'Visualize my data!'

Translating Smart Home sensor data into relevant feedback for elderly, informal caregivers and formal caregivers

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Abstract

Background: As older people are intended to live at home for as long as possible, the use of Smart Home technologies become increasingly important, for example monitoring the elderly on a distance. The sensor data generated by Smart sensors can be translated into relevant information for elderly themselves, their formal caregivers and their informal caregivers, but it is relatively unexplored how to convert this sensor data into knowledge and how to provide feedback to its users.
Objective: The objective of this study is to identify the needs and wishes of formal caregivers, informal caregivers and elderly about the relevance and visualization of Smart Home sensor information for a Personal Health Record (PHR) and the Electronic Patient Record (EPR) and for providing persuasive messages and assistance for elderly.
Methods: For this study, the CeHRes Roadmap is applied and the formative research phases of contextual inquiry, value specification and (pre)design were performed. Semi-structured interviews with elderly and informal caregivers and a focus group with formal caregivers were conducted.
Results: The results showed that caregivers and elderly overall had a positive attitude towards home monitoring. Main results show that a health summary visualized in a status display that allowed the elderly and caregivers to obtain more in-depth information is preferred and also the use of persuasive messages and assistance for elderly can be valuable. The possibility to set personal preferences regarding the user interface was found important.
Conclusions: In conclusion, this study provides a basis for the further analysis of sensor data gathered from Smart Homes technologies and the development of a PHR and the content of the EPR. It also gives recommendations about providing persuasive messages and assistance to elderly. This study can contribute to the question how to convert Smart Home sensor data into knowledge, information and persuasive feedback and how to visualize relevant information in a meaningful, holistic, understandable, usable but concise manner that concentrates on regular living aspects by using a human-centered approach.

Keywords
Smart Home; logdata; data analysis; visualizations; persuasive features; elderly; caregivers; Personal Health Record (PHR); Electronic Patient Record (EPR); feedback.

Introduction

The number of elderly in our society is growing [1]. People have longer life expectancies and many elderly deal with multi-morbidity, which means they need more and complex care. All this will lead to higher costs in healthcare and a high pressure is therefore put on elderly care. It is important to improve self-management and facilitate elderly with supporting tools to live independently for as long as possible.

Informal caregivers play an important role in this development. Ambient assisted living (AAL) systems can be used to monitor health and behavior of the elderly living at home and assist caregivers by providing high quality data about their family members [1, 2]. There is a great need for such Smart Home environments and Smart Home technologies are being implemented all over the world [3].

There are several definitions to define Smart Homes. The definition of Demiris and Hensel [3] is used in this study: "*A residence equipped with technology that facilitates monitoring of residents and/or promotes independence and increases residents' quality of life*" (p. 33) . The technologies within the Smart Homes are integrated into the home and should be unobtrusive for a better acceptance of the elderly [3, 4]. The Smart Home puts all the pieces of assistive devices together with the aim to help elderly to extend the time they are living independently within their own home environment, to monitor their health status and to early detect health problems or dangerous situations with the use of technical support [3, 5, 6].

The many devices in the Smart Home produce a big amount of sensor data and therefore need to be filtered and stored in databases, so it can be used for analysis [4, 5]. As everyday behavior of elderly is closely related to their health status, it can be important to detect deviations in the routine habits of the elderly and to receive automatically alarms when data exceed the threshold of the fixed device to prevent life threatening complications [2, 5, 7]. Analyzing sensor data can give insight and information about for example the recognition of activities and behavior like routines, patterns, habits, lifestyle prediction, social interaction monitoring and also security and surveillance [5].

The sensor data can be translated into meaningful health information displayed in Personal Health Records (PHRs) for informal caregivers and elderly or Electronic Patient Records (EPRs) for formal caregivers, to provide the users with real-time feedback. It can also be used to tailor persuasive text messages and for remote assistance to motivate elderly towards healthy behavior [6, 7, 8]. According to van Gemert-Pijnen et al., [1] the EPR is a computer-based clinical data system designed to replace paper-based patient records and includes a complete record of all health-related information of a person. The Personal Health Record is defined by Tang et al. [39] as: '*an electronic application through which individuals can access, manage and share their health information, and that of others for whom they are authorized, in a private, secure, and confidential environment'* (p. 122). Caregivers are able to take proactive actions to ensure the wellbeing of the elderly after analyzing their health information [2, 5].

However, it is relatively unexplored how to convert this sensor data into knowledge and how to visualize the relevant information for the caregivers and elderly [2, 6]. Many Smart Home projects focus on technological possibilities and do not provide understandable visual displays of information that are customized for elderly users and caregivers [8]. Current research indicates that there is need for a greater characterization of the health information needs of elderly, informal caregivers and formal caregivers, to reflect all stakeholder requirements for visual displays and EPRs/PHRs that integrate sensor data from AAL systems [10, 11]. It is therefore important to involve them in the process.

This study presents the needs of elderly, informal caregivers and formal caregivers about the relevance of Smart Home sensor information for activities of daily living and safety aspects and their preferences for receiving and the visualization of this sensor information. Recommendations for providing persuasive messages and assistance for elderly and the content of the PHR and EPR are given, with the aim to provide the sensor information in a meaningful, simple, holistic yet concise manner that clearly communicates the wellbeing and health of elderly.

Related work

Smart Home technology and effects

In the recent years, there are several Smart Homes developed and also many Smart Home research is carried out all over the world [3]. Demiris & Hensel [3] conducted a systematic review of Smart Home projects and their evaluation all over the world and they identified 114 publications for 21 projects. Results show that current research is mainly focused on technologies for functional monitoring (activity levels, motion, ADL, emergency detection), followed by safety monitoring (environmental hazards, safety assistance, location technology) and physiological monitoring (measurements of vital signs, blood sugar level, bladder output). Current research is less focused on monitoring social interaction (video-mediated communication) and the target group was most of the time frail elderly and elderly with cognitive disabilities.

Only a small number of studies investigated the effectiveness of these Smart Homes [11]. Most research describe the preliminary evaluation of technologies, the user-friendliness and the preferences for certain technologies and acceptance of devices, but none of the studies found by Demiris & Hensel showed the effect of Smart Homes on health outcomes like injury or illness detection or prevention of nursing home placement [3, 12]. Smart Home technologies might have a positive effect on quality of life of elderly by improvements in safety, security and independence, but this is not formally addressed in the studies. Only one randomized controlled trial from Tomita et al. [12] showed significant results in maintaining the functional status and cognition by using Smart Home technology. The results of other studies do show that the Smart Home technologies can accurately detect abnormal movement and behavior and are able to control various electronic devices [11].

Demiris & Hensel [3] concluded that the field is in relatively early stages and therefore there is lack of an extensive body of evidence. So although the advancement of sensor technology has proven to be cost-

effective, easy to install and less intrusive to meet the preferences of elderly and respond intelligently in an unobtrusive manner, longitudinal studies and large randomized and controlled studies focused on this subject are needed to assess the effectiveness of Smart Home technologies or clinical outcomes [3, 5, 8].

Health monitoring

As already mentioned in the previous sections, Smart Home technologies can be used for several purposes. Health monitoring systems are able to automatically monitor and report the elderly's health and their daily life patterns [13]. These systems use embedded sensors and/or wearable sensors to provide information. According to Suryadevara et al., [4] an important task in the analysis of the data is to learn, recognize and understand the daily activity patterns from a large data set. Within the data analysis it has to become clear what normal behavior and patterns are so that any irregular behavioral changes or dangerous situations can be detected and can give a warning alarm. It can also predict future behavior. Alemdar et al. [2] mention that the everyday behavior of elderly is closely related to their health status and can be deduced by examining the activities of daily living in terms of start time, duration and frequency. Activity-based lifestyle monitoring with for example infrared motion sensors can collect user's movement and average time spent in each room and can give insight into the circadian activity rhythm of elderly [13]. More or less activity than usual or a mismatch of the sequence of activities can for example be correlated with irregularities of the activity patterns of elderly. Some of the changes are short term, like changes in the last few days [2]. For example, very frequent usage of the toilet may indicate that the elder has an urinary infection. Others are long term and concern several months or years. Preparation meals that takes more time or reading the newspaper that takes less time can for example indicate a mild cognitive impairment or dementia.

Health monitoring systems can also contribute to the prediction of lifestyle disease [13]. For example; frequent drinking, eating, sleeping, toileting and a lower weight can be related to the development of (pre)diabetes. Therefore, an important element in the success of a well-being monitoring system largely depends on the understanding of the normal lifestyle and the deviation from that norm in terms of behavior [4].

Visualizations for PHRs and persuasive technology

Sensor data generated in Smart Homes can be translated and used to provide feedback for the elderly themselves or their caregivers [14]. The feedback can be provided by displaying the health related sensor information on electronically devices (e.g. PHR, EPR), but context-aware computer systems can also infer the elder's activity and be used to provide elderly with health related persuasive messages to motivate behavior change or to provide them with remote assistance[16, 17].

Persuasive technologies are technologies that support users in changing their attitude or behavior to increase their wellbeing [16]. Limited research has yet been conducted on which persuasive technologies has been applied for elderly and which persuasive features were preferred [18, 19]. Most research available about persuasive technologies and elderly is focused on stimulating physical activities [17]. Preliminary findings suggest that persuasive technology for elderly is promising. For example, the results of Albaina et al. [18] and Consolvo et al. [19] indicate that glanceable representations of information on mobile displays or virtual coaches can motivate elderly to exercise more. A virtual coach was not seen as critical for motivating people to exercise more, the display of information alone or text messages could also suffice if they were specific, personalized and catchy. Previous research also showed that spoken language was the most preferred interaction modality for elderly unfamiliar with technology [20].

