quickly: unlikely-likely	8.50	0.55
29	Using the system would improve my job performance: unlikely-likely	8.33	0.82
30	Using the system in my job would increase my productivity: unlikely-likely	8.00	1.10
31	Using the system would enhance my effectiveness on the job: unlikely-likely	8.33	0.52
32	Using the system would make it easier to do my job: unlikely-likely	8.33	0.82
33	I would find the system useful in my job: unlikely-likely	8.33	0.52
EASE OF USE			
34	Learning to operate the system would be easy for me: unlikely-likely	8.33	0.82
35	I would find it easy to get the system to do what I want it to do: unlikely-likely	8.50	0.55

36	My interaction with the system would be clear and understandable: unlikely-likely	8.33	0.52
37	I would find the system to be flexible to interact with: unlikely-likely	8.67	0.52
38	It would be easy for me to become skillful at using the system: unlikely-likely	8.33	0.52
39	I would find the system easy to use: unlikely-likely	8.83	0.41

The psychologists' overall reaction to the system was very positive. The usability by the psychologists showed that our system responded to their needs, was efficient in support of diagnose a patient and was easy to learn to use. Overall we can say that it was very much appreciated by the psychologists.

Moreover, there were some positive comments regarding the systems' functionality as: "innovative and flexible", "it is quite simple", "easy to use", "easily evaluation of specific patient's daily operations", "effortlessly monitor the patient's skill at real time" and "Clear and easy to follow". On the other hand there was one negative comment: "Choice of colours for messages and buttons could be problematic for someone with colour-blindness."

7.7 Thessaloniki @Home pilots general conclusions

As a general conclusion we can say that the Dem@Care system is able to provide all the necessary tools to the clinician in order to support efficiently the patients. Adapted and personalized interventions based on regular sensor-based monitoring, combined with automatically or manually generated reminders can lead to improved clinical status.

A pair sample t-test with the pre and post clinical assessment for all the participants revealed that there is significant improvement in RBMT ($p=0.050$) and in MoCA ($p=0.026$). It is very important to see improvement in the episodic memory in people with memory deficits because episodic memory makes up the category of declarative memory, one of the two major divisions of memory, which deteriorate in dementia over time. Regarding MoCA it is considered to be a more sensitive tool than MMSE in the diagnosis of MCI and as for people with mild and moderate dementia is thought to be a very difficult test. In our participants we saw improvement as well even though they were at mild stage of dementia. These results indicate that cognitive deficits can be eliminated after specific interventions applied.

Regarding the 3 MCI participants, after a 4 month protocol there has been great improvement in their cognition, memory, performance of activities of daily living, emotion and sleep. Based on Dem@Care system output, there was significant improvement in the duration and quality of sleep. Moreover, the system provided correlation between sleep improvements and other activities of daily living. The system also provided evidence regarding less TV usage. Finally, at the end of the intervention there was significant improvement in various tests and especially in Hamilton and MMSE. Especially, the Dem@Care system supported revealed abnormal activity of REM sleep which helped the clinicians to find out the early onset of PSP. More specifically the clinician identified through the outputs of the sleep sensor the absence of REM activity.

All of our participants were living alone. They have been examined neurologically and neuropsychological with specific measures in order to see the exact cognitive and emotional condition before and after the specific interventions. After the installation of the system and the specific interventions we discovered that our participants improved their cognitive functions,

activities of daily living and emotion. They became more aware about their personal issues and problems. We noticed improvement in their cognitive functions and sleep. These positive results are mainly based on the Dem@Care system for the following reasons: a) early detection of problems or issues that could not be identified through clinical assessment only, b) objective and regular measurements, c) successful personalized interventions based on the a and b and d) direct guidelines from the system and the clinician to the patient.

One of the most important aspects in our home pilots were the messages (prompts, reminders, guidelines) that the patient was able to see through a specific tablet user interface. Parts of these messages were automatically sent from the system based on fusion analysis of the sensors' data. These messages are based on 365/24/7 monitoring (something which is not feasible by the clinician). Moreover, messages from the clinician to the patient were used as reminders.e.g. specific messages such as the exact time and date of the appointment, clinical advice. Finally, the caregivers were able to monitor the progress, the issues or even the problems that the patient faces, and they did not rely completely to the clinician reports.

