User-centred Design and Evaluation of Health Information Technology

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In loving memory of my dear mother Guðný
who sadly passed away during the evaluation of this thesis.

Abstract

Health information technologies play an important role in exchange of information and coordination of continuity of care in health care services. This thesis explores the approach of user-centred design and evaluation in the development of health information technology, with the main research focus on end-user involvement. A study on user-centred design and evaluation in the externally funded research projects *United4Health* and *eHealth- extended Care Coordination* was conducted. In addition, the internal project *Visually impaired users touching the screen - A user evaluation* evaluated visually impaired users using mobile technology. In the EU project *United4Health,* a collaborative telemedicine system for remote monitoring of chronic obstructive pulmonary disease patients was developed. The regional project *eHealth-extended Care Coordination* addressed the information flow within inter-municipal health care teams to build a collaborative information system that facilitated coordination between municipalities. In both projects, end-users were involved in workshops in an early design phase and participated in usability evaluations during the iterative development. A mixed methods research approach including observations, semi-structured interviews and a questionnaire was used for data collection in the user-centred design process. The data analysis was based on a qualitative content analysis from a human-computer interaction perspective. This thesis also addresses the topic of the usability evaluation of health information technology from the perspective of the technical infrastructure necessary for optimisation of data collection and retrospective analysis of data. In this regard, a usability evaluation of a mobile touchscreen together with visually impaired users was made.

The results from the user-centred design and evaluation research are presented in this dissertation through a collection of 9 scientific published papers in international peer-reviewed journals and conference proceedings. This study contributes to the knowledge of user-centred design in several ways. Firstly, this thesis provides an understanding on how to actively and efficiently involve users in design and development of health information technology by conducting empirical research. Secondly, it contributes to the knowledge on how to run usability evaluations of health information technology in high fidelity laboratory settings, health care environment and patients' homes. Thirdly, it provides recommendations for a technical infrastructure in order to optimise the outcome of usability evaluations. The Norwegian Social Science Data Services approved the studies presented here.

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Research Environment

The PhD studies involved in this dissertation have been performed at the University of Agder (UiA), Faculty of Engineering and Science, Department of Information and Communication Technology (ICT) as part of the PhD program in ICT. The project contribution of the PhD candidate was made in close collaboration with the Centre for eHealth and Health Care Technology at Campus Grimstad, UiA.

One of the PhD specialisation courses was made in collaboration with the University of Nebraska, USA, and another with the Abertay University in Dundee, Scotland, UK. One of the basic PhD courses was conducted at the Aalborg University in Denmark.

The Norwegian Ministry of Education and Research financed the PhD studies.

Personal Background

Prior the PhD studies, the PhD candidate held a Master of Science in Telemedicine and eHealth awarded by the University of Tromsø, Norway. The master degree provided relevant background knowledge in telemedicine applications, implementations of health information technology and qualitative research methods, which inspired to continue in the research field as a PhD research fellow.

The reason for starting the PhD studies was a personal interest in telemedicine and ICT solutions for health care services, with the awareness of how new technology and improvements of existing solutions can positively impact the daily practices for the providers of health care services and the everyday life of services' users.

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Abbreviations

ACM	Association for Computing Machinery
ALFA	Activity Log File Aggregation
API	Application Program Interface
CIS	Collaborative Information System
COPD	Chronic Obstructive Pulmonary Disease
DOI	Digital Object Identifier
EHR	Electronic Health Record
EU	European Union
ETO	Limited Telemedicine Monitoring
FTO	Full Telemedicine Monitoring
FP7	Seventh Framework Programme for Research
F4V	Flash Video Format
GP	General Practitioner
GUI	Graphical User Interface
HCI	Human-Computer Interaction
HIS	Health Information System
HIT	Health Information Technology
IARIA	International Academy, Research and Industry Association
ICD	International Statistical Classification of Diseases and Related Health Problems
ICT	Information and Communication Technology
IEEE	Institute of Electrical and Electronics Engineers
IMC	Inter-municipal Cooperation
IOS	Mobile Operating System (Apple Inc.)
IP	Internet Protocol
IS	Information System
ISO	The International Organization for Standardization
IxD	Interaction Design
KS	Norwegian Association of Local and Regional Authorities
LAN	Local Area Network
MMR	Mixed Methods Research
MMSE	Mini Mental Status Evaluation
MP4	Digital Multimedia Format
NHN	Norwegian Health Network

OS	Operating System
NSD	Norwegian Social Science Data Services
NSF	Norwegian Nurses Organisation
PC	Personal Computer
PDF	Portable Document Format
PIN	Personal Identification Number
PMD	Personal Medical Device
PSP	Policy Support Programme
QSR	Qualitative Data Analysis Software
RFFA	Regional Research Fund Agder
RQ	Research Question
SD	Standard Deviation
SMS	Short Message Service
SOA	Service-Oriented Architecture
SUS	System Usability Scale
SPO$_2$	Pulse Oximetry
TA	Think Aloud
UCD	User-centred Design
UCSD	User-centred Systems Design
UI	User Interface
UiA	University of Agder
UID	User Interface Design
USB	Universal Serial Bus
UX	User Experience
U4H	United4Health
VLAN	Virtual Local Area Network
VLC	VideoLAN Client (Media Player)
VPN	Virtual Private Network
WHO	World Health Organization
WMV	Windows Media Video
QSR	Qualitative Solutions for Research

Part I

1 Introduction

The background and the motivation for the PhD research study are presented in this chapter. The definitions of User-centred Design (UCD) and eHealth related terms are discussed in section 1.2. The problem statement and research questions are stated in section 1.3, followed by the limitations of the scope. The structure of the thesis is outlined in the last section 1.5.

1.1 Background and Motivation

In the National Health and Care Services Plan (2011-2015), the Norwegian government presented the goals for safe and effective health and care services in order to promote good health and prevent diseases, stressing the importance of technology innovation in achieving these goals [1]. The Norwegian Coordination Reform [2] that was adopted in 2012 focused on continuity of care. The reform demanded from health care services an implementation of structural changes that promoted an increased use of ICT solutions to improve collaboration and coordination of services. The application of this reform addressed the need for an effective coordination and collaboration between professionals, organisations and end-users of the National Health and Care Services. This could be achieved by a balanced combination of medical expertise, technology innovation and interdisciplinary research where new technological solutions could satisfactorily meet the demands of the health care services. Despite the fact that health care services usually involve heterogeneous user groups, such as health professionals, administrative employees and patients, these groups share a common need: *easy-to-use* systems that support collaboration and coordination between users.

In this context, this PhD research study had the ultimate goal to use UCD as a methodology for the development of health information technology with an active involvement of users. Three projects were incorporated into the PhD research study

(further presented in Chapter 2), with a focus on design and evaluation of health information technology.

This PhD research study was made within the field of eHealth, with foundation in research methods from Human-Computer Interaction [3][4] and inspiration from Information Systems [5][6][7], design research [8][9] and health sciences [10][11].

The Nordic countries have a strong focus on eHealth, with a policy on improving quality, effectiveness and the empowering of patients through information technology, where enhancement of usability is one of the goals [12][13]. UCD has already been used in health contexts, such as in [14][15][16][17], where the studies show the importance of user participation from the early stage of designing a technological solution. However, many studies do not reach final deployment stage. The motivation for this PhD research study was to provide methods and experiences for how UCD can practically be used in development of health information technologies, with a special focus on *user involvement* and *usability*. The contribution to the research community is a detailed description of two UCD processes, one of an application whose final result has been deployed in real settings and another with a four year long development process.

1.2 Definitions of Terminology

Terms related to the research field are defined through literature and studies made in the area and explained in the following two sections.

1.2.1 Terms related to User-centred Design

There are several research fields concerned with how to design technology in systems' development. For instance, User-centered Systems Design (UCSD) [18], User Experience (UX) [19], User-centred Design (UCD) [20][21] also called Human-centred design, Interaction Design (IxD) [22][23] and Human–Computer Interaction (HCI) [24][25] are all research areas aimed at improving the way which people interact with technology. These research areas have different approaches, but they share methods for designing effective technologies and systems for human use.

In this thesis, the term *User-centred Design* (UCD) refers to end-user involvement in all the stages of technology design and development. Chapter 4 elaborates more on the practical approach of UCD.

Usability is a term applicable to products in general, but also to systems and user interfaces. Usability is often described as the quality of use [26] or the ease of use of a

software user interface. Jakob Nielsen [27] described usability as a "*quality attribute that assesses how easy user interfaces are to use*". He further characterized usability by five quality components [28]:

> "*Learnability: How easy is it for users to accomplish basic tasks the first time they encounter the design?*
>
> *Efficiency: Once users have learned the design, how quickly can they perform tasks?*
>
> *Memorability: When users return to the design after a period of not using it, how easily can they reestablish proficiency?*
>
> *Errors: How many errors do users make, how severe are these errors, and how easily can they recover from the errors?*
>
> *Satisfaction: How pleasant is it to use the design?*"

Bevan [26] described usability as follows:

> "*The objective of usability is to achieve quality of use. Usability requirements should be stated in terms of the effectiveness, efficiency and satisfaction required in different contexts. User-based evaluation can be used to validate achievement of these requirements.*"

The term *usability*, has the following definition by the International Organization for Standardization (ISO), ISO/DIS 9241-11 [29]:

> "*The extent to which a product can be used by the specified users to achieve specific goals with effectiveness, efficiency and satisfaction in a specified context of use.*"

In this thesis, the term *usability* is used in relation to usability evaluation and user interfaces. Chapter 5 elaborates more on evaluation of usability.

1.2.2 Terms related to eHealth

The term *eHealth* usually refers to health services and information that make use of information and communication technology as a way to improve healthcare at all levels [30].

The World Health Organization (WHO) has the following definition of eHealth [31]:

"E-health is the transfer of health resources and health care by electronic means."

WHO outlined three main areas of eHealth:

1) *"The delivery of health information, for health professionals and health consumers, through the Internet and telecommunications.*

2) *Using the power of IT and e-commerce to improve public health services, e.g. through the education and training of health workers.*

3) *The use of e-commerce and e-business practices in health systems management."*

Further, WHO points out that eHealth provides new ways for efficient and improved use of resources, such as information, funding and medicines. The Internet also enables interaction and collaboration across organisations, health care providers and the public.

WHO defined *Telehealth* as the surveillance, health promotion and public health functions including computer-assisted telecommunications to support management, literature and access to medical knowledge.

Telemedicine is defined as the use of telecommunications to diagnose and treat diseases and ill-health [31]. Telemedicine can be defined as a remote electronic clinical consultation, with the delivery of health care and the exchange of health care information across distances made with use of technology. Telemedicine covers a diverse spectrum of technologies and clinical applications [32][33][34]. Telemedicine has the potential to improve the equity of access to health care services and, in turn, also the quality of the health care [33]. The use of mobile technology for monitoring diseases and personalized management is becoming popular. Mobile devices are used for collection of data from patients, electronic transfer of data over internet and mobile networks allowing for a remote feedback from health care professionals and interactive communication. The aims are to improve long-term cost-effectiveness, real time monitoring, the shortening of feedback times and the reduction of hospital visits [35].

Telemedicine systems often involve the interaction between multiple user groups through a system, e.g., by means of a device, a patient at home can communicate with a nurse in a telemedicine or health centre, or with a GP at their office. Communication in these scenarios of use is usually multimodal, that is, synchronous (e.g., videoconference) and asynchronous (e.g., data transmission and dispatch), what makes it crucial to know between *whom*, *how* and *when* the information transmission and personal contacts occur. Thus, an effective telemedicine application requires a detailed analysis of end-users' needs to inform system designers where the usability is crucial for the continuous, efficient and satisfactory use of an application.

Remote monitoring means the use of devices to remotely collect, store and communicate biometric parameters from patient to health care providers [36]. The technology allows providers to monitor and intervene in patient care.

Health information technology can be defined as computer hardware and software for storing, sharing, and analysing health information for communication and decision making. A central component of health information technology is the electronic health record (EHR) [37][38].

In this thesis, the terms used are *health information technology, eHealth, telemedicine* and *remote monitoring* in the context of interaction between technology, users and health care services.

1.3 Problem Statement

End-users of health information technologies often report a low degree of usability and these technologies are described as complex, not intuitive and requiring user training for successful use [39][40][41]. There is a national agenda on technology innovation across the National Health and Care Services of Norway [1][2] to support communication, optimisation of resources and increase of cost effectiveness.

This PhD research study aims to contribute to knowledge on how to address user needs, including suggestions and preferences, in the development of health information technology by involving end-users from an early idea generation until final deployment. End-users of technology from primary and specialised health care services together with patient representatives were targeted in this research by involvement in three projects related to development and evaluation of health information technology.

A mixed methods research approach (MMR) [42] was chosen in order to study the end-user involvement. The outcome of this thesis is expected to provide methods and experiences for how user involvement in design and evaluation can practically be performed and inform development of health information technologies that are *easy to use* and with a high level of *user satisfaction*.