There are several already existing Smart Home platforms for displaying relevant sensor information that include visual elements through text-based, colored tables and charts [9]. Most of them are focused on formal caregivers and some on informal caregivers and they are mainly focused on displaying motion activity. CASAS and Tunstall's ADLife are examples of platforms for caregivers that provide information on more aspects like for example the resident's sleep, activity, social life and nutrition [10, 16]. These platforms are generally well received but there is still a need to design applications that display Smart Home data in a meaningful, holistic, yet concise manner especially for elder users. Gil et al. [22] suggested that the focus of visual representations should therefore concentrate more on living aspects that are regular like sleeping, eating etc. that have a relationship with wellbeing.

Many research is focused on the appropriate design of visuals displays [10]. The elderly's ability to perceive, understand and remember the information contained within the data is affected by how the data is presented [23]. Reeder et al. [10] describe that for the visualization of relevant data for elderly, bar charts and the use of

time series plots for large data sets are the most common visual display. Elderly are more likely to be someone who is not familiar with ICT or computers and this it is a major complication factor in the successful provision of visualizing data and information. It is therefore important to reduce the large amount of sensor data that is visualized. Also the use of date labels for the displayed data, consistent backgrounds and labels are recommended to reduce the cognitive load during the interpretation of visual displays. It is also preferred to present a simple clean display instead of something cluttered [24]. For elderly it is important to display the information as simple as possible and avoid three-dimensional displays as they could have problems to correctly interpret the intended meaning of the display. The use of visual metaphors can also contribute to the comprehensibility, acceptability and learning time of new products as it requires minimal cognitive processing by the users [10, 24].

Also informal caregivers need simple displays of data that will not take them days to learn [21]. Formal caregivers are most of the time more interested in the trends across time while informal caregivers preferred current data on a day-to-day basis to see how their elder is doing at that moment [26]. When the health of elderly is declining, formal caregivers could analyze the visual displays to identify the sources of the decline and it could also be used for the evaluation.

So although there is many literature about the appropriate design of visual displays, there is limited literature about how sensor data can be translated into useful, understandable and meaningful information for their users [6, 11]. It is therefore important to explore the best approach for visualization of the data by asking the elderly and their caregivers about their information needs and expectations and about which visual tools can convey the information the best to their opinion [6].

Perceptions of elderly and caregivers about Smart Home technology

There are a few studies that investigated the perceptions and experiences of elderly and informal/formal caregivers with Smart Home technologies, but these few studies do show that Smart Home technologies were generally accepted and thought to be helpful and useful [7, 8, 9]. Detecting emergencies is hereby seen as more important than monitoring to detect trends or predict issues or concerns [8].

Portet et al. [32] mention that security is pointed out as the main need of elderly within Smart Homes. The most important in this is the fear elderly have to fall. Also cooking hob and oven safety control, sleeping patterns monitoring, activity monitoring, emergency alarm and automatic lightning systems were perceived as useful [9, 13]. Elderly also felt that smart-technologies could help to improve their independence [11].

Also formal and informal caregivers considered Smart Home technologies to be beneficial [8, 11]. Informal caregivers' main needs were to have information about their elder's nutrition, fall incidents, medication compliance, sleeping quality, safety, social contacts and location in the house [21]. For the formal caregivers especially the nutrition, fall incidents, medication compliance and sleep quality of the elderly were important aspects.

Focused on social aspects, video calling, where voice and video are combined, seems to be engaging and enjoyable for elderly and their informal caregivers [36]. It may encourage people to remain actively engaged and to participate in their normal lives with friends and family. Also the use of socially assistive robots is in ongoing development [37]. First results show that there seems to be a potential for the use of robot systems in elderly care for functional and affective reasons, but additional research is required to experimentally investigate the effects of these robots.

Next to the advantages, elderly also perceived violation of privacy when using these technologies [35]. Especially video monitoring, activity monitoring and sleeping pattern monitoring were most related with privacy concerns. Also confusion about technologies, user-friendliness of technologies, the need of training for new technologies, false alarms and reliability of the system were issues where elderly were concerned about.
However, it is believed that elderly will show less resistance and more appreciation when they get more experienced with the Smart Home devices.

So although there are studies that investigated the perceptions and experiences of elderly and caregivers with Smart Home technology, there is still need for research that identifies goals, needs and preferences regarding the use of Smart Home sensor data for these groups [10].

Objective and research questions

The objective of this study is to identify the needs and wishes of formal caregivers, informal caregivers and elderly about the relevance and visualization of Smart Home sensor information for a PHR and the EPR and for providing persuasive messages and assistance to elderly.

This study aims to investigate the following research question:
How can sensor data from the Smart Home technologies be translated into relevant and useful information with respect to the user needs (elderly and caregivers) and what recommendations can be given based on the results?

Methods

In order to achieve the goals of the study, a qualitative research approach is applied.

CeHRes Roadmap

For this study, the CeHRes Roadmap is applied (Figure 1). This roadmap is a tool to explore and test how an eHealth technology can be perfectly suited to the users and to explore how an eHealth technology can be successfully implemented in practice[1]. It can therefore be used to plan, coordinate and execute the participatory development process of eHealth. The aim of the CeHRes Roadmap therefore fits the objective of this study to actively involve users in the process for the development of a new product.

The roadmap consists of five different phases and connecting cycles of activities and refers to the participation of the stakeholders during the process of development [1]. The first step is the contextual inquiry. The objective of the first component in the roadmap is identifying and describing the stakeholders' needs and problems and also investigate how technology can contribute to minimizing problems. The next component is the value specification which provides information about the added values the key-stakeholders attribute to the eHealth intervention. In the third component, design, the outcomes of the value specification and contextual inquiry are translated into functional requirements and persuasive features for the prototypes that are evaluated by the stakeholders before the final design is made. Within the operationalization component, a final business model for the implementation of the eHealth intervention will be made by the project team. In the last component, the summative evaluation, the effects of the new technology are measured during the summative evaluation. After the last phase, redesign can be necessary that makes the evaluation a continuous process.

Within this study, the formative research phases of contextual inquiry, value specification and (pre-)design were performed. The needs and wishes of elderly and caregivers are identified and translated into requirements for further development. Simple mock-ups of visualizations of relevant information were shown and adjusted according to the feedback received, which indicates the (pre-)design phase.

The CeHRes Roadmap combines the human-centered design with a business modeling focus [27]. A human-centered approach in this study is used to guarantee that the end users are involved in the design and implementation process to promote better accessibility, usability, understandability and more efficient development. A business modeling focus is needed to create an optimal fit between the technologies, the health organizational procedures and organizational resources.

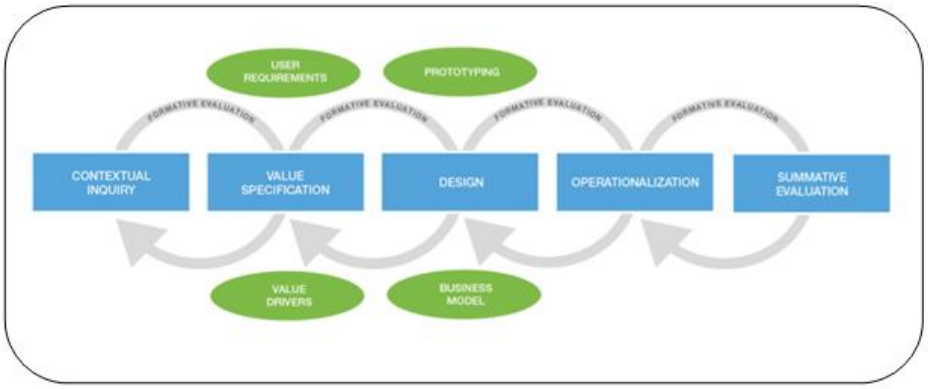

Figure 1: CeHRes Roadmap

Persuasive System Design model

The Persuasive System Design (PSD) model by Oinas-Kukkonen and Harjumaa [31], a framework for designing and evaluating persuasive systems, is also applied. For this study it is specifically used to identify the needs and wishes of elderly for a persuasive system that provides persuasive text messages and remote personal assistance.

Study setting

For this study, a Smart Home in a nursing home located in Hengelo, the Netherlands, is used to collect sensor data.