7.8 Mobile Health Solutions in @Home Environments

Mobile Health solutions have been explored in the context of @Home Thessaloniki pilots, in search for compact and easy-to-install deployments. Maintaining the same clinical value of Dem@Home, the mobile health platform HealthMon, addresses complementary issues such as high deployability, immediate feedback and a wider audience, of general-purpose health monitoring [66]. The HealthMon platform is, in other words, an exploitable asset emerging from @Home in Thessaloniki, which focuses in more recent, cloud-enabled sensor technologies.

Following the emergence of wearables with rich sensing capabilities in the market, we investigated various wearables suitable for our prototype. Currently, we selected just one affordable, retail sensor, MS Band[4], and repurposed it to general-purpose clinical monitoring scenarios, for any condition that may impair independence e.g. dementia, Parkinson's or ageing. Multiple sensor modalities, such as physical activity levels, posture and heart rate, are unanimously stored and interpreted to produce real-time alerts (using Semantic Web technologies). HealthMon's constant monitoring capabilities are available to end-users and informal carers e.g. family and medical doctors alike, through mobile and web applications. The framework focuses on adoptability and deployability, receiving positive user feedback, while further plans include the inclusion of more sensor modalities.

While HealthMon, as an exploitation effort is presented also in D9.12, this subsection presents its clinical usage, and user-acceptance trials carried so far.

[4] MS Band: https://www.microsoft.com/microsoft-band/en-us

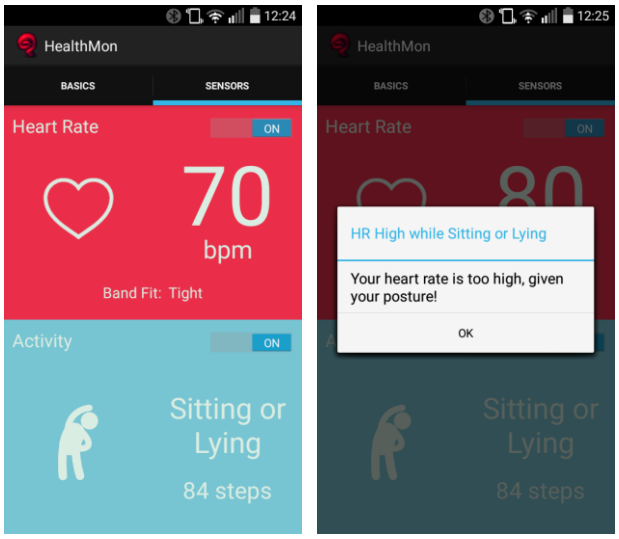


Figure 182. The HealthMon mobile application in Android, showing real-time HR measurements, the band's fit to the user's arm, posture and steps for the day (left), while contextualized alert notifications appear as pop-ups (right).

7.8.1 HealthMon Usage

The HealthMon framework is comprised of two counter-parts: the mobile and web applications, each serving its own purpose. The HealthMon Mobile application (implemented for the Android smartphone platform) directly connects to the wristband at all times and therefore remains with the end-user. The application continuously monitors for changes in sensor readings, processing them (to relieve some server processing load and taking advantage of the phone's capabilities) and immediately streams them online (over 3G or WiFi). Processing in HealthMon produces both fused modalities such as posture and contextualized alerts such as low HR given the posture or profile. As the application is designed to appeal to elder and young users alike, and the former can be intimidated by technology, the phone can remain hidden, attached to a charger as has been done in all four @Home pilots in Thessaloniki.

The user interface of HealthMon Mobile, as shown on Figure 182, visualizes all sensor measurements as seen on the left, refreshing the values immediately after they show up on the band itself (response time of under a second). Current HR is shown on the top, accompanied by a Tight or Loose indication, based on the band's contact sensor. This indication simply lets the user know of the measurement's credibility and prompts him to tighten the band. The lower part of the application shows posture detection and step count. Posture can be either Sitting or Lying, Walking or Running. The step count refers to total steps for the current day. Meanwhile, the user may set various preferences, which serve as rule thresholds for the analysis. When rules are triggered, a relevant notification with sound pops up on the user's phone as shown on the right segment of Figure 182, where HR is too high for the Sitting or Lying posture.