The following three research questions (RQs) were stated for the PhD research study:

> *RQ1: How can health information technology be developed taking into account the needs and requirements of the end-users during all the phases of development?*

> *RQ2: What technical infrastructure is suitable for user evaluations of health information technology?*

> *RQ3: What lessons and methodological procedures are transferable and applicable to other development projects of health information technology?*

1.4   Limitation of Scope

This dissertation has the primary focus on the user-centred design and evaluation of health information technology in the context of the studied research projects. Medical and organisational aspects, technical requirements and information security for development are not covered in this thesis. The ideas and suggestions derived from the user-centred design and evaluation research study are aimed to benefit other projects' in health information technology development.

1.5   Structure of the Thesis

This thesis consists of two parts: *Part I* provides an overview of the research process related to the projects carried out during the PhD study and *Part II* presents the scientific contribution from the PhD research study by means of a collection of publications. The papers are presented in a thematic order, with the same content as the original papers with an adapted format.

Part I

Part I provides an overview and a summary of the thesis. Chapter 1 consists of introduction and motivation for the PhD research study. Problem statement and research questions are stated. Chapter 2 describes the research background with an

overview and the context of the three research projects involved in the PhD research study. Chapter 3 describes the research methods applied in the PhD research study on UCD and an evaluation of health information technology. Chapter 4 presents related work conducted in the field of UCD followed by the practical application of UCD in the projects involved. Chapter 5, firstly presents a literature review on usability evaluation and, secondly, the practical application of usability evaluation in the three projects involved. In Chapter 6, the main results from the PhD research study are discussed. Chapter 7 presents the summary of the thesis' contributions and future work.

Part II

Part II consists of 10 Appendices. In Appendix A, 9 peer-reviewed published scientific papers are listed (Paper I-IX) and included in the scope of this thesis. In addition, 3 more papers are listed (Paper X-XII), but outside the scope of this thesis. The PhD candidate was the first author in 10 of the publications and second author in 2 of the publications. Out of the 9 included papers, 3 are international journal papers (Paper I, II and III) and 6 are international conference papers (Paper IV-IX), all with the status *published*. They are fully presented in Appendices B-J.

Paper I-III were written as part the European Union (EU) research project *United4Health* (U4H) [43], which designed long-term telehealth solutions for chronic disease patients.

Paper I presents the UCD process of a collaborative information system for a telemedicine service. The collaborative information system provided a platform for management of remote monitoring of chronic obstructive pulmonary disease (COPD) patients at home. Representative end-user groups were involved in the UCD process in user workshops, evaluations in laboratory and in health care settings.

Paper II presents the UCD process of a mobile application for remote monitoring of COPD patients. A tablet device application was developed based on information gathered during a workshop and group interviews with end-users where iterative development and evaluations were part of the process. User evaluations showed positive results on the ease of use and user satisfaction regarding the interaction with the application.

Paper III presents the usability evaluation in the field of a mobile application for remote monitoring of COPD patients. The field trial was performed with six COPD patients at their homes, continuously using the system's application on a tablet for seven days. The field trial consisted of three phases: 1) participant's user training; 2) participant continuous use of the application for one week at home; 3) usability evaluation and interview at participant's home. 23 usability issues were identified during the field trial, which were iteratively resolved in a later phase.

Paper IV-VIII were written within the research project *eHealth- extended Care Coordination* funded by Regional Research Fund Agder (RFFA) [44], a regional research project focused on collaboration and information flow in inter-municipal health care teams.

Paper IV presents the UCD process of the user interface of a collaborative information system for an inter-municipal dementia assessment team. A prototype for the collaborative information system was designed with the active involvement of end-users in workshops and user evaluations. The prototype was validated from operational and a qualitative usability perspective, including a graphical evaluation by graphic design experts.

Paper V presents the usability evaluation of electronic dementia assessment forms and a collaborative final assessment report by videoconference, in order to evaluate the potential application of these electronic tools in an inter-municipality workflow of the dementia team. The evaluation showed that electronic forms helped to reduce the paper load of the process, allowing repeated access to the forms for retrospective amendments and reviews. The videoconference with document sharing was reported to be an effective tool to cooperatively work on the final report of the dementia assessment between the members of the dementia team.

Paper VI presents how the prototype described in Paper IV was evolved into the final version of the collaborative information system. The aim of the paper was to present findings of the usability evaluation with end-users of this final version of the system. Mixed methods such as observations, semi-structured interviews and a questionnaire were used for data collection in the usability evaluation. The results showed that the new information system supported the collaborative work of the inter-municipal dementia team with a sufficient level of satisfaction among the end-users, even though participants initially showed some reluctance for a final implementation of the system.

Paper VII describes the user involvement during the different phases of the four-year research project *eHealth- extended Care Coordination*. The development of the collaborative information system for dementia assessment was made through a UCD approach, where mixed methods, such as observations, semi-structured interviews and questionnaire, were used for data collection. The paper concluded that end-user involvement usefully informed the development.

Paper VIII and IX focus on the technical infrastructure for usability evaluations, in order to optimise the environment for adequate high quality data collection that allows an effective retrospective analysis of the data.

Paper VIII focuses on the end-to-end infrastructure for usability testing of eHealth technologies. The paper objective is to describe the requirements and technical aspects necessary for a test infrastructure. The infrastructure was used in the *United4Health* project [45], simulating both the Point-of-Care and the Health and Care Service Provider.

Paper IX presents recommendations for a technical and physical infrastructure in a controlled laboratory environment for user evaluations of mobile technology. The reflections were made within the research project *Visually impaired users touching the screen - A user evaluation of assistive technology* where VoiceOver, a screen reader in Apple Inc. products, was tested. The paper reports on challenges related to the use of the test infrastructure, such as how to obtain valuable data when interactive high-speed gestures are performed and how to optimise the recording and syn-chronisation between audio and video data.

2 Research Background

The research background, key concepts of the three projects involved in this PhD research study and the role and contribution of the PhD candidate are presented in this chapter.

2.1 Centre for eHealth and Health Care Technology

The PhD candidate has worked in a close collaboration with the researchers at the *Centre for eHealth and Health Care Technology*, a research centre at UiA [46], Norway. The centre was established in 2010 with a multidisciplinary cooperation between the Faculty of Health and Sport Sciences, Faculty of Engineering and Science and the Faculty of Social Sciences and was defined as one of the strategic focus areas of UiA with the vision to do user-centred high quality research and development aimed at current and future care practices. The centre contribution aims at increasing the effectiveness, efficiency and security of technology for citizens in their daily life. In the clinical laboratory at Campus Grimstad, UiA, a 450m2 area called "mini Health Care Norway" has been established, including a patient home with smart-house integrations and with a secured health network infrastructure. In addition, the facilities include a state-of-the-art usability laboratory for controlled laboratory tests of new ICT solutions and procedures. The centre has five employees in full- and part-time positions, 12 PhD research fellows and several master students, all of whom are involved in the centre's research projects.

2.2 The Research Project United4Health

United4Health (U4H), [43] (from now on called *Project I* in this thesis) is a research project partially funded by the Seventh Framework Programme for Research of the European Union (EU FP7) [47] and Point-of-Care Services Agder a sub-project financed by the Research Council of Norway, with a focus on the patient experiences with telehealth solutions for management of long-term conditions in Europe. More than 20 countries have been involved in the project in the period 2012-2015. Over

20.000 patients with chronic diseases such as diabetes, hypertension, congestive heart failure and COPD were enrolled. The aim of the project was to transform the way in which healthcare is delivered, deploying technical solutions at a regional scale that were adapted into routine care. New technology was used to support the collaboration across organisational borders and health care information management of remote monitoring.

The Norwegian contribution to the U4H project [45] was connected with the development of a collaborative telemedicine system for remote monitoring of COPD patients after hospital discharge, and a follow-up study of the patients and technology involved. The Norwegian partners were hospitals, universities, municipalities and companies.

UiA (in Southern Norway) was responsible for the development of the new collaborative telemedicine system. The development included design in parallel with a 1) tablet application to be used by the patients for home measurements of pulse oximetry (SpO_2, i.e., pulse and blood oxygen) and a questionnaire on self-reported symptoms to be filled out daily; 2) an information system (IS) (in Norwegian called *Forløpsjournalen*) for a telemedicine centre for information management and communication efficiency. Measurements' data were transmitted from the tablet device over the mobile network. The IS was designed for a sustainable operation and was deployed within the secured Norwegian Health Network (NHN) [48]. Further details on privacy and security are described in [49] and are not covered in this thesis.

About 200 patients were planned to be enrolled in a research study with the use of the tablet application for remote monitoring in the South-Norwegian region of Agder. The hospital partner was responsible for the selection of patients for the research study and introduced remote monitoring to the COPD patients. The municipality partner established a telemedicine centre managed by specially trained nurses. The nurses used a dedicated information system for management of home measurements and daily follow-up of the COPD patients including a video conference system (software Cisco Jabber Video for Telepresence, v4.2 [50]).

In order to achieve acceptable levels of effectiveness, efficiency, and satisfaction, a UCD process [14][18][51] was employed for the development of the collaborative telemedicine system. Early in the design and development, representative end-user groups were contacted and invited to a workshop to design the functionality and the UI of the telemedicine system.

2.2.1 The role of the PhD Candidate in Project I

The PhD candidate had a central role in the UCD process and was responsible for applying to the Norwegian Social Science Data Services (NSD) [52] for permission for data collection. The PhD candidate was responsible for preparation and coordination of the workshop and usability evaluations in the Usability Laboratory in facilities of Centre for eHealth and Health Care Technology at Campus Grimstad, UiA. The workshop was held together with stakeholders and key informants from a patient organisation, municipalities and hospital. The system development was performed through iterations where user evaluations informed subsequent system refinements. The PhD candidate was the test leader and had the role of the moderator in the sessions in the laboratory test room. In addition, the PhD candidate moderated group interviews with end-users regarding evaluation of the telemedicine system. In total 24 test participants contributed to the UCD process. As part of the final evaluation of the telemedicine system, the PhD candidate together with a member of the research team, visited health care professionals at their work to perform usability evaluation and interviews. In addition, visits were also made to the homes of COPD patients who had used/were using the technology. A mixed methods approach such as observations, interviews and questionnaire was used in the data collection. All transcriptions were made by the PhD candidate and qualitative content analysis was applied to the collected data, with coding and categories [3]. The PhD candidate coordinated and worked together with the research group reporting from the UCD process in scientific publications (paper I-III and VIII). The PhD candidate was the first author of two published international journal papers based on this research project, one international conference paper and another two as co-author.

2.3   *The Research Project eHealth-extended Care Coordination*

The project *eHealth- extended care coordination* (in Norwegian *Samhandling uten grenser*) was funded by the Regional Research Fund (RFFA) [44] and executed in four phases from 2011 to 2015. The project (called *Project II* from now) focused on information flow in inter-municipal health care teams in Southern Norway.

In the first phase of the project, a field study mapped out the information flow in inter-municipal health care teams and identified the need for improved ways of communication and coordination. The collaborating municipalities used different information systems and among the bottlenecks identified was lack of access to medical information for the members of the inter-municipal health care teams. A

collaborative IS was suggested in order to improve the information flow in inter-municipal contexts of operation. One of the main goals for the project was to establish user requirements for a collaborative IS, in order to facilitate sharing of medical information between the municipalities.

In the second phase, an inter-municipal dementia team with representative end-users from four municipalities participated in a UCD process which consisted of user workshops, laboratory evaluations and interviews, for the purpose of collecting user requirements and development of a functional prototype for a collaborative IS for dementia assessment. The user interface design was evaluated in the Usability Laboratory at the Centre for eHealth and Health Care Technology together with end-users and graphic experts.

In the third phase, a usability evaluation of electronic dementia assessment forms for home visits and a videoconference solution for collaborative dementia assessment report writing were performed with the participation of an inter-municipal dementia team.

In the fourth project phase, the final version of the collaborative IS was developed by a project partner (Devoteam AS in Grimstad, Norway) and deployed within the secured Norwegian Health Network (NHN) [48]. The user interface design was evaluated in the Usability Laboratory together with end-users.

2.3.1 The role of the PhD Candidate in Project II

The PhD candidate had a central role in the UCD process for the collaborative IS and was responsible for applying to NSD for permission for data collection. Further, the PhD candidate planned the agenda of user workshops and coordinated the usability evaluations. The PhD candidate was the test leader in the usability evaluations and moderated the test sessions in the test room. In total, 6 researchers from UiA were involved in the research process. The PhD candidate coordinated the evaluations in phases two, three and four, and contributed to meetings with interaction designer and developers. In total, 7 end-users from inter-municipal team contributed to the UCD process. A mixed methods approach such as observations, interviews and questionnaire was used in the data collection and analysis. All transcriptions were made by the PhD candidate. The results of the UCD process have been presented in four international conference publications (paper IV-VII) with the PhD candidate as first author.

2.4 Visually impaired users touching the screen - A user evaluation

Visually impaired users touching the screen- A user evaluation was a master's project [53] of a student in the Health and Social Informatics program at UiA (called *Project III* from now). The study aimed to discover what challenges visually impaired users experience when they interact with a mobile touchscreen using hand gestures. For people with visual impairments, a touchscreen can become a significant accessibility barrier since this type of screen does not usually provide audio or tactile feedback when it is touched. However, there are currently being developed solutions that will enable visually impaired users to adopt this technology.