Figure 2: Smart Home in Hengelo

Table 1: Relevant Smart Home sensors and generated data categorized by Demiris & Hensel [3]

Domain	Device	Generated data
Physiological monitoring	Smart blood pressure monitor	Diastolic and systolic blood pressure values
	Smart weighing scale	Weight values
Functional monitoring and emergency detection and response	Infra-red sensors (in every room) [1]	- Motion - Entering predefined areas (location in the Smart Home) - Frequency and location fall incidents - Sleeping patterns
	Pressure and incontinence sensors in the bed, toilet and chairs	Detecting presence in bed/toilet/chair and frequency incontinence in bed/chair
	Click sensors in the kitchen cabinets and automated electric stove	Frequency opening kitchen cabinets and use electric stove
	Obli (registers fluid intake) [2]	Fluid intake
	Home trainer [3]	- Frequency use home trainer - Number calories burned, distance, speed, distance, heart rate
Safety monitoring and assistance	Smart watch with GPS, pedometer and alarm function [4]	- Location of the user outside the Smart Home - Walking steps, distance, calories burned - Time, date, location alarm button pressed
Social interaction monitoring and assistance	Palm scanner at the front door (gives entrance to the Smart Home when a hand palm is recognized) [5]	Registration who entered the Smart Home on specific time/date
	Video communication with family, friends and caregivers	Frequency video communication
Cognitive and sensory assistance	Medido (automatic medicine dispenser that gives a sound signal when medicines need to be taken) [6]	- Medicines taken - Frequency medication forgotten

[1] http://www.eaglevision.nl/
[2] http://www.obli.info/
[3] http://www.fujitsu.com/nl/
[4] http://www.mobiletrack.nl/
[5] http://www.fujitsu.com/nl/
[6] http://www.medical.philips.com/

The Smart Home will be inhabited by several elderly and is used as a test environment. The sensors and technologies installed were focused on several aspects or domains defined by Demiris & Hensel [3]. Only sensors that generate meaningful data for this study are mentioned in Table 1. Included are sensors that generate data about health aspects, activities of daily living, safety, lifestyle and motion detecting.

Figure 3: Smart Home sensors: infrared sensors (1), Obli; registers fluid intake (2), home trainer (3), Smart watch (4), palm scanner (5), Medido; automatic medicine dispenser (6)

Participants

It is important to determine the end user population at the start of the process to know which characteristics and wishes should be taken into account for a successful implementation of technologies [27]. The end users are people who use the technology directly or indirectly, in this study the elderly, formal caregivers and informal caregivers.

Five community-dwelling elderly (65+) and five informal caregivers drawn from the nearby community were interviewed. The KATZ-index of independence in activities of daily living is used to score the elder's level of impairment [28]. A score of 6 indicates full function, 4 indicates moderate impairment, 2 or less indicates severe functional impairment. Inclusion criteria for the elderly were: to be 65 years or older and a score of 5 or 6 (no severe impairment) on the KATZ-index. An exclusion criterion for the elderly was: being unable to give clear answers to the questions asked (assessed by the researcher during the foregoing guided tour in the Smart Home). An inclusion criterion for the informal caregivers was that they needed to have experience in caring for one or more family members.

Three formal caregivers (one also involved within the development of the EPR) and one graphical designer participated in a focus group. An inclusion criterion was that they needed to be familiar with the Smart Home and its functions.

The study was approved by the ethical commission of the University of Twente (application number: 15260). All participants signed an informed consent for participating the study.

Procedures and analysis

Interviews elderly and informal caregivers

Five semi-structured interviews with elderly and five semi-structured interviews with informal caregivers were held at their own place to uncover their needs, their motivations and their wishes regarding the relevance of sensor data for the content and the visualization of the PHR and for receiving persuasive text messages and remote assistance. The same interview protocol was used for all the interviews that took approximately 60

minutes. All participants were familiar with the Smart Home as they had a guided tour or were shown a video of the Smart Home with all the sensors and technologies.

The interview protocol included:

- *Open questions.* Open questions were asked regarding the perceived usefulness and opinion about home monitoring in general.
- *Card sorting task.* Card sorting is a design method that can be used to create an information structure for a website or an application [29]. In this study, closed card sorting is used. Each participant was given cards with all the relevant sensors and information and they were asked to sort the card in two categories; relevant and not relevant. They were also asked to combine cards into subgroups for combined sensor information they wanted to see and to prioritize in order of relevance. Empty cards could be used to write down sensors/information that was not yet provided in the Smart Home but could be relevant to their opinion. After the card sorting task, questions about what, how and when they wanted to see and receive this information were asked.

Figure 4: Example of card sort in an interview

- *Visualizations of sensor information.* Prior research about preferences and requirements for visualizing data for elderly and informal caregivers was searched and reviewed to identify guidelines for developing simple visualizations of sensor data.
  In the interviews, participants were shown different visual display types for various sensor information and summaries (snapshots) of health information and were then asked about their preferences. Positive aspects, possible improvements, understandability and completeness were also discussed. Based on the feedback, prior research and the sensor information needs, the visualizations were further adapted to give recommendations for the PHR.

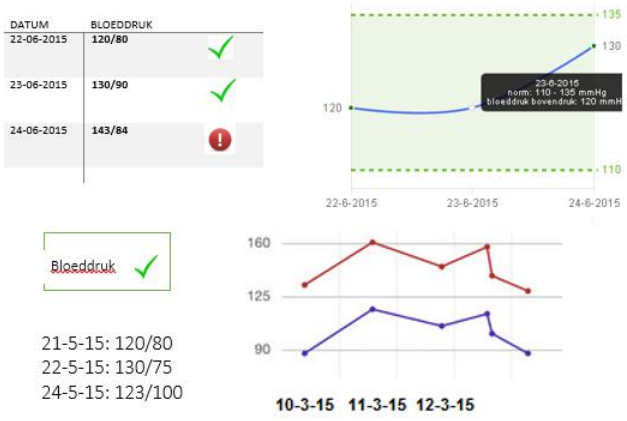

Figure 5: Examples of different visual displays of blood pressure

Figure 6: Examples of concise (A) and extensive (B) snapshot

- *Persuasive messages/remote assistance*: The elderly were asked questions about their preferences for receiving persuasive messages on an electronic device by a virtual coach (with speech), by text-messages and remote assistance provided by a living person. Based on the quotes, persuasive features according to the PSD model were identified to determine which persuasive features were stimulating (positive influence), neutral (no effect) or blocking (negative influence) [30, 31].

All the interviews were voice recorded and transcribed for further analysis.

Figure 7: Example of persuasive text message provided by a virtual assistant

Focus group with formal caregivers

A focus group with three district nurses and one graphical designer was held to identify their preferences about what sensor information gathered from the elderly in the Smart Home should be displayed in the EPR and to identify their preferences for the visualization of this information. The graphical designer only participated within the visualization part and did not give answers related to the content of the EPR.

The focus group protocol included:

- *Card sorting task*. Each participant was given cards with all the relevant sensors and information and they were asked to sort the cards in two categories; relevant and not relevant. This was done individually so the participant could not influence each other. After this, all the cards were placed on a whiteboard to discuss differences and similarities of categorizing the cards. They were also asked to combine cards into subgroups for combined sensor information they wanted to see and to prioritize in order of relevance. Empty cards could be used to write down sensors/information that was not yet provided in the Smart Home but could be relevant to their opinion. After the card sorting, questions about what, where in the EPR, how and when they wanted to see and receive this information were asked.

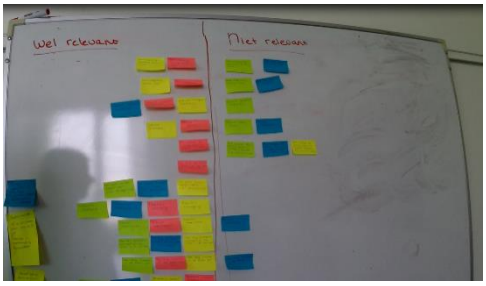

Figure 8: Example of a card sort in the focus group

- *Visualizations of sensor information.* Prior research about preferences and requirements for visualizing data for formal caregivers was searched and reviewed to identify guidelines for developing simple visualizations of sensor data.
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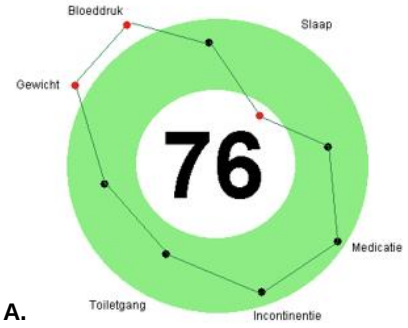
The focus group was voice recorded and transcribed for further analysis.



A.

B.

Figure 9: Example of visualizations of health summaries (A: hGraph[7], B: snapshot)

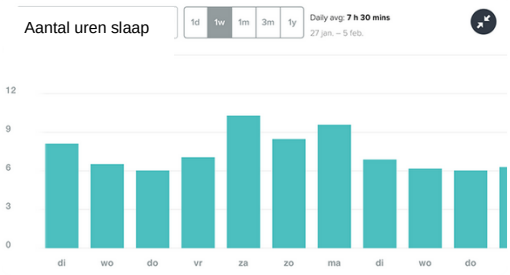


Figure 10: Example of visualizations of sleep pattern

Qualitative data analysis

For the qualitative analysis of the interviews and the focus group, deductive coding is used. The transcripts are used to identify labels and sublabels and also to identify persuasive features. Based on the content of the interviews and focus group and also the labels that were identified, a coding scheme was made. The transcripts were coded by one researcher, where quotes were grouped into labels and sublabels according to similarity. The interviews were taken separately, so in the results, individual frequencies are given. In the focus group, it was strived to reach consensus between the participants, so no individual frequencies are given in the results.

[7] http://hgraph.org/

Results

The results consist of the results of the focus group and the results of the interviews with their subcategories (activities of daily living, safety, additional sensors, delivery of data, visualizations and for the interviews the general opinion of home monitoring and persuasive features). The results of the focus group and interviews, the participants demographics and a table that summarizes the results are presented below.