While the mobile application is only available to the end-user bearing the device, the end-user himself (e.g. when away from the phone), his carers, doctors, friends and family can still monitor data and receive alerts through the HealthMon web application (implemented in Java and JavaScript). The HealthMon web application is accessible from any device with web ac-

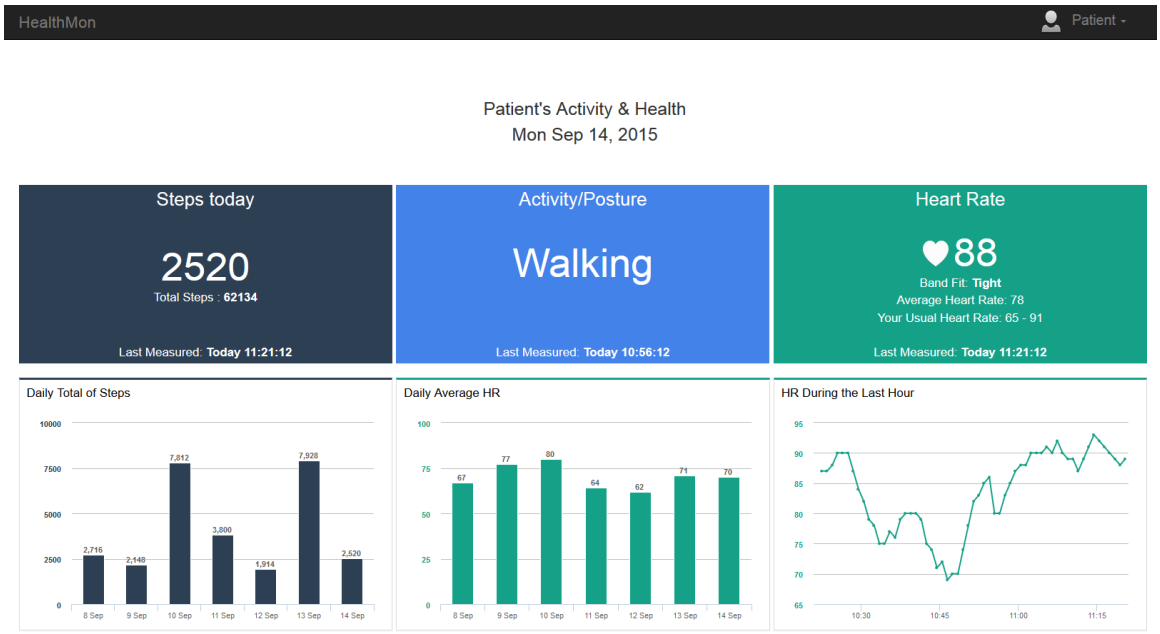


Figure 183. HealthMon's web application user interface, showing historical and real-time detection of posture, daily steps and current heart rate for the individual

cess and adapts to tablets, PCs and smartphones (via responsive design). Each user is provided with login credentials and associated with (currently) a single person to monitor.

After logging in, the application brings up the monitoring screen, shown on Figure 183. The three tiles on the top show real-time measurements as in the mobile counterpart: posture, step count for the current day, HR and band fit. However, here, they are accompanied by historic measurements (accumulated on the server). Apart from trend monitoring, these historic data also help build the user's profile. E.g. the user's usual HR and its range are estimated by the average value and its standard deviation. This range of usual HR is shown to the user and also causes the tile to turn red when the HR measurement is outside this range. The rest of the alerts are properly propagated from processing on the mobile side.

7.8.2 Deployment and Evaluation

The HealthMon application has already been deployed to home users of all ages for evaluation in Thessaloniki, Greece [66]. First, we performed a survey and evaluation of wearable devices, where we asked 31 users to evaluate retail wristwatches[5, 6] based on appearance, specifications and comfort, after performing a long walking task. The technical evaluation results are out of the scope of this deliverable, but the overall device acceptability outcome, which concerns clinical usage, is reflected on Figure 184. Specifically, it depicts the answers to the question: "Given all device characteristics and price, which one would you personally buy and use?". Evidently, MS Band ranks behind UP24, but since the latter does not offer all

[5] Jawbone UP24, UP3 - https://jawbone.com/up

[6] FitBit Charge HR, Zip - http://www.fitbit.com/

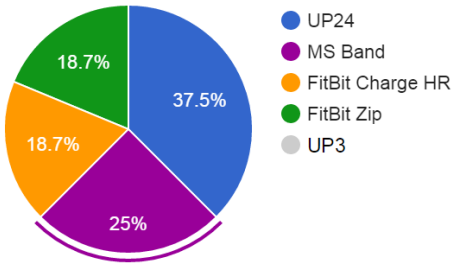


Figure 184. User evaluation for wristband adoption according to appearance, specifications and comfort

the required modalities (e.g. HR and posture) and rapid-feedback capabilities, the former was selected for deployment.