In Project III, a usability evaluation of the screen reader VoiceOver from Apple Inc. developed for IOS devices such as iPhone and iPad, was carried out. VoiceOver is intended to allow a user to interact with the UI through gestures with fingers combined with speech feedback. The study included six visually impaired test participants that participated in usability evaluation at the Usability Laboratory at the Centre for eHealth and Health Care Technology, UiA.

The research team identified a number of challenges related to the use of the test infrastructure for usability evaluation, such as how to obtain valuable data when interactive high-speed gestures are performed on a mobile touchscreen and how to optimise the recording and synchronisation between audio and video data for high quality analysis.

2.4.1 The role of the PhD Candidate in Project III

The PhD candidate was the supervisor of the master student and gave advice regarding NSD, planning of test and analysis. Further, the PhD candidate was the observer in the observation room during the usability evaluations together with one other researcher. The PhD candidate was responsible for technical preparation of the test facilities. The PhD candidate has published one international conference paper (paper IX) focusing on technical infrastructure in mobile testing based on the experiences from this project. The master student was one of the co-authors.

3 Research Methodology

This chapter describes the research methods applied in the study of UCD and evaluation of health information technology. Firstly, the research design with an overview of qualitative, quantitative and mixed methods research is presented. Secondly, the data collection of empirical material is described in section 3.2. Reflections and insights on the research approach are discussed in section 3.3. Ethical considerations are formulated in section 3.4, followed by the declaration of conflict of interest.

3.1   Research Design

The aim of the PhD research study on UCD of health information technology was to gain understanding on how to usefully include user needs in the design of a technology solution and the complexity of the interactions between end-users, developers and the research team. A combination of qualitative and quantitative research methods was applied to obtain an in-depth insight throughout the steps of the UCD process. The following text generally describes qualitative and quantitative research methods, includes a comparison of the methods and reflections on their complementariness.

Qualitative research methods have a basis from the field of social sciences and seek to understand social phenomena in a natural context. One of the benefits of qualitative research is achievement of in-depth accounts from individuals and groups using different techniques such as participant observation, interviews, focus groups and case studies [54][55][56]. The research material of qualitative research, usually textual material, is systematically collected and interpreted. One of the concerns of the scientific community is related to the validation of subjective qualitative material and representativeness of sample size. Triangulation and reflexivity have been suggested to improve the validity of qualitative data [57][58].

Quantitative research methods stem from natural sciences and focus on systematic measurement techniques. Quantitative data is usually in numerical form and its

analysis made through statistics and mathematical modelling [3][59]. One of the strengths is the collection of large sample data with validation, verification and hypothesis testing. The outcomes are precise and numerical results. Criticism regarding the method is lack of personal expressions to interpret the meaning of phenomena or behaviour in a qualitative way. Qualitative and quantitative methods are often compared to each other in the validation of research results and they are frequently presented as adversaries in the methodological battle [60]. Kuper et al., (2008) provided a brief explanation of the difference between the methods [61]:

> *"In general, quantitative research focuses on answering the questions "what?", "how much?", and "why?", whereas qualitative research focuses on answering the questions "why?" and "how?"*

Mixed Methods Research (MMR) is often called *the third methodological movement* and applies the qualitative and quantitative approaches in conjunction with one another [62]. The use of MMR can strengthen and enrich research results, as well as achieve a result with strong validity [42][63] Johnson et al., (2007) provided the following definition of MMR [64]:

> *"Mixed methods research is the type of research in which a researcher or team of researchers combines elements of qualitative and quantitative research approaches (e.g., use of qualitative and quantitative viewpoints, data collection, analysis, inference techniques) for the broad purpose of breadth and depth of understanding and corroboration."*

This PhD research study on UCD of health information technology applied a MMR approach. The rationale for choosing triangulation of the methods was to strengthen the validity of the results and to provide an detailed understanding during the UCD processes. The UCD processes consisted of several steps divided into two main phases: (1) workshop with representatives of the end-user groups to gather user requirements and (2) iterative development including user evaluations and interviews. The qualitative methods were chosen to gain in-depth understanding of the user needs and the user experience of the technology, before and during the development. The quantitative approach was used for measuring user satisfaction during the evaluation of the technology.

The research methods involved in the study of the UCD process were based on an initial *literature review*. From the literature review the methods *observation study*, *interview* and *questionnaire* were considered appropriate for the study of the UCD process. Each method is further described in the next sections. The data collection and related analysis are also explained.

3.1.1 Literature Review

In the preparation of the PhD research study on UCD and evaluation of health information technology, a literature review was made to gather information from other studies in the same topic. In the literature search, the Internet sites of the University of Agder's Library in [65], The Norwegian Electronic Health Library [66] and Google Scholar [67] represented the main search engines. Search terms included *User-centred/centered design*, *Participatory design*, *Human factors in design*, *Interaction design*, *Usability studies*, *Usability evaluation*, *Human-computer interaction*, *Qualitative content analysis*. The Internet sites of the Norwegian government [68] and the Directorate of Health [69] were sources of relevant information regarding eHealth policy and implementation practices in Norway.

Research studies [17][70][71][72][73] from the literature review provided the groundwork and inspiration for how to outline the PhD research study and contributed to the choice of usability evaluations, interview and questionnaire. The books *Interaction design* [22], *Web Usability- a user-centered design approach* [51] and *Research Methods in Human-computer interaction research* [3] that were thoroughly read, contributed to an understanding of the foundations of the research topic.

In addition, the syllabus in the PhD specialisation courses in *Human-computer Interaction Research* and *Usability Evaluation* (IKT 712 & 715), the PhD basic courses in *Research Methods in Information Systems* (ME 606) and *Scientific Project Creation and Management* (TFL 600) were very useful and provided relevant knowledge regarding the research topic.

3.1.2 Observation Study

The user workshops in *phase 1* of Project I and II were classified as observation study. The workshops were organised in order to understand the context of use for the technology and provide background information to the research team with the perspective of the participants. Therefore, observation was used as a qualitative method [22][74]. The workshops were led by the research team and were performed as

interactive sessions between the research team and end-users. The workshop's participants had the role of key informants for the research projects. The workshop sessions focused on prepared topics regarding description of existing workflow, context of use for new technology, suggested way of interactions and suggestions for the graphical user interface (GUI). In addition, participants described the organisation of their working place, work processes and the use of existing systems.

The workshops were audio-visually recorded using a portable video-camera. The recordings were made in AVCHD video file format, converted to MP4 format and then imported to the software QSR NVIVO 10 [75] for viewing and transcription. The language used in all recordings was Norwegian and all transcription was made verbatim in Norwegian. A qualitative content analysis [3][76][77] was made of the transcripts, coded into categories supported by QSR NVIVO 10. The content of each category was translated into English for publication purposes. Examples of the coding categories of the workshops' transcripts are: *Workflow description*, *Context of use*, *User suggestion for interaction with system*, *User suggestion for user interface design* (UID).

The results from the end-user workshops in Project I and II are described in Papers I, II and IV.

The user evaluations in *phase 2,* the iterative development in Project I and II, were classified as observation study in laboratory and inspired by the field of Human-computer Interaction (HCI) research [3][22][70].

For the preparation of the user evaluations, the research team needed to understand the context of use for the health information technology. The end-user workshops provided the necessary information about the existing end-users' workflow. The test plan included tasks to be solved by participants. The tasks were related to daily activities typical for the end-users (i.e., health care professionals or patients). Test participants in the evaluations were end-users of the health information technology.

The use of Think Aloud (TA) protocol is common in usability studies [70][71][72]. The usability evaluations in this research study followed a similar procedure with slight variations. Some of the evaluations were made in a pilot phase, while others at the end of the technology development. They were all based on recommendations on research methods from Lazar [3] and the test procedure was inspired by Jaspers [70] and Kushniruk and Patel [72]. In all the usabilty evaluations participants had to complete a task list, with a determined number of tasks and subtasks. The tasks were presented one by one and the participant had to declare the task *solved* or *unable to*

solve to the moderator before moving to the next one. Participants had to complete one by one of the tasks and subtasks and while doing each task, participants had to speak out loud in order to help the research team to understand the following:

- *What does the user think?*

- *How is the problem solving of the user?*

- *Why does the user choose the action?*

In the first evaluations all tasks were presented in order on a sheet of paper. Later on, each task was placed on a separate page, in order to facilitate the focus on only one task at a time. In all evaluations, the participants were asked to try to solve the task on their own, with the possibility of asking for help when needed.

The task success rate and the time for the completion of each task were measured. The total time for each test session was also measured. The user evaluations in the usability laboratory were audio-visually recorded with two cameras and one screen capture tool (Telestream Desktop Presenter), all merged into one file (MP4 and F4V video file format) and imported to a qualitative analysis software (QSR NVIVO 10). The recordings were viewed and transcribed verbatim in Norwegian language by the research team. The transcripts were coded into categories for a qualitative content analysis. The coding categories were dynamically refined, with initial use of categories presented in [72]. During the analysis the categories were merged and new ones evolved from to the content of the data. Following are examples of categories used in the analysis: *Interaction with the system*, *Functionality of the system*, *Suggestions from the users* and *Graphical UID*. Sub-categories examples are. *Graphics*, *Lay-out*, and *Choice of colours*, *Icons* and *Labeling*. The errors identified were categorised into *minor* or *major* problems.

The results of the user evaluations are presented in Papers I, II, III, IV, V, VI and VII. A literature review and the performance of usability evaluations are described in details in Chapter 5.

3.1.3 Interviews

Structured pre-test interviews were made before each user evaluation for the collection of background information. After the user evaluations, semi-structured group interviews were carried out in order to qualitatively complete the feedback. The interviews allowed informants to speak freely about the user evaluation and the user experience as well as reflect on the UID. The interviews were also used to map out the

users opinions on the evaluation process in a group, using the group dynamics in a cross-disciplinary setting. In this line, Miller and Dingwall [78] stated:

"....an interview is not a conversation...it is a created opportunity to talk about something that the interviewer is interested in and that may or may not be of interest to the respondent."

The post-test group interviews followed an interview guide. However, some additional questions were finally included due to findings (e.g., problematic icons or labelling) in the observation study in the laboratory. At the same time, interesting points were raised in interviews that were relevant for the analysis of the observations. During most of the interviews, the informants were shown the UI on a screen to be able to view the GUI and demonstrate functionalities or problematic areas.

Interview guides were established in advance, with topics related to evaluation of UIs. Examples of topics from the interview guides:

- *What is your first impression of the UID?*
- *Graphic design, how should an optimal GUI look like?*
- *What do you think about the choice of colours, size and number of visible icons on the screen?*
- *What do you think about the layout/ organisation of screen?*
- *What do you think about the labelling: text, menus, meaning of icons.*
- *What is your experience on the navigation in the system? Is it intuitive? Is it clear?*
- *How would you describe the usability (or user-friendliness)?*
- *What is your overall impression about the system design and the functionality?*
- *How do the system design and the functionality relate to work processes and clinical work?*

Most of the interviews were audio-video recorded with one or two cameras. The video files were imported to qualitative analysis software (QSR NVIVO 10) for viewing and transcription. The transcriptions were made word by word in Norwegian, resulting in several hours of work for each interview. The transcripts were read several times before the qualitative content analysis. Examples of coding categories included: *Test*

scenario and procedure, *User training* and *New system versus existing system*. The coded categories were translated into English for dissemination purposes.

The results of the post-test group interviews are presented in Paper I, II, IV, V, VI and VII. In Paper III individual post-test interviews related to usability evaluation made in home settings of COPD patients are presented.

3.1.4 Questionnaire

The questionnaire System Usability Scale (SUS) [79] was chosen in order to evaluate the user satisfaction regarding the tested technology. The SUS questionnaire was completed individually after each test session. The SUS questionnaire was developed by Brooke in 1996 as a way to measure usability, which he reflected on as follows:

> *"Usability does not exist in any absolute sense; it can only be defined with reference to particular contexts. […] Despite this, there is a need for broad general measures which can be used to compare usability across a range of contexts."*

The SUS questionnaire contains 10 statements that are answered with a 5-point Likert-scale, see Figure 1. The SUS scale has been called a "cheap and effective tool" for assessing the usability of a product [80]. It is easy for the participants to complete, the results can be quickly calculated and it can be used to evaluate most types of UIs.

The polarity of the statements is evenly distributed: Question 1, 3, 5, 7 and 9 are positively enunciated and question 2, 4, 6, 8 and 10 are negatively enunciated.

A way to calculate the SUS score is to first sum the score contributions from each item. The score contribution will range from 0 to 4. For items 1,3,5,7 and 9 the score contribution is the scale position minus 1. For items 2,4,6,8 and 10, the contribution is 5 minus the scale position. When the sum is multiplied 2.5, the SUS scores will have a range of 0 to 100 [79]. Bangor et al. [81] described an empirical study of the SUS questionnaire, with 206 usability studies included and over 2000 participants. They used mean and standard deviation (SD) in order to calculate the satisfaction ratings and present the results.

System Usability Scale

© Digital Equipment Corporation, 1986.