Participants demographics

Five informal caregivers were interviewed. They were all female, with an average age of 52 years and a range from 47 to 56 years old. All informal caregivers were married, one lived together (20%) and four with their partner and children (80%). Four of them finished the intermediate vocational education (80%) and one of them the higher vocational education (20%). They had care experience ranging from two to five years with an average of 3.5 years. They gave direct care ranging from three times to seven times a week and their activities mainly existed of daily check-ups, doctor appointments, medicine control, household work, shopping and taken over the finances. The elderly their cared for scored on average 4.2 points ranging from 3 to 5 points on the KATZ-index. Four of them had quite some experience in using technique and one had none.

Of the five elderly that were interviewed, two were female (40%) and three were male (60%). They all lived together with their partner (100%) and their average age was 78 years old with an range from 74 to 84 years old. Three of them finished the higher vocational education (60%) and two the intermediate vocational education (40%). On average, they scored 5.8 points (no severe impairments) on the KATZ-index ranging from 5 to 6 points. They all had quite some experience in using techniques as most of them had a smart phone and used the internet.

The formal caregivers had an average age of 29.7 ranging from 20 to 47 years old. Two of them finished the higher vocational (67%) education and one the intermediate vocational education (33%). They had an average work experience in the direct care of 11 years with a range from 3 to 27 years.

Table 2: Demographic characteristics

	Elderly	**Informal caregivers**	**Formal caregivers**
	n (%)	**n (%)**	**n (%)**
Gender			
Male	3 (60)		1 (33)
Female	2 (40)	5 (100)	2 (67)
Age (years)			
Mean (range)	78 (74 - 84)	52 (47 - 56)	29.7 (20 – 47)
Living situation			
Partner	5 (100)	1 (20)	
Partner and children		4 (80)	1 (33)
Family			2 (67)
Highest education			
Intermediate vocational education	2 (40)	1 (20)	1 (33)
Higher vocational education	3 (60)	4 (80)	2 (67)
Experience with technology			
None		1 (20)	
Intermediate	5 (100)	4 (80)	
Expert			3 (100)
Level of impairment (KATZ)			
No severe impairment	5 (100)		
Care experience (years)			
Mean (range)		3.5 (2 - 5)	11 (3 - 27)

Interviews with elderly and informal caregivers and focus group with formal caregivers

The purpose of the interviews with the elderly and informal caregivers was to uncover their needs, motivations and wishes regarding the relevance of sensor information regarding the content and the visualization of the PHR and to identify the preferences of elderly for receiving persuasive feedback. After these 5 interviews, saturation and consensus was reached in both groups, as no new relevant information came up anymore.

The purpose of the focus group with the formal caregivers was to identify their preferences about what sensor data gathered from the elderly in the Smart Home should be displayed in the EPR and their preferences about the visualization of relevant information. There was reached consensus among the participants.

Activities of daily living (ADL)

Medication compliance. The most important item of the ADL that the informal caregivers and elderly wanted information about was medication compliance. All the informal caregivers (5/5) agreed that they wanted to know when their parent didn't take their medication or didn't take them on time as this could result in health problems or fall incidents, especially when a parent was living alone.

All the elderly also mentioned they wanted to know if they had not taken their medicines. Because of their increasing age, taking medication was sometimes forgotten or medication was taken two times.

For the formal caregivers, the most important was that when an elder forgot his medicines (despite the remember signals from the automatic medicine dispenser), he should first get an alert, followed by the informal caregiver and then the formal caregiver. Formal caregivers would prefer to receive this alert on their mobile phone or pager. It was also found interesting to see in the EPR how often the elderly forgot their medicines.

Location in home/daily patterns. All the informal caregivers (5/5) found it important to know and see their parent's location in the home, daily patterns and abnormalities within these patterns. They said that their parent's daily patterns were almost the same every day and that something was wrong if these were not and it should be noticed by the system. Examples of irregular behavior were when elderly were lying in bed or sitting in the chair longer than normal.

The formal caregivers found it important to know when there was extreme abnormal behavior detected by the system, for example when someone went out of bed ten times a night. This should be registered in the report so they could observe the abnormal behavior. The time spent in each room and whether this is stable/increasing/decreasing the last weeks/months was also relevant according to the formal caregivers. Continuous monitoring of the location and daily patterns of the elderly was found more relevant for informal caregivers.

Sleep pattern. For all the informal caregivers (5/5) and formal caregivers it was relevant to get insight into the sleep patterns of the elderly, especially when the sleep patterns were abnormal compared to their normal sleep patterns. Other important aspects were bedtime and wake-up time, frequency and duration of interruptions, sleep duration, how often elderly slept during daytime and for elderly with dementia it was also important to see if they were not wandering or turning around the day and night rhythm. When there were abnormalities, the formal caregivers wanted this to be registered in the report.

For the elderly the sleep pattern was less relevant because they already knew they slept good or not. Two of the five elderly found it interesting to see, but not really necessary. They wanted to know the sleep duration and the frequency of interruptions, also in order to get sleeping pills from the doctor.

Self-measured values (weight/blood pressure). The informal caregivers only wanted to see the weight and blood pressure of their parent when they had problems with it (3/5), especially when the blood pressure or weight was abnormal (compared to normal values).

Weight and blood pressure was also found relevant according to the formal caregivers. For elderly where daily monitoring of their weight and blood pressure was important, they wanted to see these values in the report. For elderly who measured their weight and blood pressure periodically, it was enough to see the latest values during the evaluation or when there were problems, in for example a graph.

Also the elderly only wanted to monitor their blood pressure when they had problems with it (4/5). Three of the five elderly also wanted to see their weight because they wanted to know if they gained or lost weight, especially when they had been sick.

Physical activity (home trainer/pedometer). Even though all the informal caregivers said that if their parent was less physical active, this could mean they didn't feel good, only one informal caregiver thought she would look at this data in the PHR. For the rest is was less important because their parents were not that physically active anymore, were not able to use the home trainer or they knew they did exercise and walk enough.

The formal caregivers didn't find it relevant to see the results of the home trainer or pedometer because they thought it was the responsibility of the elderly themselves.

For the elderly, two of the five thought it would be nice to see how many steps they had been taken on a day and four of the five wanted to see their activity on the home trainer to see whether they had enough physical activity. The rest already knew they were active enough. All elderly said they were less active when they were not feeling good.

Incontinence. For the informal caregivers, it was not that important to see how often and when their parent was incontinent (4/5), but it became more important when they were the first contact person. The most important was that if it went wrong, someone came to help their parent with changing their clothes and if it happened frequently, they should change their incontinence materials.

The formal caregivers would find it relevant to see when an bedridden or dependent elder was incontinent so they could help him. They preferred to get an direct alert on for example their mobile phone. Also for nightshifts it was found relevant, because normally they had to wake up elderly to see if their bed was wet. For the evaluation it would also be relevant to know how often and what time an elderly was incontinent, so they could anticipate on it.

The elderly did not find it relevant to see this in the PHR (4/5). The most important was that caregivers were informed and helped them if they were not able to do this by themselves anymore.

Toilet frequency. Most informal caregivers (3/5) didn't think it was important to see their parent's toilet frequency, because their parent had no problems with it or had a catheter. The formal caregivers and some informal caregivers (2/5) said it only was important to know when the toilet frequency was abnormal compared to the normal frequency as this could be a symptom of the beginning of an urinary infection. When there were abnormal values, the formal caregivers wanted this to be registered in the report.

For most of the elderly it was no added value to see their toilet frequency(4/5). They thought it might be relevant when they were more independent or sick, but they agreed it was more relevant for the caregivers to know. Only for one elder it was relevant to see because he had some problems with his bladder and he was always monitoring his toilet frequency.

Use of electric stove/frequency of opening kitchen cabinets and fluid intake. For both formal and informal caregivers this data was only found relevant when they had the feeling elderly had problems with it, or for the formal caregivers with the evaluation. They especially wanted to know the abnormalities within the daily patterns. When an elder was for example eating and drinking less than normal, this could mean they were not feeling well, were unconscious or simply forgot to eat and drink.

Only one elder found it relevant to see his eating pattern and three of the five elderly found it useful to see their fluid intake. They were concerned if they drank enough, forget to drink or needed to monitor their fluid intake for the urologist.

Safety

Fall incidents. The most important aspect of safety that informal caregivers wanted to know, was when their parents had a fall incident (5/5). Informal caregivers mentioned that this already happened a couple of times and that they were concerned that it would happen again, especially because some parents didn't always mention it. Finding out the reason why they felt and if it was increasing was also found important. After a fall incident, informal caregivers wanted to check if everything was okay with their parents.

When there was a fall incident, formal caregivers indicated that they needed to have an alert immediately. They also wanted to see how often this occurred, because sometimes elderly got up by themselves and didn't raise an alarm.

For all the elderly it was not relevant to see how often they had a fall incident, because they would remember this. Most of the elderly didn't experience any fall incidents yet. If it would happen to them frequently, they

could imagine that they wanted to see this in the PHR to know if they needed more help and to find out the reasons why they felt.

GPS. All the informal and formal caregivers found it relevant to see where the elderly were located when they left their houses. The GPS function was especially important for elderly with dementia who could get lost. A function that enabled the formal caregivers to see where the elder normally walked, visualized with thicker lines and thin lines for not regular routes, would also be interesting for them.

Alarms. Four of the five informal caregivers found it important to know how often their parents raised an alarm because it meant that there was something wrong or it could be a sign of restless and they wanted to ask their parents about it. When they were the first contact person, they needed to know immediately when their parent raised an alarm so they could check up their parents to see what was going on.