Five users were recruited for piloting, out of which two are the @Home Thessaloniki users of Pilot3 and Pilot4. The three young users are healthy and in their late twenties. Clinicians were able to objectively monitor the result of their interventions by means of the user interface as shown on Figure 183, where walks outside (above 5000 steps) are successfully completed on two days (10th and 12th September).

As for adoption beyond piloting, the totality of end-users (100%) accept to adopt the technology, responding to the question "Would you continue to use HealthMon in your daily life?".

7.8.3 Conclusions

The HealthMon platform, was found to be an affordable and easy-to-deploy mobile monitoring solution for reduced @Home piloting. HealthMon re-purposes sensor-rich wristbands in retail, to clinical, real-time monitoring of physical activity levels, posture detection and HR measurements. Interoperability and interpretation techniques enables instant notification alerts on critical situations. HealthMon currently supports bands used so far in @Home pilots (UP24 and MS Band). But the semantic infrastructure and interoperability provided by Dem@Home can be easily reused to extend to more bands, given the necessary device capabilities for instant feedback, or sleep monitoring. Especially the sleep monitoring extenstion would bridge the gap between HealthMon and Dem@Home, or else a commercial and an R & D platform, even more. The user evaluation of wristbands and HealthMon itself has shown high acceptability of the system and willingness to adopt. Another promising extension is the continued research on posture recognition from modalities offered by a wristband, as it could provide fall detection with rapid feedback, revolutionizing mobile healthcare.

8. Dem@Care and EEG analysis

In order a) to expand the validation of the Dem@Care @lab results and b) establish the basis for future research directions, an additional assessment of the Thessaloniki @Lab short protocol pilot participants took place. More specifically 50 participants (16 Healthy, 12 AD, 22 MCI) were examined by EEG in less than a week after their participation in the Dem@Care pilot. The main goal of this study was to identify any correlations between the participants' performance in the Dem@Care @Lab activities and the EEG results.

Electroencephalography event-related potentials (ERPs), particularly the P300 component, are able to monitor electrical brain activity. ERPs are free from cultural and educational influence and can provide inexpensive and non-invasive insights into the cognitive process. P300 latency is approximately 300ms recorded following a divergent stimulus, and stems from the temporoparietal brain region. The P300 ERP appears when a subject detects an incongruent, or target stimulus during a stimulus discrimination task. The auditory oddball paradigm is the most common task and generally requires the subject to attend to a target stimulus to produce a time-locked deflection associated with cognitive processing. P300 potential may be sensitive to AD, as AD subjects show increased P300 latency compared to healthy controls.

8.1 Data acquisition

HD-EEG data were recorded with High density EEG signals (256 channels) in an attempt to capture as much information as possible. EGI 300 Geodesic EEG system (GES 300) uses a 256-channel HydroCel Geodesic Sensor Net (HCGSN) and a sampling rate of 250 Hz (EGI Eugene, OR).

8.2 Two-tone oddball experiment (Audio ERP)

The two-tone oddball experiment was applied in the study. It was consisted of a quasi-random sequence of frequent standard tones (250 Hz, probability 0.8) and infrequent target tones of high frequency (4000 Hz, probability 0.2). All stimuli (150ms duration, 5ms rise/fall time and 75 dB SPL) were presented binaurally with an ISI of 2s. Each target tone was preceded by 2–7 standards (TTI varying from 4 to 14 s), with the total number of tones being 250. The subject was asked to identify the target tone by clicking the left button of the mouse with the right hand.

The auditory evoked potentials changes of brain electrical activity caused by auditory stimulus. Important factors for interpreting results are the wave amplitude, expressed in micro volts, and wave latency, expressed in milliseconds. The stimulus contains a chain of tones which must be over the examinee's hearing threshold. The P300 wave is a measurable direct reaction of the brain to a certain sensory, cognitive or mechanical stimulus and belongs to ERP (event related potentials). P300 wave is presumably of endogenous origin. Although the P300 wave is mostly referred to the cognitive processes, a certain part of wave components' variability depends on the state of an individual's excitement. The wave is registered on the head skin of the examinee, namely on 3 specific points set on the medial line. From the frontal to the occipital side these points are marked as: Fz, Cz, Pz. The two components that this wave consists of are the P3a which is connected to the brain activity during attention di-

recting time, and the P3b, connected to cognitive processes related with information processing.