	Strongly disagree				Strongly agree
1. I think that I would like to use this system frequently	1	2	3	4	5
2. I found the system unnecessarily complex	1	2	3	4	5
3. I thought the system was easy to use	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system	1	2	3	4	5
5. I found the various functions in this system were well integrated	1	2	3	4	5
6. I thought there was too much inconsistency in this system	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly	1	2	3	4	5
8. I found the system very cumbersome to use	1	2	3	4	5
9. I felt very confident using the system	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system	1	2	3	4	5

Figure 1 The SUS Questionnaire

There are several other scales available in order to measure usability. In a study different surveys (After Scenario Questionnaire (ASQ), Computer System Usability (CSUQ), Poststudy System Usability (PSSUQ), Software Usability Measurement Inventory (SUMI), System Usability Scale (SUS), Usefulness, Satisfaction and Ease of Use (USE) and Web Site Analysis and Measurement Inventory (WAMMI)) were compared, and the conclusion was that the SUS provided the most reliable results [82]. The initial paper of Brooke [79] where the SUS questionnaire was first published has been cited over 3500 times, and studies have confirmed the reliability of the SUS with

Cronbach's alfa 0.91 [81] with the conclusion that SUS can positively supplement a usability test and evaluation program.

The SUS questionnaire was used in both Project I and II, and the results are presented in Papers I, IV and VI.

3.2   Data Collection

The data collection entailed in total three user workshops, 25 user evaluations in laboratory and nine user evaluations in the field. Nine group interviews and nine individual interviews were carried out. All interviews were performed in Norwegian and lasted from 30 to 45 minutes. The audio-visually recorded material from workshops, user evaluations and interviews comprised about 60 hours in total. The SUS questionnaire had in total 45 respondents.

Regarding the observations, the main part of the observations took place in the Usability Laboratory and the Centre for eHealth and Health Care Technology. In addition, a few visits were made to the *field* (observations at work place of health care professionals). During the observations in the field, the context of the work place, the workflow and exchange of information regarding telemedicine follow-up was studied mainly by observing the nurses and the technology involved. The observations were used to obtain an understanding of the organisation, the roles of the health care professionals, and the treatment chain related to remote monitoring and telemedicine. The observations took place during day time. Field notes were taken together with several pictures in order to visually illustrate the context.

During the PhD research study, there were over 35 informants from the end-user groups. In addition, other people with different professions contributed by informal talking and counselling. In general, the degree of involvement of the end-user groups was satisfactory. Moreover, many participants enthusiastically contributed to the workshops, evaluations and interviews.

3.3   Reflections on Methodology

In qualitative research, there has been a concern on how to assess quality and how to judge qualitative work. Mays and Pope [57] outlined how qualitative methods might be judged, and argued for an assessment according to validity and relevance. They pointed out the following recommendations when doing an assessment:

"Worth or relevance: Was this piece of work worth doing at all? Has it contributed usefully to knowledge?

Clarity of research question: If not at the outset of the study, by the end of the research process was the research question clear? Was the researcher able to set aside his or her research preconceptions?

Appropriateness of the design to the question: Would a different method have been more appropriate? For example, if a causal hypothesis was being tested, was a qualitative approach really appropriate?

Context: Is the context or setting adequately described so that the reader could relate the findings to other settings?

Sampling: Did the sample include the full range of possible cases or settings so that conceptual rather than statistical generalisations could be made (that is, more than convenience sampling)? If appropriate, were efforts made to obtain data that might contradict or modify the analysis by extending the sample (for example, to a different type of area)?

Data collection and analysis: Were the data collection and analysis procedures systematic? Was an "audit trail" provided such that someone else could repeat each stage, including the analysis? How well did the analysis succeed in incorporating all the observations? To what extent did the analysis develop concepts and categories capable of explaining key processes or respondents' accounts or observations? Was it possible to follow the iteration between data and the explanations for the data (theory)? Did the researcher search for disconfirming cases?

Reflexivity of the account: Did the researcher self- consciously assess the likely impact of the methods used on the data obtained? Were sufficient data included in the reports of the study to provide sufficient evidence for readers to assess whether analytical criteria had been met?*"*

Based on the recommendations of Mays and Pope [57], the following text presents reflections regarding the previous seven elements regarding validation of the PhD research study on UCD and evaluation.

Worth or relevance: this study showed that involvement of end-users was relevant for the design process, with a significant contribution in the design, evaluations and results of the projects described.

Clarity of research question: the research questions guided the research throughout the study, and they were successfully answered based on the findings.

Appropriateness of the design to the question: the mixed methods approach provided sufficient data in terms of quantity and quality to obtain valid and ethically compliant results. The chosen method guided the research to successfully answer the research questions formulated at the beginning of this thesis.

Context: the context is thoroughly described in chapter 2 as the background for the study.

Sampling: representative end-user groups were included in the study. A larger number of participants and informants could have contributed with more data in terms of quantity, but in terms of quality, the data collection performed covers all the end-user groups represented.

Data collection and analysis: the data was systematically collected. The theory of human-computer interaction and qualitative content analysis provided the groundwork for how to collect and analyse the data.

Reflexivity of the account: The presence of a researcher can influence informant's behaviour, decisions and/or opinions, which has been described as the *Hawthorne effect* [83]. However, strict steps were taken (e.g., communicating to participants that tests were to evaluate the technology not them; that their opinions and actions would not be judged) to minimise interference with genuine user participation. In the qualitative content analysis, the categories emerged mainly after that the data collection was done.

3.3.1 Insights from using Mixed Methods Research

One of the experiences with using MMR approach in the study on the UCD process of health information technology, was the opportunity to collect a rich and detailed research data. The qualitative methods allowed participants to comment their experiences and opinions on the user needs, system's functionality and UI from an early project phase until the final version, providing the research team with valuable insights throughout the different stages of technology development. A disadvantage of the collection and analysis of the complexed data collected was the time consumption, with use of several hours in laboratory for preparation and performance of tests, followed by an extensive time for transcription and coding. The advantage of the transcription was the gain of the understanding through the research material collected.

Already during the phase of transcription several patterns were identified, resulting in the inclusion of new coding categories.

One criticism regarding qualitative methods is the subjective nature of data and analysis. A quantitative method was used to collect data on user satisfaction after the user evaluations in laboratory, in order to triangulate the collection of qualitative data. The advantage was to have individually filled out questionnaires that provided a result based on statistical analysis. The combination of quantitative and qualitative method provided results on the entire UCD process with a high level of details, personal expressions and quotes, as well as numbers and statistics, which was positively appreciated in the reviews of the related papers in Part II. The use of quantitative method alone, would not have provided such a rich material with expressions and opinions of the end-users, but could instead had provided a material based on a larger sample allowing a more extensive statistical analysis. The use of a qualitative method had a smaller sample than a quantitative method would have required, but it allowed the research team to gain in-depth insights, highly relevant for the development.

A limitation of the qualitative method is a small sample size, impacting on the generalisability of the results. In usability studies, findings might be not statistically significant, but very relevant when qualitatively identifying problems with the UI, which impacts on the user experience and user satisfaction. Even though there were a reduced number of users involved in observations and interviews (n=24 in Project I and n=7 in project II) they meaningfully represented all the end-user groups involved.

There was complementariness of the findings between the research approaches. In project II, the SUS score of the questionnaire was lower in the final evaluation (Paper VI), compared to the first evaluation (Paper IV). In an early project phase, participants had a positive attitude towards a new system for improving the inter-municipal communication. In the interviews after the final evaluation, the test participants expressed some skepticism regarding implementation of the new system, explaining that during the projects time, they already had some of the functionalities implemented in the existing system. In this case there was complementariness, the quantitative method showed a reduced user satisfaction score and the qualitative method contributed in explaining *why*.

In Project I, the SUS questionnaire's scores improved in 9 out of 10 questions from the first evaluation until the second evaluation, performed two weeks later. Several changes were made in the system between these evaluations. In the second post-test group interview, the users expressed satisfaction with the improved functionality and

graphical design of the system. Again, the interviews confirmed the findings in the SUS questionnaire, showing complimentary findings with use of the mixed methods approach.

3.4   Ethical Considerations

The research projects were approved by Norwegian Social Science Data Services (NSD) [52] with the project numbers: 28027, 35356, 37920 and 40636. All participants received oral and written information about the projects and confidential treatment of the collected data. All participants signed a consent form and their participation was voluntary. Participants were aware that they could withdraw at any time without giving a reason. In such a case, their data would be consequently withdrawn and destroyed. The participants representing patient groups were informed that the main aim of the projects were the development and functional evaluation of eHealth technology, not a medical follow-up. All participants signed an explicit written consent. The collected research data has been stored in password protected computers, provided by the UiA, with access granted only to members of the research team, following the NSD regulations.

3.5   Declaration of Conflicting Interests

To reflect on the role of the researcher and potential biases, the PhD candidate did not previously know any of the informants and study participants, neither had she worked or had close relations with the working environment of the health care professionals. The PhD candidate declares there was not any conflict of interest with any of the participants, organisations and publishers involved in this thesis.

4 The User-centred Design Process

In this chapter, the background of UCD is presented followed by a description on how UCD was applied in the PhD research projects.

4.1 The Background of User-centred Design

In the 1980's, the UCD which focused on user needs and iterative design with user evaluations [84][85] came into the scope with influences from fields such as cognitive psychology, mathematics, computer science, engineering, human factors and ergonomics and socio-technical systems design. UCD has been defined in the ISO standard 9241-210 *Ergonomics of Human System Interaction* [29] (former ISO 13407 and ISO TR 18529) with the main elements of:

- *The active involvement of users and a clear understanding of user and task requirements.*

- *An appropriate allocation of function between users and technology.*

- *The iteration of design solutions.*

- *Multi-disciplinary design*

When the first ISO version of the standard was adopted, it was considered a *"quantum step forward for Human Factors and HCI"* [26][86] and it identified the common problematic practice when doing user evaluations late in the design, with the final product and allowing only minor changes to the UID. A recommended way to avoid this was *"to adopt a user-centred approach to design with a continual cycle of user-based evaluation"* and divide the development into three phases; *concept*, *prototype* and *release* [26], see Figure 2. Further, Bevan stressed the importance of understanding the context of use and specification of the usability requirements in each phase, and recommended repeated evaluation with 3-5 users, as a cost-effective design

feed-back. He recommended evaluations of simple mock-ups in early design phases and a final evaluation with more than 10 participants.

	concept	prototype	release
understand context			
specify usability			
build solution			
evaluation by users			

Figure 2 The development phases of UCD, (from [26]).

Gulliksen and Göransson [87] provided a set of principles for user-centred system design based on own experiences from a study. They recommended the following principles:

- *"The work practices of the users control the development.*
- *Active user participation throughout the project, in analysis, design, development and evaluation.*
- *Early prototyping to evaluate and develop design solutions and to gradually build a shared understanding of the needs of the users as well as their future work practices.*
- *Multidisciplinary design teams.*
- *Integrated design."*

To summarise UCD, it refers to involvement of users in all stages of design and development, and there are several approaches as to practically perform this.
In the words of Karat [20][88]:

"For me, UCD is an iterative process whose goal is the development of usable systems, achieved through involvement of potential users of a system in system design. In this I am somewhat less specific about what role users play ….."

"I suggest we consider UCD an adequate label under which to continue to gather our knowledge of how to develop usable systems. It captures a commitment the usability community supports—that you must involve users in system design—while leaving fairly open how this is accomplished."

4.2 The Application of User-centred Design

A UCD approach was applied in both Projects I and II. The steps followed in practical approach are described in this section.

4.2.1 The User-centred Design in Project I

Project I had the aim to develop a collaborative telemedicine solution for remote monitoring of COPD, see Figure 3. The plan entailed two developments: 1) a tablet application to be used by COPD patients at their home; 2) an information and management system for the remote measurements, to be used by health care professionals in a telemedicine centre.
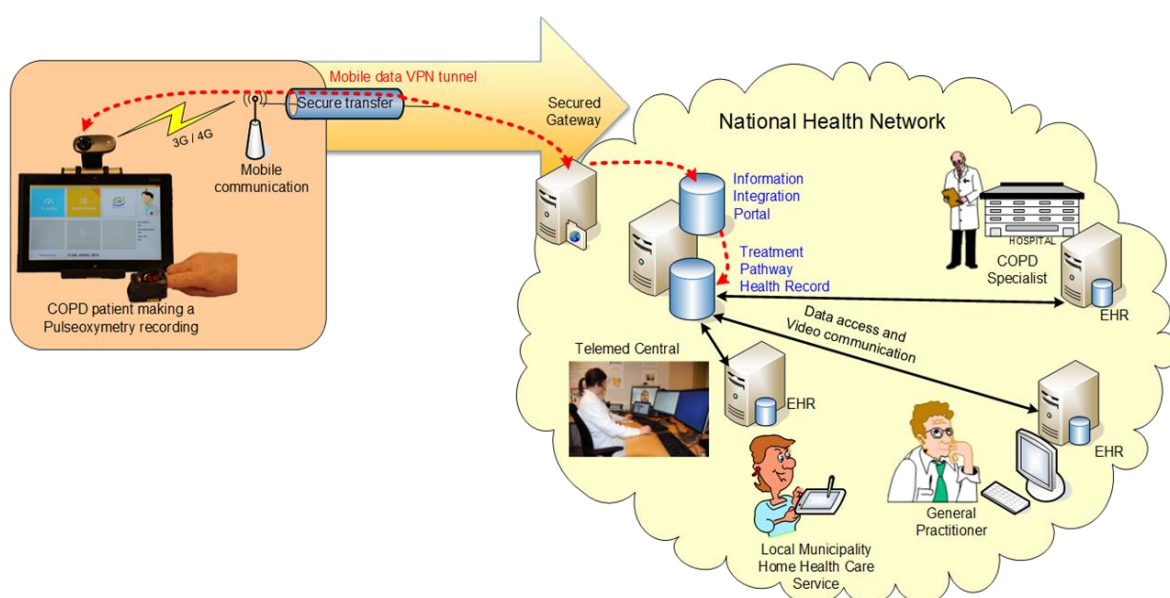
Figure 3 The Collaborative Telemedicine System

In an early stage of the project, two research groups were established: a technical one and a medical one. The PhD candidate was a part of the technical group, and UiA had the role of the project leader of that group. There was a project plan with partners with differentiated commitments: hospital, municipality, the university and an invited patient organisation.