Also formal caregivers always wanted to have an alert so they could take action. They also found it important to see when and how often the elderly raised an alarm to recognize patterns and anticipate on that.

None of the elderly found it interesting to see how often they raised an alarm, but one thought it could be helpful to see if he was restless or bothering the caregivers too much with pressing the alarm button.

Who entered the house. The hand palm scanner can give information about who entered the Smart Home if he or she is authorized by the system. Only one informal caregiver said she would look at this information in the PHR because her mother often said nobody visited her, while she knew she just forgot that (1/5). The rest of the informal caregivers didn't find it relevant, because their parents could tell this themselves.

For the formal caregivers, this function was only found relevant when someone was lonely or when there were people entering the house at abnormal times. If this was the case, they wanted to see if elderly still got visits or who entered the house on what time.

None of the elderly found this information relevant at the moment, but some said it could be useful when they were forgetful and couldn't remember who visited them.

Additional sensors

Caregivers were asked what functions that were not available in the Smart Home yet should also be valuable for them. Some informal caregivers mentioned that they wanted to know if their parent showered or washed them self regularly, if the house was clean, if there were enough groceries, if their clothes were clean and if their parent still had enough social contacts.

Temperature, saturation and respiratory rate were named as valuable additional functions by the formal caregivers. It was found important to know when these values were abnormal and formal caregivers would like to receive an alert then. It was also important that when some sensors were not working, this was reported in the EPR.

Delivery of data

Storage. The formal caregivers prefered to have an extra tab page next to the already existing tab pages where the EPR consisted of (e.g. the care plan, report, medical history etc.), where all the relevant sensor data information should be stored. The same applies to the report. Abnormal values should be registered in a special report and not within the regular report because it was difficult to group the sensor data information in the already existing domains. Formal caregivers did not want to see all the relevant information continuously, only when there was a periodically evaluation or when problems occurred. It was questioned if all formal caregivers would read the reports and all the relevant information gathered from the sensor data for the evaluation, but this was already a problem they were facing with now.

Alerts. Informal caregivers often said they wanted to receive an alert when something was wrong with their parents and if they were the first contact person. If they were not, they only wanted an alert when an fall incident happened, the rest they could see in the PHR. The most frequently named items to receive an alert as first contact person were fall incidents (4/5), medication compliance (4/5), alarms (4/5) and abnormalities within daily patterns (2/4). Receiving the alert on their mobile phone would be the best option according to the informal caregivers, because they could read it immediately and take action. One informal caregiver said she didn't want to get alerts, because she was not able to go directly to her parent when something was wrong and it would give too much pressure. It would be better for her to see this in the evening in the PHR.

Too many alerts prevented the formal caregivers to do their job, that's why they only wanted an alert when there was a critical situation like alarms, fall incidents and forgotten medicines. The system should be able to

detect dangerous/abnormal situations and health problems and send them an alert or make a note in the report. When for example the kitchen cabinets were not opened, presence was detected but there was no movement, the system should recognize that.

The elderly only wanted to receive an alert on their mobile phone when they forgot their medication (4/5). One elder didn't want to receive this message on her mobile phone because she was always struggling to read the small letters. An extra alert on the medicine dispenser or a telephone call from a caregiver was enough for her.

Modifiability. All the caregivers and elderly mentioned that the PHR and EPR should be modifiable according to their needs. For the formal and informal caregivers there should be an option to set alarms and parameters that were the most important for them and the elder. Due to the diversity of elderly and their health problems and needs, it was found really important that the sensor information displayed in the EPR and PHR could be adjusted for each person by for example an option (not) to show sensor information. Only information relevant for the elder in question should be displayed to avoid an overkill of (irrelevant) information. Some aspects were also not relevant for their parent at the moment, but could be relevant within a few months or years.

For the elderly it was also important to have an option (not) to show sensor information. Their health was fairly ok by now, but this could also change very quickly. They thought that if they had more problems with their health, they would probable see more information gathered from the sensors than they wanted to see now.

Visualizations

Daily patterns/presence per room. All the informal caregivers agreed that they preferred the more extended version of the presence per room (Appendix A; figure 14a). In this figure they could see daily patterns and also abnormalities within these daily patterns like the sleeping pattern, frequency of going out of bed, how often elderly went outside etc. They all found the figure easy to read and to understand and they were also very content with the all the information that was visible in the figure. In addition, they would like to see the amount of activity in the figure. The more extended version of the presence per room showed more information than the circle diagram that only gave the percentages of the occupancy per room (Appendix A; figure 14b). The circle diagram was found less necessary if the other extended figure was also provided, according to four of the five informal caregivers. One informal caregiver said she also found the circle diagram relevant, because she could easily see a shift in daily patterns like more time spent in the bedroom for example.
For the informal caregivers it was found more relevant to see a combination of sensor information at a single glance than to see them separate because the combination could say something about for example the lifestyle of their elder. For example, the use of the stove, kitchen cabinets, toilet etc. provides lots of relevant information combined, as it shows lifestyle, but less information separate.

Blood pressure and weight. All the informal caregivers and all the elderly preferred to see this information in a clear table instead of a graph (Figure 5). In a table, the informal caregivers could more easily and in one glance see the values than in a graph. Some informal caregivers (2/5) did mention that the graphs were useful when they wanted to see progress or an overview and also the display of target ranges would be useful. Their opinion about the option for tables to see if certain values fall within or without the target ranges (green mark or warning sign) was divided.

Formal caregivers also would like to see the raw relevant sensor data in a table and have the possibility to switch and see a line graph with target ranges for a complete overview and to see extreme values. Especially for the evaluation it would be relevant to see an overview of the last few weeks, months or year in a graph. Also the option to only see the information between certain dates was found useful. For blood pressure, it would be relevant to add the heartrate.

Four of the five elderly agreed that they never wanted to see a graph, because they found it difficult to read and understand. One elder thought that sometimes he would like to see the line graph with target ranges to monitor the progress within a year for example. For four of the five elderly it was enough to see whether the values were good or bad and they didn't want to see a table, only if they wanted to know the exact values. One elder mentioned that when a red sad smiley was showed when there were abnormal values, it would scare the elderly and that the warning sign or something like that would be better.

Sleep pattern. Both elderly and informal caregivers preferred the bar-chart over the line graph to see sleep patterns (Appendix A; figure 13). For the elderly, the line graph was difficult to read and interpret, but the

bar-chart was understandable for them. Informal caregivers liked the bar-chart, but also wanted to know how often their parents went out of bed during the night.

Also for the formal caregivers, the bar-chart for the sleep pattern was more appreciated than the line graph. The bar-chart was found useful and easy to read. Some things could be added like interruptions and interruption times and the use of different colors for day and nighttime. It was found relevant that extra information could be shown when you click on a specific date in the graph with the mouse pointer, for example the bedtime and wake-up time. Also the option to only see the information between certain dates was also found useful here.

Snapshot. A snapshot where all relevant information was provided at one page would be valuable for all the elderly and informal caregivers. The status display for all the health information (Figure 6a) was preferred and found easy to see if everything was ok at one glance. For the informal caregivers it felt safe to know that everything was going well with their parents and if something was wrong, they could see it immediately. The elderly mentioned it was nice to quickly see an overview about their health status, because the main thing to know for them was that they were ok. A meaningful text why certain aspects were abnormal was found relevant. The other more extensive snapshot (Figure 6b) was found relevant if the informal caregivers wanted to see more information about some aspects. They suggested that if a person clicks on for example the blood pressure in the concise snapshot, the table with blood pressure values should be showed. For some elderly and caregivers it would be easy to see the status display on their mobile phone, because it was always within their reach and they could immediately see if everything was ok with them or their parent.

The formal caregivers were not very enthusiastic about the hGraph that gives a visual representation of the health status, because they could only see if something was abnormal, but couldn't directly see why it was abnormal (Figure 9a). They did like the idea of seeing status displays for different aspects as sleeping, eating, vital signs etc. in a simple list, because it was more easy to read and they could see if there were any problems on specific aspects at a single glance (Figure 9b). A meaningful text why certain aspects were abnormal was found relevant. From the status display it should be possible to switch to a table or a graph to see trend details for specific aspects. If for example the blood pressure was outside the ranges, they would like to click on the red status display and then see an overview of the last blood pressure values. For multiple clients, the status display of all clients should be provided on one page to get a full overview.

Frequencies. For the sensors where frequencies were relevant to see, for example the frequency of toilet visits, use stove/opening kitchen cabinets, fall incidents etc., it was found relevant to see this in a bar chart according to the caregivers. It should be possible to see this information for the previous weeks/months with averages, but also for specific days to see what time the activity happened.

Persuasive features based on PSD model

The elderly were asked about their preferences for receiving persuasive messages on an electronic device by a virtual coach (with speech), by text-messages and remote assistance provided by a living person. Persuasive features and their corresponding category of the PSD model were identified based on the quotes of the interviews with the elderly. Table 3 and 4 present the stimulating and blocking features, but there were also other findings.

Four of the five elderly said it would motivate them to work (better) on their health and social life if the Smart Home would provide motivational messages on for example the television screen. Most elderly preferred to see only text messages on the screen, because sometimes they didn't feel the need to listen to a virtual assistant on their screen and a text message could suffice. When the elderly received feedback that was more related to their own health, for example abnormal blood pressure values, the elderly preferred to speak to someone personal so they could talk about it and get advice.