8.3 Analysis and Results

In the following graph, the differences between healthy and MCI group regarding P300 amplitude, which is higher in healthy participants than MCI, are presented.

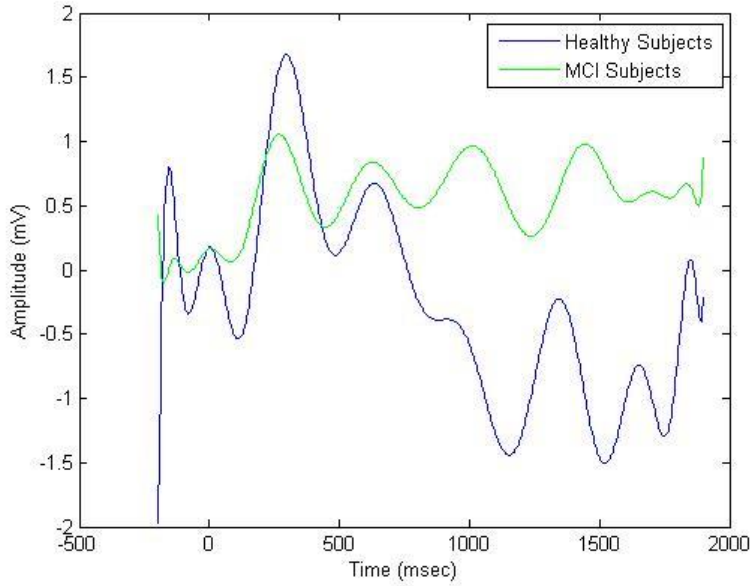


Figure 185. N220, Latency N200, P300 and latency of P300 between Healthy and MCI

A Pearson correlation analysis was conducted, between the EEG results and the successful attempts of the participants in the short protocol activities. The results are presented in the following table.

Table 61. Correlation between the @Lab participants' performace and the EEG results

	N200			LatencyN200			P300			LatencyP300		
	Pearson Correlation	Sig. 2-tailed	N	Pearson Correlation	Sig. 2-tailed	N	Pearson Correlation	Sig. 2-tailed	N	Pearson Correlation	Sig. 2-tailed	N
Total Suc. Attempts	.031	.834	48	**.286***	.049	48	.006	.967	48	-.021	.888	48
AnswerPhone Suc. Attemps	-.042	.778	48	**.322***	.026	48	.044	.768	48	.041	.782	48

BankApp BankAmount Suc. At-tempts	**.393****	.006	48	-.104	.484	48	**.355***	.013	48	**-.342***	.017	48

Components of auditory ERPs (N200 and P300) are considered to reflect sensory processing and cognitive processes and they can be useful in monitoring of electrophysiological functioning related to cognitive impairment.

N200 is generated in frontal-central cortical areas and it is thought to reflect processes of selective stimulus evaluation and conscious discrimination. P300 wave is generated in various regions of the brain, mostly temporal and parietal cortices. It is associated with cognitive processes such as attention, recognition and categorization of the stimuli, working memory, and decision making

After statistical analysis we found that there are statistical significant correlations between activities in Lab and specific ERP components N200, Latency N200, P300 and latency of P300

Information regarding the dynamics of N200 during the course of AD and especially the effect of activities performance on a sensor-based system on N200 characteristics are very few. It is usually assumed that changes of N200 are similar to the changes of P300.

- Total successful attempts are highly positive correlated with latency of N200. This indicates that people with slow processing as shown in brain signal couldn't complete and perform successfully the activities in Lab.
- Latency of N200 is also correlated with phone task successful attempts. This indicates that people who cannot accomplish activities which involve executive functions have slow processing and longer period before activation.
- There is strong evidence that the N200 latency subcomponent has the potential to be a reliable neurophysiological biomarker of the cognitive deterioration present in MCI progression, and preclinical AD. This is very useful if we take into account that in correlation with specific tasks in Lab indicate that worse performance is associated with slow cognitive processing
- The significant correlation between N200 and P300 and @Lab task of Bank Amount shows that the P300 ERP components are associated with the processes of information encoding and memory formation. Decrease of P300 latency observed in negative correlation with bank account task which indicates that elapsed time before activation is slower and this affects performance in complex tasks which involve executive functions.