The UCD process was divided into two phases: (1) workshop with representatives of the end-user groups to gather user requirements and (2) iterative development including user evaluations, interviews and a field trial (see Figure 4). The UCD process had a total duration of 6 months during the years of 2013-2014.
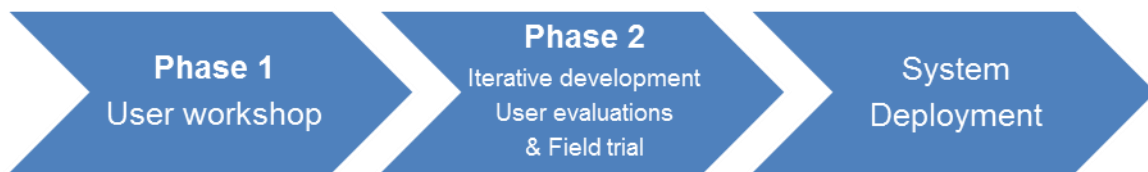
Figure 4 The UCD process in Project I

In the first phase, key informants in the defined end-user groups (through the project plan) were invited to a one-day workshop. The workshop was useful to map out the context of use, plan a remote monitoring procedure. In addition, user suggestions on functionalities and UI were made through paper prototyping. The workshop stimulated active involvement of all participants. The participants also viewed a prototype demonstration in order to gain an understanding about how remote monitoring, wireless measurements and videoconference worked. Finally, throughout several discussions about pre-defined topics, the user requirements for the development were established.

The people responsible for the development of the tablet application, was a group of master students, supervised by a member of the research team. An industry partner was responsible for the development and implementation of the collaborative information system. The medical and technical research group had both separate meetings and fellow meetings during the entire UCD process.

A user evaluation was made together with end-user groups on an early prototype version. Several usability issues were identified, categorised and assigned a priority. Several refinements were performed on the prototype, and two weeks later a second user evaluation was made together with the end-user groups.

A field trial was run with real end-users (voluntary COPD patients at home and nurses at the telemedicine centre) of the technology when the development had come closer to a final version. The field trial was essential in order to test the technology in a realistic user environment with real users. Several issues were identified and improvements were made before the final implementation.

The UCD process involved 24 end-users in total. Several project members and advisers participated during the process.

The workshop, user evaluations and all interviews were audio-visually recorded in order to document the UCD process. The recordings lasted approximately 30 hours. Details of data collection and analysis are presented in Chapter 3.

The conclusions of the Project I described the involvement of end-users from early project idea as essential in order to understand the context of use and how to organise the remote monitoring procedure. For the development and the usability aspects, the participation of end-users in evaluations and in the field was crucial in order to have a firsthand feedback on functionality and suggestions on improvements to develop a system that was *easy-to-use* and adapted to the users' needs and described work processes.

The details and results from the UCD process in Project I are further presented in Paper I, II and III.

4.2.2. The User-centred Design in Project II

Project II had the aim to develop an IS to be used by a dementia team as part of an inter-municipal cooperation (IMC). In the first project phase, a field study was made in order to map out the information flow within inter-municipal health care teams. A development project with a UCD approach was planned based on information from key informants in the field study (see Figure 5).
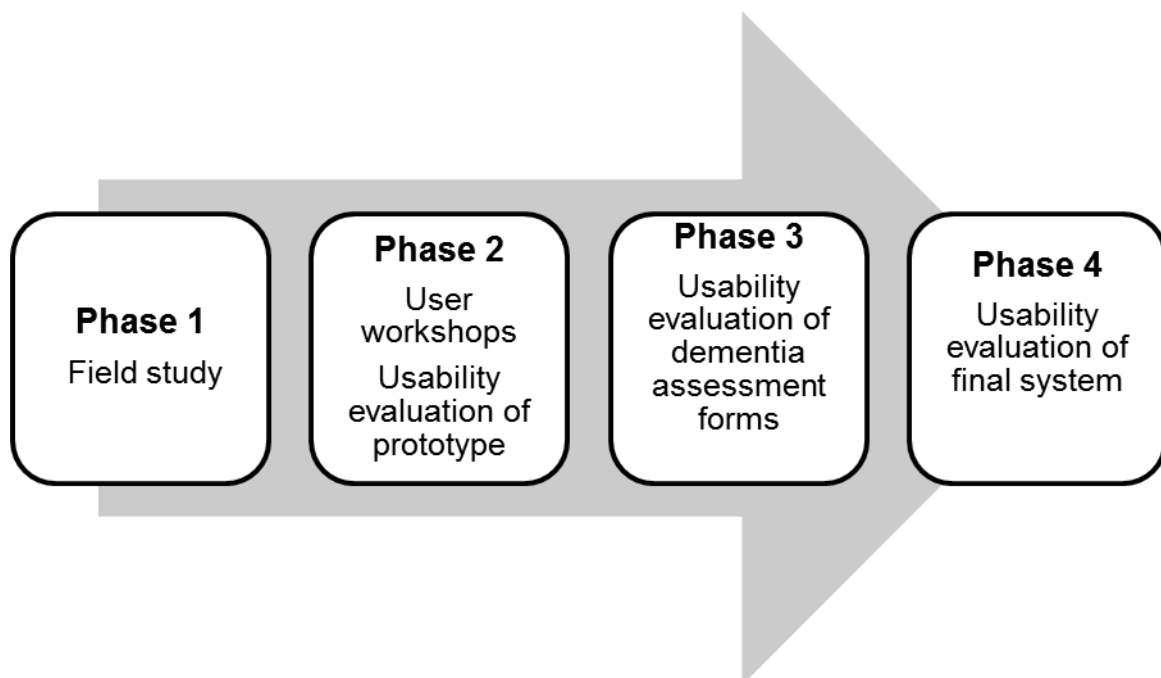
Figure 5 The User-centred Design process in Project II

In the second project phase, key informants participated in two user workshops together with the research team supported by an interaction designer. Details of

context of use, workflow, interaction with existing system, suggestions for functionality of new system and UI suggestions through paper prototyping and graphical sketches were mapped out in the workshops. Based on the information gathered, the interaction designer made the first graphical sketches (wireframes), then a complete graphical design shown on a computer screen that illustrated the UI. Finally, an interactive web-application with the graphical UID was developed and tested in usability laboratory. The test was made together with end-users and graphic experts, identifying several usability issues that needed improvement.

Digital dementia assessment forms [89] for dementia teams [90][91] were developed and tested in usability laboratory based on the findings of the first two phases of the project. The evaluation also included a videoconference communication and a shared document's visualisation. The final version of the IS was developed and implemented to NHN [48] for testing purposes in the last project phase. Finally, a usability evaluation was made together with end-users.

The workshop, user evaluations and most interviews were audio-visually recorded in order to document and evaluate the UCD process. The recordings lasted approximately 20 hours. Details of data collection and analysis are presented in Chapter 3.

In total seven end-users participated in the UCD process and six people comprised the research team. In addition, several advisers contributed in the early phases for the sake of information security and legal aspects.

The Project II had a total duration of four years and ended in June 2015. One of the lessons learned, is that user needs identified in an early project phase changed during the project. New technologies and functionalities in existing systems filled the gap identified, which impacted on the interest on implementing the new IS. The research group suggests a shorter time span and a more rapid technical development in order to avoid this issue. As future work, the research group proposes validation of the IS through a field trial in a real user environment.

The details and results of the UCD process in Project II are presented in Paper IV, V and VI and the specificity of the user involvement is described in Paper VII.

5 Evaluation of Health Information Technology

This chapter focuses on the evaluation of health information technology, with a review of literature and studies in the research area followed by descriptions of the approach and technical infrastructure applied in the usability evaluations from Project I, II and III.

5.1 Literature Review on Usability Evaluation

Wyatt and Wyatt [92] addressed the topic on *why* and *how* to evaluate health IS. They stated that health IS can be complex and difficult to evaluate. Creating an IS is not straight forward, as it requires prototyping and formative evaluations during the development and a summative evaluation for answering the question: *"What is the impact of the new ICT system on the problem it was intended to address?"* The key questions have to be defined before the evaluation, which should include different perspectives, such as the organisation (system owner) the hospital staff (users) or patients. The selection of the research method ranging from qualitative and quantitative methods should be appropriate and reliable. Wyatt and Wyatt described three kinds of study design: simple before-after, controlled before-after and randomized trial. They conclude that health care organisations and policy makers have to spend money wisely and evaluation of health information systems is a way of assessing impacts of new technology.

Bastien [93] presented a review describing test procedures and tools for user tests with the focus on: number of participants, test procedures, remote usability test and testing tools for mobile applications. Usability evaluation was defined as: *"a way of ensuring that interactive systems are adapted to the users, their tasks and that there are no negative outcome of their usage"*. Further, usability evaluation was described as a step in a UCD process and with the goal to assess to what degree a system is effective, efficient and whether the attitudes and responses from the intended users are positive.

Three approaches were described for usability evaluation: 1) inspection, 2) user based evaluations and 3) model-based evaluation. The approaches were not specifically developed for the field of health informatics, but their use in this specific field has increased over the years. User-based evaluation means that users participate in the evaluation and are asked to do typical tasks or explore a system, while being observed and recorded. The goal is to identify flaws that cause errors or difficulties in the use of the system. Measurements are made regarding time per task solving, numbers of completed tasks and numbers and types of errors. A usability test has a defined number of steps:

"1) definition of test objectives, 2) qualification and recruitment of test participants, 3) selection and description of tasks, 4) choice of measures and how data will be recorded, 5) preparation of test materials and usability laboratory, 6) choice of tester and design test protocol, 7) design or selection of satisfaction questionnaire and data analysis procedures, 8) presentation and communication of test results."

The paper concluded that regarding the number of test participants, there are different views on the topic, depending on the purpose of the usability test.

Kushniruk and Patel [72] made a methodological review on approaches for evaluation of health IS. They applied theories from cognitive science and usability engineering, focusing on assessing HCIs and usability of clinical systems in laboratory and natural settings as formative evaluation during iterative development and summative evaluation of a completed system. Usability methods are interdisciplinary, involving cognitive psychology, computer science and systems- and usability engineering. The objective of usability evaluation is to improve the design and effectiveness of clinical systems. Usability was defined as: *"the capacity of a system to allow users to carry out their tasks safely, effectively, efficiently and enjoyably"*. When assessing a clinical information system, the following aspects from cognitive psychology and usability engineering guide the process:

"1) how easily can a user carry out a task in the system, 2) assess how user attains mastery in using the system, 3) assess the effects of systems on work practices, 4) identify problems users have when interacting with the system."

During a UCD approach, evaluation focuses on cognitive skills when using a system performing representative tasks in order to generate descriptions of problems that

arise. The aim is to gain better understanding of the interaction between health care professionals and the clinical system when conducting clinical work. In a usability test, all user-computer interactions, activities and actions are recorded with TA often applied. After a usability test, a questionnaire, retrospective interview or focus group is done in order to evaluate the system. The information from usability evaluation provides valuable information related to a system's acceptability in a clinical context. There are different kinds of usability tests: exploratory test, test of prototypes, assessment tests, validation test and comparison test.

Kushniruk and Patel further described nine phases in the process of evaluation:

1) *Identification of evaluation objectives:* can include assessment of functionality and usability, input to prototype refinement, identification of problems in HCI, evaluation of the effects on decision making process and assessment of the impacts of new ICT on clinical practice and workflow.

2) *Sample selection and study design*: includes definition of participants for the evaluation, usually representative end-users of the system. Three dimensions are useful in categorising users: computer skills, role in the working place and expertise of working domain. 8-10 users provide a rich data material and can find 80% of usability problems. Study design: within-group design (prototype-testing), between group design (comparison of different systems or groups) and single group design (when a group performs same task to assess problems with the design of user interface).

3) *Selection of tasks and context*: controlled in laboratory study or natural settings (for instance observation of system's use in a clinical setting). The development of medical cases has to be careful including realistic scenarios of clinical situations for extracting high-level quality data of user interactions.

4) *Selection of background questionnaire*: the aim is to collect background information before or after the test. Obtain demographic data, role on working place and computer skills.

5) *Selection of evaluation environment*: the physical location for the test, use of stationary observation room with one-way mirror or portable solution for a clinical setting.

6) *Data collection*: usually the participant is asked to perform a task using the system. The session is audio-visually recorded and screen capture movements are registered, which allows analysis of mouse-clicks, menu selections, facial expressions

and gestures. Think aloud, verbalising thought when interacting with system, is a formalised method to collect and analyse qualitative data.