Table 3: Stimulating persuasive features

Persuasive feature (category PSD)	Quotes
Self-monitoring (primary task support)	"*I think I'll be more active when I can see how many steps I took and how many I still need to take to achieve the goal"*
Personalization (primary task support)	*"It would be great if you can decide by yourself if and when you want to receive text messages or a virtual coach on your screen"*
Social role (dialogue support)	*"I think it is very important for elderly, social contact (real person)"*
Reminders (dialogue support)	*"Sometimes, I sit in my chair working on my computer all day and forget to move that day. It would be helpful is someone reminds you that you should be physically active"*

Table 4: Blocking persuasive features

Persuasive feature (category PSD)	Quotes
Praise (dialogue support)	*"It don't want it to say, do this, do that. It should be saying positive things, otherwise it's not working for me"*
Tailoring (primary task support)	*"Not always the same message should appear, otherwise you don't do it anymore"*

General opinions home monitoring

All the informal caregivers were positive about the functions and possibilities that the Smart Home offered. It gave them a secure, safe, comforting, peaceful and good feeling that they could monitor their parents at a distance. Being an informal caregiver and check up your parent at daily basis was sometimes a burden for them. If they could monitor their parent at a distance, they didn't need to visit their parents every day. Also the fact that parents didn't always tell the whole truth about their health status was a reason why they were that positive. Two caregivers shared the opinion that their parent could probably live longer and independent at home when they were monitored.

Also the elderly were positive. According to the elderly, they felt safe when knowing they were monitored by their caregivers and someone would help them if there were problems. They were not really concerned about their privacy as long as it would help them to live longer and more independent at home. They did mention that they wanted to decide what information could be seen by whom. One elder mentioned that, looking at the new caring system, the need for technical innovations was really necessary.

Table 5: Summary of the results about the relevance of receiving feedback about sensor information. ++ extremely relevant. - not relevant

Label	Sublabel	Formal caregivers [FC]	Elderly [E]	Informal caregivers [IC]	Quotes
Activities of daily living	Medication compliance	++	++	++	[E] "Sometimes I cannot remember if I already took my medicines or not. So it might be that I took them twice sometimes".
	Location in home/daily patterns	+	N/A	++	[FC] "You can monitor if their movement pattern is reducing, stable or you need to do something with it. Or if someone didn't move for like 3 hours, but it can also be that he's watching the Titanic of course". [IC] "Imagine she is still sitting in the chair at 01.00, that's not normal because normally she goes to bed at 23.00, so there can be something wrong".
	Sleep pattern	+	+/-	++	[IC] "My mother has early dementia. If it gets worse, you often see that they turn over their day and night rhythm".
	Self-measured values	+	++	+	[E] "Yes, very, very important for me. I don't want to get a beer belly, so I weight myself every week".
	Physical activity	-	+	-	[IC] "Looking at my mother, she is very inactive, so it's not important".
	Incontinence	+	-	-	[FC] "That would be handy for nightshifts. You don't need to enter someone's room with a flashlight, take off their blanket and feel if they are wet anymore".
	Toilet frequency	+	-	+/-	[FC] "The system must know the normal toilet pattern and recognize if something is abnormal".
	Use of electric stove/frequency of opening kitchen cabinets and fluid intake	+	-	-	[E] "That is especially important for the informal caregivers, but I know that myself".
Safety	Fall incidents	++	-	++	[IC] "Very important. Elderly always say there are doing fine, but meanwhile they already felt down several times".
	GPS	+	N/A	++	[IC] "Image, my mother walks outside, gets lost and you cannot find her anymore. I'll tell you, that happens all the time, that would be horrible!".
	Alarms	++	-	++	[FC] "…I want to have an alert then". "You should visit the older person earlier if he is always pressing the alarm button one hour in advance".
	Who entered the house	+	-	-	[IC] "If someone has dementia, they say all the time: 'well, no one has visited me today!', but you just saw your brother walk out her house..".

Discussion

In this exploratory study, we aimed to identify the needs and wishes of formal caregivers, informal caregivers and elderly for designing a PHR and the content of the EPR and to identify the preferences of elderly for receiving persuasive feedback. Therefore, interviews and a focus group were conducted.

Interpretation of results

The results showed that caregivers and elderly overall had a positive attitude towards the monitoring of elderly at a distance. For the informal caregivers, the most important information about their parent to know was the medication compliance, location in home/daily patterns, sleep pattern, alarms, fall incidents and location outside the home (GPS function). Formal caregivers were interested in almost all the information that could be collected from the sensors for the content of EPR, except for physical activity. However, it should be taken into account that it is important to prevent an overload of information, as this problem often occurs when there is a big amount of data available. The medication compliance, fall incidents and alarms were found the most important according to them. These findings were expected, as critical situations mostly are perceived as most important to know and the informal caregivers specifically answered by thinking about their own parents, while formal caregivers thought about elderly with all kinds of characteristics and impairments were this information could be relevant [8]. A difference between the needs of formal and informal caregivers was that the formal caregivers were more interested in trends across time and the informal caregivers were more interested in data on a day-to-day basis. This can be explained by the fact that informal caregivers are more closely related and want to know what is going on right now and see relevant information continuously, while formal caregivers mostly want to see the information when there was a periodically evaluation or when problems occurred.

The above findings largely correspond with Zulas et al. [21] about the formal and informal caregiver's needs from elder care assistive Smart Homes. However, while Zulas' study was focused on the general opinion of needs for sensor information, this study gives insight into the needs of very specific sensors that were already integrated in the Smart Home including extra information about other sensors and preferences for visualizations. Also, Zulas et al. [21] explored the needs of caregivers while the interface for the visualization of sensor data was already made. This research involved the users in an early stage of the process to identify the sensor information and visualization needs and used these as a basis for the development of a PHR and the content of the EPR. By involving end users early in the process, the final product will be more customized according to their needs and wishes which improves the accessibility, usability and understandability.

The elderly were less interested in the sensor information they could get provided with because most of the information was found more relevant for the caregivers. The most important items in which they were interested in were medication compliance, self-measured values (blood pressure and weight) and physical activity. For the elderly, the most important was that they knew they were ok and that critical situations were detected and they would receive help. Current research investigated the perceived usefulness of Smart Home sensors according to elderly [8, 32], but did not identify the elderly's needs to see this sensor information as this study did.

All three groups identified the need for the possibility to modify the sensor information displayed in the PRH and the EPR. This was also found in previous research [21]. As every person is unique, they all have other needs and problems which also emerged when the elder's age was increasing.

Elderly showed positive attitudes towards persuasive messages and assistance. Persuasive messages would motivate them to work on their health and a virtual assistant with speech was not seen as a necessity to help them with this. Except when the feedback was more related to

their own health, they would prefer to speak someone in person, also to serve as a social role. Tailoring and personalization were identified as important stimulating features as the system should provide information tailored to the needs and interest of elderly with a content that could be personalized. Elderly wanted to decide how, when and what information appeared on their screen. The messages had to offer enough variation and praise them with positive feedback so the elderly stay motivated. Providing real-time information about their progress towards targets and giving reminders to reach their target behavior was also found helpful. This is in line with previous research, that describe that text messages could suffice if they were specific, personalized and offered variation [23, 25]. Previous research also showed that spoken language was the most preferred interaction modality for elderly [20]. This study revealed that spoken messages were not preferred because elderly did not want to be interrupted. This difference can be explained by the fact that previous research was focused on elderly unfamiliar with technology, while in this study all elderly were familiar with technology.

This study also identified the preferences and wishes for the visualization of sensor information. The main results show that all three groups preferred to see a summary of all the health related aspects in a status display that allowed them to obtain more in-depth information when preferred. This status display should be available on the mobile phone of informal caregivers so they could always check if everything was okay with their parent. This finding corresponds with Demiris et al. [8], although no examples of visual summaries were given in this study.

Based on the results, where the needs of sensor information and the feedback on the visualizations were identified, further improvements for the visualizations were developed. These can be found in the section 'recommendations for practice and further research'. By involving the elderly and caregivers in the process of developing sensor information visualizations, the visualizations fit their needs and wishes. With the status display of health related aspects serving as a basis for the PHR and the EPR, the sensor data is displayed in a meaningful, holistic but concise manner that is also usable and understandable for elderly. Aspects that are sometimes still missing in recent Smart Home platforms [9]. It is concentrated on regular living aspects that have a relationship with wellbeing like sleeping, eating etc., which is recommended by Gil et al. [22].

Limitations

A limitation of this study is that the coding process is performed by one researcher and other researchers may analyze and interpret the data differently. In total, ten participants for the interviews and four participants for the focus group were included in this study and therefore it could be hard to make conclusions or to generalize findings. Despite the small sample size, there was consensus reached and the participants were drawn from the nearby community which could make them representative for this specific group.

There is a possibility of selection bias, because only elderly who were interested in the Smart Home were interviewed. Less interested elderly would probably lead to different results for this research. According to Rogers [33], these interested elderly or 'early adopters' frequently serve as opinion leaders who can persuade others to adopt the innovation by providing evaluative information. Early adopters are needed to serve as an example for the late adopters. For this research it means that early adopters are needed first to use and evaluate Smart Home technologies and late adopters will probably follow.

Recommendations for practice and further research

Knowing the needs and wishes of the caregivers and elderly and knowing the requirements for visualizing sensor data from existing literature, concrete recommendations for the PHR, EPR and persuasive feedback can be given.