This is one of the first studies which tries to correlate behavioural activity (objectively measured by sensors) and high-density EEG-based brain activity, providing correlations between task performance during a lab protocol and specific EEG brain signals. The statistical analysis revealed the correlation between specific tasks of the protocol (which are two of the most complex and difficult for the participants) and ERP components (P300 and N200). In future

research, we are planning to involve more participants in the EEG analysis. We expect this study to lead the way towards exploring the correlations between multiple and various assessments. More specifically, we plan to investigate correlations between the following inputs:

- Typical clinical assessment (MRI, blood test, questionnaires, etc)
- EEG-based clinician assessment (EEG recordings assessed by the clinician)
- Sensor-based protocol (automatic analysis based on sensor output – Dem@Care @Lab protocols)
- EEG-based automatic assessment (Automatic analysis of EEG signal)

9. Conclusions

The overall conclusion of the final evaluation of the Dem@Care system is that it has a potential to contribute to an added value for both clinicians in their clinical work, and for people with dementia and their informal caregivers in managing their daily lives. The system has with its design proved to work in so varied clinical contexts as a clinical lab for assessing cognitive functions of people with dementia, a context of clinical assessments in nursing homes for people with severe dementia suffering from BPSD, and in clinical assessment and support of people with mild dementia still living in their private homes. Several of the tested approaches of using multi-sensing technology in the three different contexts are innovative. The @Lab tests were among the first that tried to demonstrate the use of ICT-based tools for the purpose of clinical assessment of potential dementia patients. The use of sensors for monitoring behavioural and psychological patterns in people with BPSD in nursing homes, has to our knowledge never been described before.

Even though the evaluation indicates positive results in all the three tested operational contexts, there are also many indications that the system needs further technical development before it is ready for clinical use and the commercial market. These refer to the system's technical robustness, analysis of sensor data into relevant clinical information, and ease of use in clinical or care settings, and in the home. While there is more to be done, in the fourth Thessaloniki home pilot, which took into account all identified limitations from previous cases, most of these issues have been addressed. There is also a need for further testing and evaluation in studies that can provide robust results in all three tested operational contexts, which is already prepared for @Nursing homes. The challenges within clinical and care support of people with dementia that the system addresses in the three tested contexts all have large societal impacts. This include the challenge of a making a timely, early and accurate diagnosis of dementia, the challenge of supporting people with dementia and the informal carer in the private home with a community based care approach, and the challenge of improving care for people with dementia suffering from BPSD in institutional care.

9.1 @Lab

The test of the Dem@Care system in the @Lab context is the most extensive evaluation conducted in the project, involving a large cohort of participants in both Nice and Thessaloniki. The evaluation process has been conducted in the controlled environment of a clinical lab where controlled assessment procedures could be well-maintained, which contributes to the possibility of generalising the evaluation results. It addresses the need for improving existing diagnostic procedures of dementia and related disorders by using innovative and novel solutions for providing additional objective information for the assessment within specific assessment domains (behaviour, cognition, activities of daily living). This information can together with other clinical and biological data contribute to earlier and more accurate diagnosis procedures of AD and related disorders. Early and timely diagnosis of dementia is a very important aspect of improving the situation for people with dementia in early stages of the disease by introducing as early as possible proper medical treatment and personalised support aimed at improving the ability to manage everyday life.

Introducing new tools that are able to detect fine and subtle changes in behavioural, cognitive and functional patterns, may allow earlier diagnosis, even at the point when memory

functions are still intact. This could lead to earlier, and thus potentially more effective prevention and treatment of AD and other dementia variants. In this sense, the aim of this evaluation was to investigate the possibility of using technologies for assessment purposes. The results of the continuous evaluation led to the introduction of the Dem@Care system for outcome measurements within clinical trials in AD and related disorders.

ICTs can indeed provide useful information for assessing specific domains of AD patient's life, and hence address the current need to use innovative measures that demonstrate clinically meaningful cognitive, behavioural and functional outcomes. In addition, it is proposed to consider the use of ICT in the design of clinical trials.

It is important to underline, that no single composite measurement alone can cover the entire spectrum of AD, from early to late stages. However, in combination with already existing clinical assessments and biomarkers, ICT can provide additional diagnostic relevant information that is captured in a more reliable and objective manner, and therefore completes the evaluation of a patient's cognitive and functional status.