7) *Analysis of process data:* Verbal transcriptions that are time-stamped and the coding schemes should be worked out prior to analysis and are used to identify and classify usability problems, cognitive processes and HCIs. Common coding categories: *"Information content, Comprehensiveness of graphics and text, Problems in navigation and Overall system understandability"*.

8) *Interpretation of findings*: Involves qualitative (effects of technology and decision making) and quantitative analysis (task accuracy, time and frequency of problems).

9) *Iterative input into design*: meaning that tests are repeated after changes of features in the system to evaluate effects of the refinements.

5.1.1 Think Aloud Protocol

Ericsson and Simon [71] are the founders of the TA protocol and they examined the validity of verbal reports as data with the framework of human information-processing theory to propose a model. They presented a model that argued that verbalised information from short-term memory is reliable as empirical data. They classified two kinds of verbalisations; *concurrent* where the participant has to perform the task and make verbalisations and *retrospective* with verbalisations after test. The concurrent protocol can impact on the performance of the task, but the retrospective one depends on the memory of the participant after the task performance. In an experiment or study, the researcher is interested in the subject's reasons for the behaviour or problem solving and that is how the TA protocol collects information.

Jaspers [70] described empirical research on three most commonly used evaluation methods: the expert-based heuristic evaluation and cognitive walkthrough (not in the scope of this thesis) and the user-based think aloud technique. The TA method has its origin in verbal reports and cognitive psychology and has the aim to gather information on cognitive behaviour during problem solving. The TA method has two steps; first a data collection is performed in a systematic way and afterwards analysis of data is done to describe the cognitive processes during the problem solving. During a TA protocol, the test participants are asked to talk out loud about their thinking when solving a problem. Each test session is recorded as the participant interacts with a system or prototype following a scenario description or a task list while verbalising the thoughts. Analysis of the data provides detailed insights into usability problems and

tries to define what causes these problems. One concern was raised regarding the TA method: information from the participants is subjective. Therefore, representative end-users have to be selected, in order to have applicable usability results. In order to gather relevant background information, a questionnaire is completed before or after the test session. The TA protocol collects a rich material from each test session; and, therefore, a small test sample, approximately 8 test participants, is sufficient to understand task behaviour and usability problems. When testing complex systems with many different types of user groups, a more extensive test involving all the user groups is required. The aim of the scenario description or task list is to provide an example of a work-related situation and try to understand the HCI when performing the tasks, so it has to be representative and related to the work domain.

Before the test session starts, the participant has to be informed about the procedure of the test and when the test starts. Next, they have to perform a certain task in the system talking about what comes to mind. The laboratory scenario is usually a new situation for participants; therefore, before the start of the test, an example task while talking aloud is introduced to help the participant become familiar with the test situation. During the test session, the moderator is supposed to intervene only when the participant stops talking or is blocked or does not understand what to do. Therefore, before the test, a decision on how to intervene has to be made in order to avoid reducing reliability and validity.

The analysis of recordings focuses on the HCIs and for that reasons the verbal comments are transcribed for content analysis and coding. The video recordings are viewed to understand how the participants performed the tasks and to find HCI problems. Before the analysis, a coding scheme should be developed to identify how problem solving was performed. There are two ways of working out a coding scheme; bottom-up coding approach worked out from episodes in the data collection or top-down approach based on pre-defined categories based on HCI literature. The results of the coded protocols are summarised, and usability problems and their causes are presented, which is useful for design or re-design of the system.

In some scenarios, the problem solving of participants should not be disturbed, then a retrospective protocol can be used to collect additional information. When comparing concurrent and retrospective protocols, the concurrent one provides more complete and detailed descriptions of cognitions of computer interaction, and it generates more specific usability problems. Retrospective protocol usually generates more general usability problems.

The conclusion was that TA protocols with questionnaire for background information, verbalisations and recorded HCIs provide a useful context for identifying system functionalities and features as well as the main causes of problems to users. TA method identifies 1/3 of the problems found in heuristic evaluation, but the TA finds more severe and recurring problems. Compared to cognitive walkthrough, TA finds more severe problems, which is explained by a large amount of data from about 8 test participants. Jaspers specified the following steps for a test plan of a usability study:

"1) purpose of usability test, 2) problem statement or test objectives, 3) methods used in inspection/testing, 4) a user background setting or user profile, 5) list of heuristics, 6) test environment and equipment, 7) description of evaluator and/or end user instructions, 8) types of data to be collected, 9) report contents and presentation."

Fonteyn et al., [94] described how to obtain more accurate verbal data in order to provide validity of the analysis of the TA protocol, providing in-depth data from a small number of test participants. A retrospective interview after a concurrent protocol was suggested in order to collect a complete description of the scenario. During a TA protocol a simulation (scenario or case description) is used for the problem solving and the tasks should be revealed in different parts, not all initially. For validity reasons, an expert panel can be used in the preparation of the scenario description in order to provide realism and relevance. Moreover, it is advisable to execute the test session in a silent place, a written consent is required, and a demographic data collection for a descriptive data analysis is recommended.

Nielsen [95] described the TA method as one of the main methods for evaluating UIs through user testing, and it can be used during all the different parts of the iterative development cycle. The aim of this paper was to investigate the relation between numbers of test participants and usability problems found in a user test of a UID. The definition of a usability problem was: *"any aspect of a user interface that is expected to cause problems with respect to some salient usability measure (learnability, performance, error rate, subjective satisfaction)"*. Two experiments were presented using TA method. Each single test subject found about 1/3 of the usability problems and after five test participants approximately ¾ of the usability problems were found. The outcome of every single test session should be summarized and also prioritized regarding severity to obtain the result. A small number of test subjects, (4 ± 1) was

recommended for each iteration. The conclusion was that usability test identifies major usability problems with a small number of test participants.

Nielsen et al., [96] made a review on the TA technique, and asked the question *"What do researchers think they get when they ask people to think aloud?"* They identified the TA method as the main technique in usability testing, also emphasizing that MMR combining different techniques is common in this field, which was also confirmed by Hollin [97] and Horsky et al. [98] who stressed that no method identifies all problems related to usability, and different methods can be applied in different phases of development cycle. One of the weaknesses of the TA technique is that test participants can feel uncomfortable in the test setting, due to observation and measurement in laboratory setting which might influence the performance of the test [96].

Van den Haak and de Jong [99] made a comparative study on the TA methods concurrent and retrospective protocol. They emphasized the fact that test participants might carry out problem solving in a different way, when they do think aloud. Their study showed that both methods result in a similar number and types of problems, but for concurrent protocol the success rate of task performance was lower, which might be explained by the influence of the TA procedure on the task solving.

5.1.2 Empirical Studies on Usability Evaluation of Health Information Technology

Svanæs et al., [73] did a study on methodological aspects when testing mobile technology to be used in clinical settings. Clinical work in health care services is highly mobile and mobile technology gives health care professionals access to information and communication at the point-of-care. Due to legal and ethical aspects, usability test is seldom performed in real hospital environment. Instead, these authors recommended equipping a usability laboratory with hospital-like environment for usability test of mobile technology. Li et al. [100] and Borycki and Kushniruk [101], also recommend simulation in order to create a realistic scenario for evaluation of clinical information systems.

Svanæs et al., [73] classified the outcome of usability test into three groups: GUI usability, physical and bodily aspects of usability and social aspects of usability. They further recommended transcription of data and analysis of patterns of use. Li et al. [100] used qualitative methods for coding.

5.2 The Practical Application of Usability Evaluation

In this part, the practical application of usability evaluation in the Projects I, II and III is presented with focus on research team, test participants, test procedure and test infrastructure.

5.2.1 Usability Evaluation in Project I

In Project I, during the development of the collaborative telemedicine system, user evaluations were made in usability laboratory as a role-play simulating the use of the technology. The research team consisted of four people with ICT, health and HCI background. The test participants were end-users of the system (patients and health care professionals) and people who performed with the roles of technicians. The test procedure included pre-test questionnaire for background information of the test participants, test session, post-test SUS questionnaire and a group interview. The task list in the test sessions was based on a concurrent TA protocol, which was prepared based on the previous workshop and field study. The test simulated the remote monitoring procedure, using separated test-rooms (up to three) where the participants interacted with each other between the rooms. In each room, there was a moderator and a camera recording the sessions. All camera sources were shown simultaneously on a screen in the observation and control room.

The results of the user evaluations are presented in Paper I and II. The technical test infrastructure is presented in details in Paper VIII.

In the last step of Project I, a five week-long field trial was run that included nurses at the telemedicine centre and patients at home. The field trial entailed three steps. Step 1 included user training of the patient with a tablet. In step 2, the patient used the tablet device at home for one week. In step 3, on the seventh day, members of the research team visited the patient at home and made a usability evaluation and carried out an interview. The usability evaluation was based on a TA protocol and was video-recorded with a portable camera. The interviews were made to complete the feedback about the user experience and suggestions on changes and improvements to the system.

The results of the patients' evaluation of the tablet device in the field trial are described in details in Paper III. The role of the field trial in home setting, as a step in the UCD process is described in Paper II. The results of the nurses' evaluation of the information and management system during the field trial are described in Paper I.

5.2.2 Usability Evaluation in Project II

In Project II, usability evaluations were made during the development of an IS for inter-municipal dementia team. The research team consisted of six people with ICT, health and HCI background, participating in the different parts of the project.

In the first phase, a usability evaluation of an interactive web-application was made in the laboratory. The test participants were end-users of the application. The test procedure included a pre-test interview for background information of the participants, the test session based on a TA protocol with tasks based on field study and user workshop, post-test SUS questionnaire and group interviews. A moderator was present in each of the test session. The results are presented in Paper IV.

In the next step, electronic forms for dementia assessment [89][90] were developed. They were usability tested together with a videoconference system. The test procedure was similar to the first phase, but in addition including simulation and role-play. The results are presented in Paper V.

In the last step, the final version of the IS was tested in the laboratory. During the final usability evaluation, the participants were asked to grade the task solving after each task, using a 5-item scale. All participants managed to grade the tasks, but in the interviews they commented that it was quite difficult to grade during the task. The task could be difficult to solve because they did not know the UI in advance, but after some training the task would be easy to solve. The results of the final usability evaluation are presented in Paper VI.

In general, participants were positive during the evaluations, making constructive comments about the test process. They suggested user training or individual exploration of the UI in advance in order to make the test more efficient. Further, they suggested testing in pairs or as a small group in order to add group dynamics and more reflections into the process.

The laboratory infrastructure described in Paper VIII was used in project II, using both one single test room, and two test rooms with participants interacting through technology.

5.2.3 Usability Evaluation in Project III

In Project III, a usability evaluation of the screen reader for mobile technology was made. The evaluation research team was formed by three members with multidisciplinary background: one member with experience from teaching and supporting visually impaired students with assistive technology; the other two members with professional experience in health, ICT and HCI. All had professional experience in working with visually impaired people. One team member was the moderator in all the tests.

The test participants were visually impaired users. The test procedure included pre-test interview, test session with tasks based on a pilot usability test with two visually impaired users and a group interview. In the test session, the tasks were read out loud to the test participants, who were asked to talk out loud, and inform when they finished solving the task. They were asked to grade the task solving on a 3-point scale after each task before starting the next one. A post-test interview was made with reflections on the test process.

The test infrastructure for the evaluation of mobile technology is presented in details in Paper IX.

6 Discussion

In this chapter, firstly, the research questions of the PhD research study are answered by discussing the findings of the practical application of UCD and evaluation of health information technology described in previous chapters. Secondly, the limitations of the study are presented.

6.1 Evaluation of the Research Questions

The three research questions (RQs) formulated in the introduction, section 1.3, are answered based on the results from the PhD study. RQ 1 and 2 are presented in two sub-sections, together with reflections on lessons learned derived from RQ3. RQ3 is finally summarised in the third sub-section.

6.1.1 Research Question 1

RQ1: How can health information technology be developed taking into account the needs and requirements of the end-users during all the phases of development?

This research work has presented the UCD and evaluation performed in three research projects related to health information technology. Health information technology involves various users in number and type, such as patients, health professionals and administrative officers. The interactions between these user groups and between users of the same group are partially or totally supported by health information technology. This is why the involvement of the end-user groups in the design of new technical solutions is crucial to understand the clinical workflow where the solution will be deployed, its context of use and the interactions involved. Project I and II showed that the employed UCD approach included the end-users' needs in the development of health information technology in line with ISO standard [29] and other recommendations [18][26].

The following three sub-sections *User workshops*, *User evaluation* and *Field trial* present in details the outcome and lessons learned on user involvement in the UCD processes of Project I and II.

A. User Workshops

The user workshops and field studies made in the users' environment contributed to outlining the context of use and establishing user needs. They also helped the user groups involved to become familiar with the technology and the research team. The workshops were the key to elicit users' requirements for the technology development, taking on board different aspects of GUI, interaction and functionalities, in line with [18].