As the needs and wishes differed from each caregiver and elder and the modifiability of the system was found important, no concrete recommendations can be given about the visualizations that should be displayed standard in the PHR and EPR. The needs of every elder and their caregivers should be determined and the PHR and EPR should be composed according to these needs. An option (not) to show sensor information is important, also because the need for sensor information may change over time. It can also be an option to make predefined categories for elderly based on their health status and disabilities and decide for each category which sensor information would be relevant. The possibility to set alerts and target ranges should be possible and be integrated in the system as well. In practice this means that elderly and caregivers should be able to decide which values, behavior or patterns are abnormal and give a red warning sign in the status display.

The visualizations of sensor information are adjusted according to the needs and wishes of the users described in the results. Figure 11 gives an overview about the recommended interface for the PHR and EPR. A summary of the health related aspects in a status display should be displayed first for an quick overview of the health status of elderly (Figure 11a). A meaningful text why certain aspects were abnormal is added. For the formal caregivers it is provided with exact values (e.g. blood pressure values) and for elderly and informal caregivers only with a description. Clicking on a certain aspect should give more information and show trend details (Figure 11c, 11d, 11e), but also the possibility to view the information from a sub-menu is recommended.

The values of the blood pressure (and added heart rate) and weight should be provided in a table with also the possibility to switch to a line graph with target ranges for a complete overview (Figure 11b, 11c)

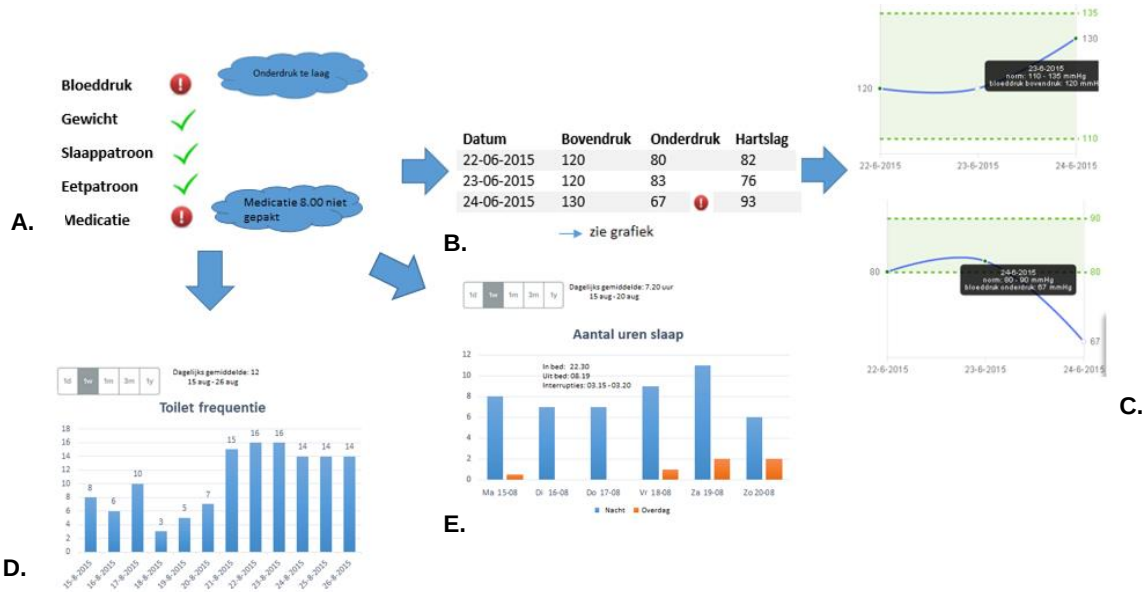


Figure 11: recommended interface for the PHR and EPR

It is recommended to display the sleep pattern in a bar-chart with average sleep duration for day and night and the possibility to see the wake-up time, bedtime, interruptions, interruption times when clicking on a specific date (Appendix A; figure 15a). These can also be switched to another display where wake-up time, bedtime and interruptions are displayed and with the possibility to see the average sleep duration when clicking on a specific date (Appendix A; figure 15b).

Simple bar-charts are recommended for the sensor information where frequencies are relevant. These should provide frequency information of for example the last seven days, but there should also be a possibility to see this information for specific days to see what time an activity happened (Appendix A; figure 16). For all the visualizations, there should be an option to filter on date and only see the information between certain dates.

Figure 12 can be used to provide relevant information for informal caregivers on a day-to-day basis. Informal caregivers would like to see the amount of activity displayed in the figure. However, the sensors in the Smart Home are not able to register this. Therefore, bed and chair occupancy can for example be added. As informal caregivers preferred to see all relevant sensor information at a single glance instead of separately, extra sensor information (e.g. toileting and opening kitchen cabinets) can be added which also gives an impression of the lifestyle and daily routines of elderly.

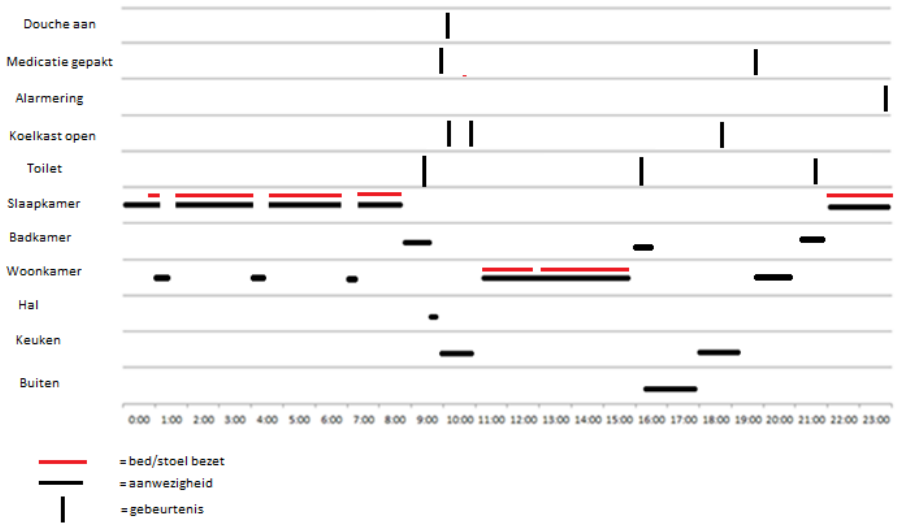


Figure 12: Example of possible visualization of presence per room with added information

Regarding the preferred additional sensors/information; the option to measure temperature, saturation and respiratory rate was mentioned by the formal caregivers. There are already several options available to measure these vital signs, like smartwatches, wearable sensors and bed-sensors. As a smartwatch is already available in the Smart Home, it is recommended to use this and extend it with the preferred functions.

Informal caregivers preferred to see the cleanliness of the house and individual and if their parent had enough social contacts. ‘Social sensor information’ like how often elderly go outside, which people enter the house, the frequency of video calling and possibly an extra function to register their phone calls, can be combined to get an overall view of an elder’s social life. Sensors that indicate the cleanliness of the house and individual are difficult to facilitate. For

the cleanliness of the individual, the time spend in the bathroom and possibly some extra functions that detects the location in the bathroom or when an elder is showering, can be combined to give at least some information about this aspect.

These simple mock-ups serve as basis ideas for the PRH and EPR and should be further customized by designers. The visualizations are developed according to the needs of their users, but still needs to be evaluated to see how the visualizations are used and valued in practice. By looking at the logdata, the use of all the functions can be evaluated. Interviews or surveys can serve as evaluation to test the user friendliness, understandability and completeness.

The formal caregivers preferred to have an extra tab page in the EPR where all the relevant sensor data information and their reports should be stored, because they thought it was difficult to group the sensor data information in the already existing domains. A recommendation will be to organize a card sorting task where formal caregivers can sort the relevant sensor information in the already existing domains in the EPR. When the sensor information is integrated in the domains, one gets the most complete information at one place in the EPR.

Providing persuasive messages on the computer or television screen and remote personal assistance from a caregiver about health related issues based on the collected information about the elder can be an added value. The elderly should be encouraged to contact the caregivers themselves, to stimulate self-management. The messages should be tailored, personalized, offer enough variation, provide positive feedback, give reminders and provide real-time information towards the progress of targets. To ensure that the messages are tailored to the personal needs and interest of elderly, diaries can be used as an input for the persuasive messages [16]. The elderly can be asked to write down their daily routines, what they like to do the most/least, what they find difficult to do, what feedback on their health they would appreciate, which reminders they could need, what they desire to do etc. This can be specified on aspects they think they need or want to work on, for example increasing their physical activity or social contacts. The output can be used to create tailored messages. The use of visual metaphors for providing feedback to elderly that requires minimal cognitive processing is not investigated in this study, but nevertheless can be recommended as it seems to be promising [22, 25]. All these functions should also be evaluated.

Additional results

Logdata protocol

These additional results describe the development of a logdata protocol. A logdata protocol can be developed to gather information about users, actions, action specifications, time and day and can be used for the analysis of sensor data [38].

All the sensors in the Smart Home produce a lot of unstructured data. To extract all the meaningful information and make visualizations to serve the elderly and caregivers, this data needs to be adjusted so it becomes functional and can be stored and used for analysis. Therefore, a logdata protocol was developed in order to describe how and which logdata should be stored and which requirements the data needed to satisfy. A codebook was made with all the information gathered from the sensors that needed to be stored to meet the needs and wishes of the users including an unique code (easy to filter), their corresponding room and the action description. The logfiles were set up according to the codebook with the specific code, corresponding room, action described and with the addition of date and time, as can be seen

in Table 6. Almost every sensor in the Smart home and the information it produced needed to be included in the logfiles except for the home automation.