In order to integrate ICT measurements into large clinical cohort trials, some research still has to be done, namely the validation of the use of such technologies in larger cohorts to demonstrate clinical meaningfulness and thus, receive recognition in the clinical scientific and medical world. This could eventually lead to a change of the attitudes of general practitioners and research investigators towards more willingness for using ICT in routine assessment procedures. The 'de-mystification' of ICT usage by showing that it is actually easy and simple to use, could facilitate its gradual integration in normal clinical work practice and increase the acceptability among clinicians.

9.2 The @Nursing home

The evaluation of the tests performed in the @Nursing home context, with the Dem@Care system with the selected sensors, indicates that it has the potential to contribute to facilitate the process of assessing more precisely the situation of the person suffering from BPSD and for post-evaluating care interventions. This is a novel and innovative way of using multi-sensor technology that to our knowledge has never been tested and described before. Qualitative indicators from assessing the staff member's clinical reasoning reveal that staff members appreciate the added value of the sensor data and that it helps them in their assessment and evaluation process. The added value refers both to specific information on the patterns of stress/anxiety and to pattern of sleep. As a consequence, the staff is able to suggest better targeted care interventions that with the contribution of the system can be evaluated later on, and that result in reducing the level of BPSD as well as the duration of the problems. These results should be viewed from the perspective that care of people with BPSD is one of the major challenges in the institutional care of people with severe dementia.

The small number of people with BPSD (four in the intervention and four in the control group), that so far has been involved in the assessment of the effectiveness of the system , does not allow us to make robust conclusions and to generalise them to institutional care of people with dementia in general. More evaluation studies are therefore needed, and in fact a bilateral agreement between LTU and CERTH is on its way towards this objective of validating Dem@Care for use at nursing homes. However, the results so far from the evaluation indicate an important way forward, for how multi-sensor technology can be used in improving the situation for people with severe dementia that address a major challenge in dementia care.

9.3 @Home

8.3.1 General conclusions

Deficits and changes in everyday functioning are considered precursors to more serious cognitive problems for PwD. The evaluation of the Dem@Care system in private homes indicates that it can enhance the provision of dementia care as it provides an ecosystem of connected devices, systems and services that provide a comprehensive view of the PwD's lifestyle, behavioural patterns and daily activities. The Dem@Care toolbox approach allows different combinations of sensors to be selected based on the clinical needs of the person. The Dem@Care system then identifies potentially problematic areas across five domains (sleep, physical activity, ADLs, mood, and social interaction) using individualised problem-detection parameters, and examines these patterns to identify improvement, stasis, and deterioration over time. One of the great strengths of the Dem@Care system is its ability to provide objective data for functional domains where accurate introspection is otherwise extremely difficult, even for people with no cognitive impairment. Dem@Care provides people with dementia and their families with relevant information about their health, including health education and lifestyle management material. They in turn become more knowledgeable and aware of their health condition, and better equipped to safely assume responsibility for their own self-care. Dem@Care provides clinicians with objective data that can be combined with patient reports and collateral from informal caregivers to improve their understanding of everyday life for the PwD, to gain new insights into difficulties that affect quality of life, and to better assist individuals in completing daily activities and maintaining independence.

The flexibility of the visualisations provided by Dem@Care is another key strength of the system, although simplified views for all end users, especially PwD and carers, is recommended. Improvements are also needed with regards to sensor integration, fusion of data from different sensors, and presentation of key clinical indicators in clear, accurate, and easily understandable reports. Ease of use will be especially important to the deployment of Dem@Care in a person's home, if the use of the sensors and interfaces are to become commonplace, particularly with those who have limited previous experience with technology. Ease of use is also vital to the deployment of Dem@Care in clinical practice as the use of multi-sensor technologies is not as yet fully accepted, nor is it common practice. It is anticipated that more and larger evaluation studies are needed to obtain evidence of the ease of use and effectiveness of the system in order to convince clinicians in caregiving settings to invest in a complex technical system such as Dem@Care.

8.3.2 Guidelines for future use of Dem@Home

This section presents guidelines for the deployment and use of the Dem@Care system in the home environment. Suggestions for future development have also been made.

Sensor deployment

Careful consideration is needed to determine the suitability of sensor deployment for each individual. The following questions should be considered:

1. What are PwD's needs/everyday problems?
2. Does the PwD acknowledge problems/ are they motivated to address them?
3. Can sensors provide a potential solution?