In the Project II, an initial field study contributed to understand the context of use for new IS supporting inter-municipal collaboration, and prepared the ground for the user workshops. The user workshops provided a detailed understanding of the workflow for dementia assessment, the main use case for the suggested new IS. The users also contributed with opinions on the GUI, expressing a need for visualising key information at one glance on the screen, differentiating functionalities by colour. The fact that an interaction designer was present in both workshops contributed with an early focus on interaction with the system and how it would best fit into existing work processes (presented in detail in Paper IV). In the final version of the IS, the proposed functionalities and the colour visualisation on the screen were very similar to the paper prototype (presented in Paper VII). One of the workshop attendees stated: *"The colours are very good because each theme has its own colour. So you can know, just by the colour, what you are choosing."* (Paper IV)

In the Project I, the proposed telemedicine service for COPD remote monitoring was new and so the proposed workflow. In the initial user workshop, the included end-user groups actively worked to define an optimal workflow for the service, which was the key in order to understand the context of use for the system. The members from the patient union provided an understanding of the daily life of a COPD patient, in many cases elderly people, and suggested feedback routines to the patient group. In addition, the end-users described their preferred way of interacting with the telemedicine system and suggested ideas for interface layout using a paper prototype (described in details in Paper I and II). In the final interface layout of the tablet, the main functions presented as touch areas, were very similar to the first paper prototype (presented in Paper II). Even though the organisation of health care services is not within the scope of this

thesis, it can be pointed out that also the workflow and routines implemented for the COPD remote monitoring were very similar to the ones proposed in the user workshop.

In Project I and II the user workshops were essential to understand the context of use and gather system requirements. The main research method employed in the user workshops analysis was qualitative. The nature of workshops was dynamic, with many participants present in the same room and with a large number of topics discussed. The fact that workshops were video recorded and transcribed contributed to a high level of details collected and reporting everything discussed. This was an advantage when compared with note taking, having the challenge to annotate all that participants say. A lesson learned from the viewing and transcription of the video recordings, was that several details and discussions of problems were retrospectively identified, adding to what the PhD candidate annotated on *live* during the workshops. Another lesson learned is that the paper prototyping that end-users created in the workshops in both projects was very illustrative and informed the subsequent development of functionality and GUI, with the final result clearly driven by the prototypes from the user workshops.

Finally, in order to prepare a UCD process, an initial field study (such as in Project II) is recommended in order to understand the context of use and to observe how the users interact with technology in their natural environment. As a following step, user workshops are recommended to provide an understanding of user needs. Finally, workshops should be led by a multidisciplinary research team, with a designer or developer involved.

B. User Evaluations

All user evaluations started with a pre-test interview, including the signing of informed consent and followed by a set of questions about background such as age, profession, computer skills and experience with technology. The background information collected was used for a descriptive analysis of the test participants for the method section of the publications, as recommended in [94].

Contact information, both email and phone number was also registered. This was important information, as a few times the PhD candidate needed to take contact for asking more questions or clarifying things after the evaluations.

In the Project II, user evaluations were made individually in the usability laboratory in an early and late design phase and in the middle phase an evaluation using role-play

when testing technology between two test rooms. The first evaluation in the Project II was made with two groups: end-users and graphical expertise. The end-users identified several graphical issues and a few navigation issues. They also expressed satisfaction regarding the colourful visualisation of key information and that the system provided new ways for communication. The graphical expertise identified issues regarding the graphical design and navigation and suggested solutions for improvements.

One of the graphical expertise stated: *"The system is clear, easy to read and understand"*. Another one expressed: *"From the design point of view, the colours are used to separate elements, which works well to get the overview of the screen. This would diminish user training"*. (Paper IV).

In the second user evaluation (Paper V), a scenario was simulated for evaluation of dementia with use of electronic forms and videoconference. This was organised as a role-play in test room 2 (or *Smarthouse*) with elderly actors playing the role of the dementia patient and a relative and health care professionals from the dementia team visiting them at home. In the first part of the test, the health care professionals used electronic dementia evaluation forms in a simulated home visit. They followed a task list, and a moderator was present observing the interaction with the technology involved. The usability of the electronic assessment forms was subjectively evaluated as *clear, self-explained and little need for user training*. The participants described the main benefit of the electronic forms as the long-term effect of electronic storage and improved availability of the data. They found that the devices could create a physical barrier that could interfere the communication with the patient and relative. Afterwards the actors were interviewed, reporting that the technical devices were unproblematic and did *not* interfere the communication.

One of the actors stated: *"In these days everyone, also elderly people, are used to laptops and tablets and these did not disturb"*.

In the second part of the evaluation, two test participants collaborated through videoconference with shared screen visualisation of the writing of a dementia assessment report. The test used two test rooms and all interactions were simultaneously video recorded.

In the third and final usability evaluation (also the last one included in this PhD research study), individual tests were made in laboratory with nine tasks to be solved. During this user evaluation, the participants were asked to use a 5-point Likert-scale to grade the difficulty of each task after solving of it. That provided immediate results on

how each participant found the task solving, but it also caused some interruption on the continuous task solving. It seemed like the participants were most comfortable with solving tasks and commenting on the user interface, and found it some cases difficult to do the grading. This is further presented in Paper VI.

Each test session ended with the individual completion of the SUS questionnaire, with the aim of providing a measure of the user satisfaction. The moderator moved away from the test desk to another desk in the test room while the questionnaire was filled in, to not interfere with the participant. The moderator never left test participants alone in the test room, to avoid discomfort or claustrophobic feelings due to automatic locking of the door. The SUS scores were calculated when all user tests were done. The inclusion of colours in the results' visualisation [80] (green, yellow, red) related to the calculated score [81] and provided an easy-to-interpret tool in the validation of the UID.

The evaluations in the Project II were supplied by group interviews (post-test interview, i.e., hours after the evaluations), in which the most essential findings from the evaluations were discussed, as seen in [72][94]. The interviews provided a platform for the discussion of UID, interactions and functionality between the end-users and research team. The users presented several suggestions in the interviews, such as user evaluation in pairs or a small group, letting the group dynamics enrich the evaluation. It was also suggested to allow the participants to explore the system before the evaluation. The research team annotated these suggestions for consideration in future projects.

There are several lessons learned from the Project II: the use of both end-users and graphic experts in the first evaluation was a fruitful approach that led to input regarding graphical and functional improvements already during the evaluation phase, and is then recommended for other projects where the GUI is new to the users, inspired by [102]. In the second evaluation, participants commented that the use of role-play and actors was realistic. The research team found the role-play useful and informative and decided to elaborate the use of it in later tests. Based on this experience, the use of actors and role-play can be recommended in order to create a realistic scenario in user evaluations, in line with [73][100], making the interaction similar to the one performed when the technology is deployed.

The post-test group interviews provided rich and detailed findings, and they were organised based on recommendations in [72][94]. Even though the interviews were prepared with an interview guide, the research team learned during the Project II that

to collect even more information on the findings from the laboratory sessions, the interviews also had to have a dynamic character. This means that the most interesting findings from the laboratory tests had to be quickly notified and prepared for discussion during the following interview. This approach required a quick and alert research team, being able to point out the most important issues to be included in the next interviews. For the test participants, interviews had the disadvantage that they had to wait for some time from the test until the interview. Group interviews could be made twice during a test day, about lunchtime and in the afternoon. Participants gave the impression of liking the interviews, being comfortable with the opportunity to sum up the test and come with suggestions that arose during or after the test.

The PhD candidate used the SUS questionnaire for the first time during the PhD research study in the Project II. The literature review contributed a way to calculate the scores and analyse the result. The visualisation of the results based on colours showed out to be illustrative and easy to interpret (Paper IV and VI) .

In the Project I, user evaluations took place both in a controlled laboratory environment and in the users' natural environment (telemedicine centre and home of patients') for the field trial .

For the evaluations in the usability laboratory, a role-play scenario was constructed, where the users interacted with the technology simultaneously between the test rooms. A task list was used to simulate the user scenario of remote monitoring, using the tablet device and the IS. The laboratory provided a test environment allowing the control of the variables studied. The laboratory test was a necessary step to evaluate the iterations for the refinement of the remote monitoring application. The role-play allowed testing the interaction between participants and the technology involved, and it played an important role in creating a realistic scenario for the test, as recommended in other studies [73][100].

In the Project I, the first UI of the IS for remote monitoring was inspired by the final UI of the Project II (further described in Paper I). In the first user test in the Project I, the colourful UI of the IS was categorised as a major issue, as the participants found it could interfere with the triage colours red, yellow and green. In addition, some issues regarding the graphic design were identified and the users suggested improvements of the functionality of the system. In the second evaluation, most of the suggestions and problems from the first evaluation were solved and incorporated in the IS. The UI had a grey scale, instead of the initial colourful UI. For the tablet device, the first user evaluation identified graphical problems such as a small text size and placement of

icons and pop-up windows. The observation of the use of the technology between the test rooms showed that the videoconference sound quality was insufficient. Several improvements in the tablet design were made between the user evaluations, in order to make the use of it as easy as possible. For instance, the amount of information presented in each screen was reduced, in order to avoid information overload.

The SUS questionnaire was filled in individually after both user evaluations, with an improved score in 9 out of 10 questions, and the other question kept the same score in both evaluations.

Lessons learned from the user evaluations in the Project I: the role-play was used in a similar way as in Project II, but with an additional grade of more complexity due to a greater number of participants and rooms involved in the test. Again, the research team considered the role-play as a success, in terms of creating a realistic scenario allowing following the interactions with technology and the communication between the test rooms. The finding regarding the problematic sound quality of the videoconference, for communication between the tablet and the IS, is an example of an interaction between technologies involved. The videoconference technology was already existing and implemented to the system, but needed a software configuration for a better user experience. Several technical tests were made by project members after the user tests, to improve the sound quality. The main aim of the user evaluations was to identify errors in the remote monitoring system that was under development, but in addition, lots of effort had to be made to solve interoperability problems with other technologies.

Another lesson learned from user test 1 in the Project I: the technology was not fully developed, meaning that errors and technology were more likely to happen compared to a later phase. The research team had two developers present during the entire test, in order to be able to assist. For a few times the developers helped the research team regarding communication with the test server and database. In addition, internal IT technicians were available on short notice to assist in the usability laboratory. This was an important precaution to take as user test I involved 15 test participants, who had travelled a distance of half an hour or more to participate in the test. A total failure of the technology, with the consequence of delaying the test to another day, would have increased the running costs of the project. A recommendation for other projects, is to plan for backup resources in the running of user tests.

A learning experience regarding the UI of the IS, which was further developed based the UI from the Project II was that what optimally works in one health care

context might need refinements or adaption when used in another health care context. The colourful UI in the IS for separation of information worked in the inter-municipal health care teams, performing dementia assessment. For the COPD remote monitoring context that used a coloured triage, a grey tone of the UI was essential to implement to not interfere colours of the information sections with the triage colours.

Finally, on the organisation of the user evaluations in Project I and II, which included pre-test interview, task-based user test (both individual and role-play), SUS questionnaire and post-test group interview, it was learned that all types of data collected were of high importance for the iterative development and an important step in the UCD process. The way of organising the user evaluations can be recommended for other health information technology projects.

C. Field Trial

A final step in the UCD process was a five week long field trial with the active participation of voluntary patients and health care professionals. The field trial allowed studying the long-term and real-time usage of the technology by COPD patients at their home and provided useful information not only about the interactions between humans and technology, but also between the different technologies involved, as seen in [15]. This helped to address the issues with interoperability problems [103], commonly present in deployment and use of health information technologies [104][105]

In the field trial, the patient participants were visited at home and a usability evaluation was made after one week of use of the tablet application. Some of the problems identified were not directly related to the UID, but to the use of a tablet in general. The double touch action and the correct speed and pressure were often problematic. In addition some of the participants had cold fingers, which lead to lack skin conductiveness and response from the tablet. This problem was solved with a stylus. This shows that when designing technology for elderly people, other factors in addition to the UID, contribute to the usability of the solution.

Recruiting participants for a field trial can be a difficult task and take time. Thanks to collaboration and helpfulness among the project partners, the recruitment process was short and the patient representatives volunteered for the field trial. A lesson learned and a recommendation for other projects, is to use own network and project partners for recruitment of participants in order to save time for the process. In addition, not all patients participated at the same time, allowing the development team

to make improvements in cycles, to be tested in the *next round* together with the next users. That is a recommendation for other field trials, to run the trial in cycles to be able to eliminate major errors as soon as possible and test the refinements in the iterations together with *new* users.

The field trial was an important step to test the technology *on live* and with *real* users.

In the interviews of the field trial, the nurses made comments such as: *"I think this system is easy to use. With small adjustments this will be a good tool to support the workflow. […] The IS seems to work well and gives a good overview, most of it is self-explained. […] The field trial has been very useful in order to identify errors that can occur when using the equipment"*.

Two of the patients in the field trial commented the tablet device: *"I think the application is very well designed so you do not misunderstand anything. I consider this system user-friendly. […] This application was easy to use because even an old person like me without computer experience could use it"*.

This confirms the importance of a field trial as a step in a UCD process, and is strongly recommended in future development and evaluation projects of health information technology.

6.1.2 Research Question 2

RQ2: *What technical infrastructure is suitable for user evaluations of health information technology?*

An infrastructure suitable for the evaluation of health information technology would be one that, firstly, optimises data collection, secondly, allows the research team to do an effective retrospective analysis under different conditions and, thirdly, does not interfere with or trouble the comfortability, safety and trust of the users. Considering the fact that a laboratory is a constructed setting unused by the participants, their comfort and tranquility are crucial to avoid interference and distortion of the test and results, as described by [70][96].