Functional requirements for the logfiles were that they should be stored in such a form that they could be imported in Excel or SPSS for the analysis. Eventually, the comma separated value file format was used. Another requirement was that the logdata should be able to be downloaded and be visible without third-party intervention and always be up-to-date.

With all this information stored in logfiles, the data can be transformed into relevant information, feedback and visualizations for the elderly and caregivers. The logdata protocol serves therefore as the basis for the analysis and therefore also for the PHR and the content of the EPR. As everyday behavior of elderly is closely related to their health status, it is important to learn, recognize and understand the daily activity patterns and to detect irregular behavioral changes [2, 4]. When an elder is living in the Smart Home, the system should therefore first monitor the elder's normal daily activity patterns/behavior and health related values so it can recognize and understand these. This can be realized by analyzing and processing the sensor data by mechanisms such as Markov models or naïve Bayes classifiers [34].

Table 6: Example set-up logfile

Code	Room	Action	Date	Time
SKBK7	House	Crossline Bedroom – Bathroom	06-07-2015	17:00:45
BKK7	House	Crossline Bathroom – Kitchen	06-07-2015	17:03:32
KK11	Kitchen	Kitchen cabinet 1 open	06-07-2015	17:04:56
VI2	Living room	Fall incident living room	08-07-2015	03:31:45
AL4	Bathroom	Alarm ripcord bathroom	12-08-2015	07:05:00

It is important that the system is also able to combine sensor data and recognize irregular behavior, early health problems and dangerous situations by the use of algorithms. When for example an elder is drinking, eating, sleeping and toileting more frequent combined with a decreased weight, the system should be able to recognize these symptoms for the development of (pre)diabetes and automatically display a red warning sign in the status display for the caregivers. The information collected must be analyzed automatically and be reported in the PHR and the EPR according to their user's needs and wishes [34].

Conclusions

In conclusion, this study provides a basis for the further analysis of sensor data gathered from Smart Homes technologies and the development of a PHR and the content of the EPR. It also gives recommendations about providing persuasive feedback and assistance to elderly. Main results show that a health summary visualized in a status display that allowed the users to obtain more in-depth information is preferred and also the use of persuasive messages and assistance can be valuable. The recognition of abnormal values, dangerous situations and behavior is seen as important and elderly and caregivers should be warned by the system by receiving an alert on their mobile phones or pagers and by showing a red warning sign in the status display.

This study can contribute to the question how to translate Smart Home sensor data into knowledge, information and persuasive feedback and how to visualize relevant information in

a meaningful, holistic, understandable, usable but concise manner that concentrates on regular living aspects by using a human-centered approach.

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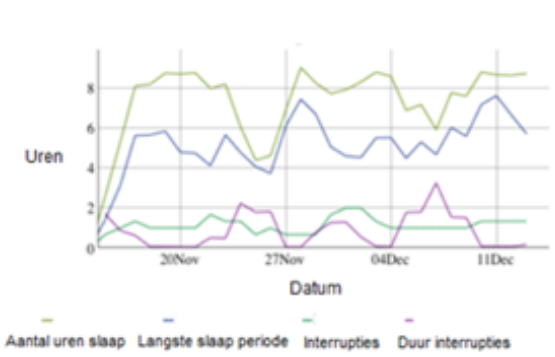
Appendix A



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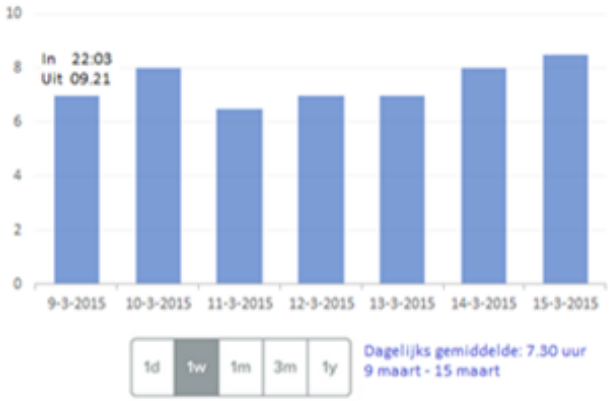
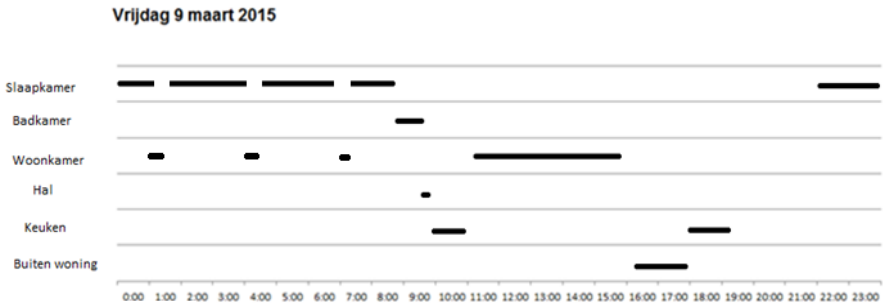
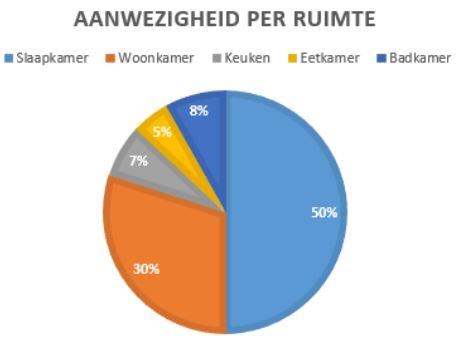


B.

Figure 13: Examples of visualizations of sleep pattern



A.



B.

Figure 14: Examples of visualizations of presence per room

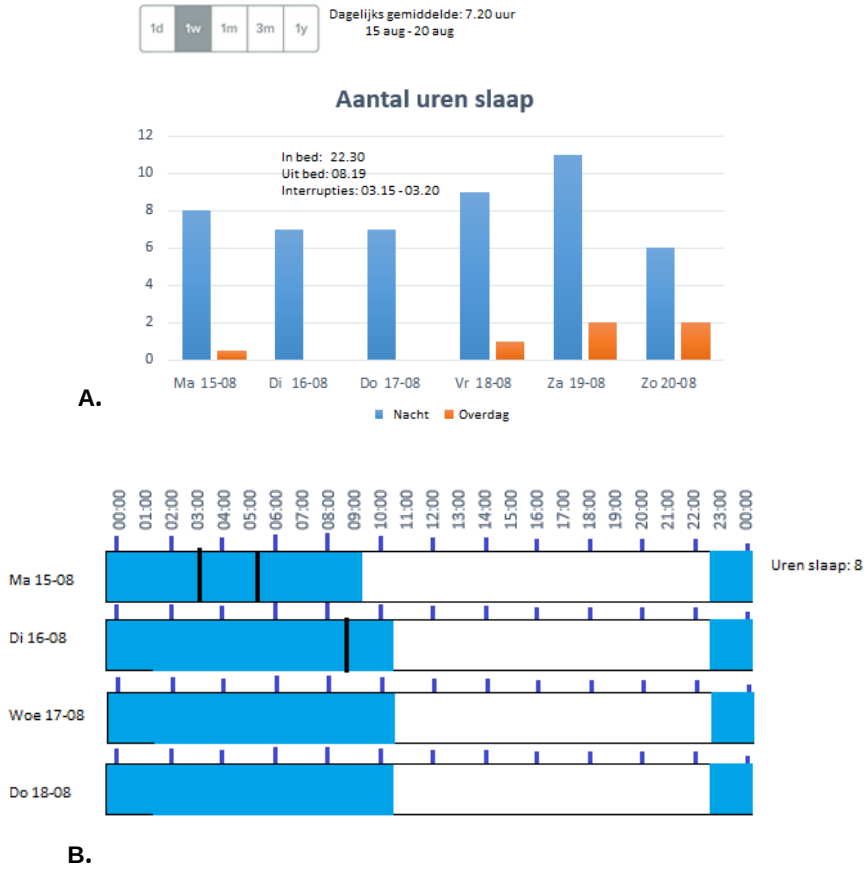


Figure 15: Recommended visualizations of sleep pattern

A.

B.

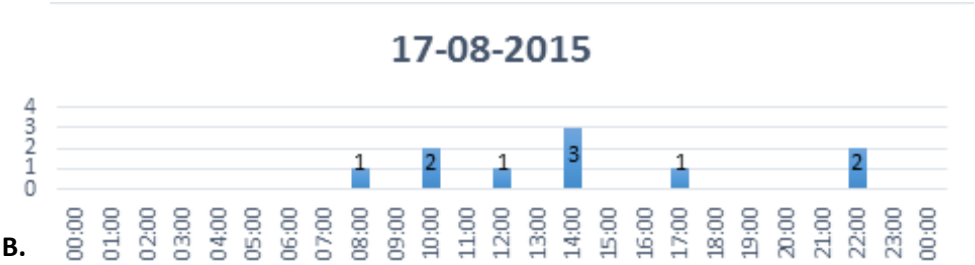


Figure 16: Recommended visualizations of frequency information