4. If so, is this the best solution?
   - What is the PwD's attitude toward technology?
   - Will a technology-based solution be acceptable/ meaningful to them?
   - Will a technology-based solution play to the person's strengths?
   - Is there a non-technical solution which may be better suited to the PwD?
   - What is the cognitive status of the person?
   - Can sufficient learning support be provided to the PwD?
   - Will the sensor place excessive demands/learning requirements on the PwD?
   - Does the PwD have a relative or carer who can support their use of the sensor?
   - What is the benefit of the sensor to the person?
   - What information will the sensor provide?
   - Is this information useful to the researcher/therapist in the context of their work with the PwD?
   - Is this information greater than that which can be provided by the PwD/carer
   - Is this benefit sufficient to justify deployment of the sensor?

Once sensors have been deployed, consideration of their suitability should be an ongoing process. The researcher/therapist should continue to ask the above questions as they work with the PwD – this is particularly important due to the progressive nature of the condition and the changing cognitive status of the person. Task-specific/rolling consent is also recommended.

General issues

- Problem identification rules must be specific to each person. Too much heterogeneity exists in this population to rely on standard rules (e.g. for sleep duration, sleep interruptions, physical activity, etc.).
- An initial data analysis period is also required in order to establish baseline measures for DTI-2 calibration for the individual, for semantic processing, and for personalised problem identification. Expect higher levels of clinical and technical support at this time.
- Feedback must be simple, clear, and relevant. Too much data or clinically worded feedback is likely to cause confusion.
- Long-term adherence requires the system to provide useful and 'fresh' guidance to end users. The value of system driven feedback will diminish if the same one or two messages (e.g. regarding the importance of sleep) are received all of the time.
- Declining patterns of behaviour may cause anxiety for the PwD and/or their family caregivers. Care is needed to monitor the impact of this data on the recipients, and automatic provision of sensor feedback should not happen in isolation of face-to-face contact with a clinician.
- Initial training periods are required to enable the end users to become comfortable with using the sensors and the Dem@Care system. Expect higher levels of clinical and technical support at this time.
- Paper-based manuals and sensor guides are required. Where possible include images that describe sensor functions and how to operate them, in addition to text instructions.

Automatic connected sensors are preferred over sensors that require a cable connection for transferring data.

- End users will encounter problems with sensors and these devices will fail from time to time, so a plan is needed in advance of deployment to deal with these issues. It is likely that face-to-face clinical and/or technical support will be needed at these times.
- End user data, especially video data, requires large amounts of storage. Consideration is needed in terms of how much data can reasonably be supported over time.
- Even though Dem@Care provides a wealth of objective sensor data, subjective assessments are still required as these can capture different aspects of health-related information that can be equally valid. In addition, quality of life is a perceived measure and is more often influenced by a person's perceptions of their wellbeing (e.g. perceived sleep quality or perceived stress) than equivalent objective measures.
- It is likely that a point will be reached where the PwD is no longer interested or able to use the Dem@Care system. Plan an effective 'exit' strategy with the end-users from the beginning. This should include the gradual removal of sensors, services and devices, as needed. Consideration also needs to be given to what happens to the historical data at the point when the Dem@Care system is not used anymore.
- Exit strategies are also needed for time-constrained interventions/research projects e.g. linking in with other services.
- Careful ethical considerations are required when working with PwD with significant cognitive impairment.
- Researchers/therapists should be mindful of the importance of the relationship between themselves and the PwD; wanting company/someone to talk to is likely to be a factor influencing the person's motivation to take part in the research.

Potential future improvements

A number of potential areas for improvement were identified from the evaluations of the final Dem@Care system. The main recommendations were:

- Retrospective data analysis for the clinician as patterns or points of change can be identified but the participants find it difficult to remember life events that coincided with these times. A facility to enable PwD and/or carers to add notes about their day to a diary could be very beneficial in helping everyone to evaluate the sensor output. The importance of context in understanding anomalies or points of behaviour change has been identified in previous research. This reporting should not be mandatory or required each day; instead it should enable key events to be noted.
- The current carer interface is similar to the clinician's interface and this contains both too much and too detailed information for family carers.
- While there are considerable improvements in the final version of the system, long-term trends in Dem@Care can be impacted by missing data. It is likely that all end users will have periods of time where data was not collected or potentially lost (e.g. if

sensor issues are encountered). Statistical analysis should be improved to reduce the impact of missing data.

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