Through Project I, II and III several experiences were made regarding the technical infrastructure. The initial user evaluation in the Project II in the spring of 2013, was the first usability evaluation together with end-users in the newly equipped usability

laboratory at Centre for eHealth and Health Care Technology. The PhD candidate was involved in the usability laboratory from the early start, and through the projects improvements were made continuously regarding equipment, furniture, where to place the cameras, the test participants and the test desk, as well as refinements in observation room with placement of equipment and delegation of tasks within the research team. It was a great relief after the first usability evaluation that the technology and proposed routines worked as intended and the data collection was satisfactorily made and stored. The next challenge was to run the second usability evaluation performed as a role-play, with use of two test rooms. Again, the technology and routines in usability laboratory were checked out and the test satisfactory. During the Project I, which involved a series of user evaluations and a larger number of test participants, the research team summarised their experiences on the test infrastructure, published in Paper VIII. As a continuation of the reflections on the test infrastructure, the Project III had another approach compared to the other two projects, with test of mobile technology and visually impaired test participants. The test team experienced that the speed in mobile testing was high, requiring optimisation of the technical infrastructure to ensure a controlled environment, in details presented in Paper IX.

The proposed infrastructure in Paper VIII and IX contributes to a controlled environment for evaluation, however, it is not exempted from potential improvements that can qualitatively benefit future tests and be applied to other mobile technologies and other user groups. For instance, to evaluate the accessibility of touchscreens and the choreography of gestures associated, the video recordings require a sufficient quality that allows zooming in with great detail. A professional software video visualisation would help to substantially reduce the speed for optimal viewing. In addition, the data should be collected through multimodal channels (e.g., video and audio), having the tools to synchronise audio and video signals, which usually incorporate latency when streamed over a network. This synchronisation is essential to detect and understand the correlation between the sounds of the interface and participant's touches on the screen.

Finally, due to the inherent difficulties of recruiting test participants and the discomfort of having to unnecessarily repeat tasks and test sessions, redundancy in data collection is strongly advised through the use of two or more independent sources of data storage, i.e., two different computers.

6.1.3 Research Question 3

RQ3: What lessons and methodological procedures are transferable and applicable to other development projects of health information technology?

Several lessons were learned during this PhD research study that can be transferred and applicable for the development of health information technology. In particular, intended solutions for clinical environments necessarily and primarily need to involve all the user groups in an early phase of the solution development. The users involved in the UCD process were in general enthusiastic, and they were happy to be able to contribute to the system development. That is in line with [97] that found that users who are involved in the process checked out that the system was designed to meet their needs.

One of the health care professionals in the Project I expressed in a post-test group interview: *"It is a fantastic feeling to be able to come with feedback and know they can lead to changes. I miss that with all other systems we have"*.

Another participant from the patient group said: *"Thanks for including us into the project; it is fabulous that COPD patients are in the scope"*.

Secondly, health information technologies are often criticized for poor design and low usability, as they are not well adapted to work processes of health care professionals [39], often causing additional work through multiple log-on procedures [40] and without intuitive navigation. Other problems are complicated information input procedures, great number of mouse-clicks to find relevant documents and large and complex forms with information overload in the UI [39][41]. In order to address these problems, observations in the field were important to understand how clinical activities were registered and the user workshops contributed to an analysis of the user context and their existing work processes to provide an understanding of how a new solution could best fit into the existing clinical workflow or, when non-existent, embed the solution in a new workflow that is built up in collaboration with the end-user groups. The use of role-play and simulation contributed in creating a realistic scenario for the user evaluations, also described in [73][100][101], and the use of actors in the patient role was highly realistic when performing a clinical scenario.

Thirdly, when designing for patient groups as end-users, the fact that chronic patients do not have the same levels of physical energy as healthy people underlines

the importance of designing *easy-to-use* solutions that minimise physical effort and mental workload. In addition, interoperability problems are common within clinical environments [104][105] so the execution of a field trial [15] is recommended in order to provide insights into the interactions between the technologies involved. A continuous long-term feedback of users' interactions with these technologies provides valuable information about how users adopt the technology after deployment.

Video recording the data collected in the workshops, user evaluations and interviews of the PhD research study allowed the research team to retrospectively reflect on the data. The process of watching and transcribing was quite time consuming, but it provided already in an early phase insights regarding the content of the research material. Already during transcription, ideas for the main coding categories arose, called bottom-up coding approach in [70]. The qualitative analysis software QSR NVIVO 10 was used for viewing and transcribing. Initially, the program was complicated to use and delayed the analysis, but after some training the program showed out to support the transcription process through some useful functions. The SUS questionnaire contributed in measuring user satisfaction, and was used in two of the projects as a complementary method. The PhD candidate found it meaningful to use the MMR approach in the user evaluations, as no method identifies all usability problems [96][97][98] and would recommend it for future projects.

6.2 Limitations of the PhD Research Study

There were several limitations associated to the PhD research study of the UCD process and evaluations. Firstly, medical and organisational factors, technical requirements and information security (mentioned in section 1.4) are important aspects within development of health information technology, but outside the scope of the thesis. Secondly, regarding the user evaluations, user-scenarios were tested in a simulated environment, with a reduced number of end-users and, in some cases, patient role played by health professionals. Although the laboratory setting realistically simulated the work environment and created highly realistic scenarios and representative end-users carried out the tests for validation of the system, the study was performed in a simulated instead of real environment. However, the benefits of the controlled environment are tangible because it offers the possibility of selecting and studying specific variables otherwise impossible in real settings. This aspect is especially relevant in health sciences, where the physical, cognitive and emotional integrity of patients may be at stake. Thus, a user evaluation in a controlled

environment should be seen as a first step in the validation of new technology, and a test of the system in real clinical settings through a field trial [15] would be recommended before final implementation.

Limitations related with the reduced number of participants (such as in Project II, n=7), might influence the generalisability and be seen as a potential impediment of the applicability of the findings on a larger scale. However, in qualitative usability studies, a small number of participants can be sufficient for having valid results (e.g., 3 users from each category) when testing three or more groups of users [95][106]. The number of users, despite being in some cases reduced, meaningfully represented all the end-user groups involved. Thus, this PhD research has meaningfully covered all end-users groups involved during the tests, emphasising the plurality of their representativeness rather than their number.

The multidisciplinary character of the research team is seen as a positive factor to strengthen the reliability of the study, with a diversity of relevant backgrounds that usefully combined through the execution of each project. In all three projects, the test sessions were moderated by the same member of the research team, in order to avoid biases regarding conflicting wording and instructions. The PhD candidate acted as the moderator in Projects I and II. Another question that arose was: *did the presence of the moderator in the usability sessions impact on the test participants' task solving?* That question is difficult to answer; however, when taking the role of a moderator, the PhD candidate had *an open mind*, strictly followed the test plan and tried to minimize any interference with the task solving, as described in [70][96]. Nevertheless, this aspect can be addressed by future research, comparing similar evaluations with and without the physical presence of a moderator.

7 Conclusion and Future Work

The objective of this PhD research study was to determine how the application of UCD and evaluation of health information technology could contribute to the *ease of use* and *user satisfaction* for the end-users of such technology.

This thesis has presented three research projects, two of which used a UCD approach in the development of health information technology and one which had a focus on user-based evaluation of mobile technology. The research work was conducted at the Centre for eHealth and Health Care Technology at UiA, Norway.

7.1 Contributions and Lessons from the PhD Research Study

The main contribution of this PhD research study lies on the empirical work on how UCD that was used in two health information technology development projects, with a focus on evaluation and usability. The usefulness of the UCD employed has been demonstrated through the practical application of the approach. The results presented are congruent with research studies on system development and usability [39][87], in order to facilitate user acceptance and efficient, accurate and satisfactory technology use in clinical environments [107]. The end-users' (e.g., COPD patients and health professionals) needs, suggestions and preferences were incorporated in the design and evaluation of health information technology. The UCD approach transformed the end-users into active contributors of the design process and allowed continuous refinement of the technology to fully develop the systems.

In the preparation of a UCD process, an initial field study is recommended for providing an understanding of the context of use and study how the users interact with technology in their natural environment. In the Project II, the idea of developing a platform for inter-municipal coordination and shared access to information through a collaborative IS, arose during the initial field study in the municipalities involved. In the Project I, visits in the field, both to the telemedicine centre and the home of COPD patients contributed to an understanding of the user context.

In Project I and II, the user workshops provided a detailed understanding of work processes. The workshops were organised as interactive sessions with a dynamic nature, where end-user groups actively contributed in describing functionality of the system corresponding to the work processes, suggestions about how to interact with the system and paper prototyping of the GUI. The workshops were the key to understand context of use, user needs and to gather system requirements. Moreover, the initial workshop paper prototypes of both projects efficiently informed the following development of functionality and GUI, with a final result clearly reflecting the paper prototypes, stressing the usefulness of low-fidelity prototypes. In this UCD phase, the involvement of interaction designers and developers in the workshops is recommended, in order to early meet and familiarise with the end-user groups, understanding user context from an early phase.

In this PhD research study, user evaluations took place both in a controlled laboratory environment and in users' home. Other studies underline that the test situation in laboratory settings can be uncomfortable for the test participants [70][96], a factor also taken into consideration in this PhD research study. All user evaluations started with a pre-test interview for background information. The importance of background information is mentioned in [70][72][94], and a questionnaire is also suggested as a way of collecting the data. The PhD candidate found the interview to be an important step, and it was preferred instead of a questionnaire, as it represents the *first contact point* between the moderator and the test participant and it was a way to for the user to familiarise with the test situation and the moderator. In the end of each pre-test interview, it was highlighted that the test session was a test of the technology and *not* a test of the computer skills of the participant. In addition, to avoid discomfort and claustrophobic feelings [96], the test participants were never left alone in the test room.

The test sessions of the PhD research study were initially organised as individual evaluations and in later phases as group-based evaluation with use of role-play and simulation, inspired by [73][100][101]. The task lists of the user evaluations were based on a concurrent TA protocol, as recommended in [70][71][72][96]. A benefit of individual evaluation is that they are characterised by *one-to-one communication* and are usually less complex to prepare. A disadvantage can be a less realistic scenario, as the focus is mainly on the GUI and the system, instead of on the interaction between peers. Role-play has the benefit of providing a more realistic test scenario, as the context of health care services and related technology interaction are usually described

as *complex*. Role-play has the disadvantage of being more complex to assemble, relying on a larger test team gathering at the same time with test participants in the usability laboratory. Individual evaluations are more flexible as they can be made one by one, or in different times in the same day to make it more convenient for the test participant. The role-play in the Project I, simulating a remote monitoring scenario, was considered as a success by the research team, in terms of creating a realistic scenario allowing following the interactions with technology and also between the technologies. One of the main findings was the insufficient sound quality of the videoconference, an already existing technology that did not work as expected and interfered with the newly developed technology.

In one of the user evaluations two groups tested the same UI with the same tasks: end-users and graphic experts, evolved from [102][108]. The test provided valuable recommendations both from end-users and graphical experts, that were incorporated in the next phase of design and development. In the last two usability evaluations of this PhD research study, the test participants were asked to grade the task solving; the first time with a 3-point Likert- scale and the second time a 5-point Likert-scale. As a benefit, that approach provided immediate insights on the difficulty of the task solving, but the disadvantage was that it could interfere with the development of the test session.

Another approach used in one of the user evaluation was the use of actors in a *patient-like* role, as described in [73][101]. That was evaluated by the participants as a highly realistic test scenario, and, based on the experience, it can be recommended to technology evaluations within a clinical scenario.

The choice of the SUS questionnaire, as a quantitative measurement of user satisfaction, was driven by its validity demonstrated across many scientific studies [79][81] and large citation number (approximately 3500 times) [67]. The SUS questionnaire was individually completed after each test session. For the results presentation, visualisation with green, yellow and red colours was used, similar to presented in [80], providing an easy-to-interpret tool in the validation of the UID. In the Project I, the SUS questionnaire had improved score in 9 out of 10 questions, keeping the other question the same score in both evaluations. This was also indicated by satisfaction expressed by the users during the post-test group interview. In the Project II, the final SUS questionnaire had a lower score compared to the initial one. The final post-test group interviews confirmed the findings in the SUS questionnaire, with some skepticism expressed by users regarding implementation of the new system

because some of the functionalities had already been implemented in the existing system of the end-users, during the 4-year long project time.

Overall, the post-test group interviews played an important role in the user evaluations. They provided a platform for the discussion of UID, interactions and functionality between the end-users and research team, enriched by group dynamics. The most important learning experience from the group interviews was the change in the nature of the interviews structure. In the planning of the projects, an interview guide was prepared for the group interviews. During the projects, the group interviews evolved and acquired a more dynamic character, as the main findings from the laboratory tests were quickly analysed by the research team to be later included in the group interview on the same day.

The field trial in the final phase of the Project I was an important step in the UCD process. It allowed studying the long-term and real-time usage of the technology together with real users in their home. The field trial provided useful information about the interactions between the users and the technology, and in addition, between the different technologies involved addressing interoperability problems [103].

To conclude about the end-user involvement, in both Project I and II, the end-user groups (e.g., COPD patients and health professionals) were involved through all the phases of the UCD process, in line with other studies and recommendations [26][29][87]. The end-users' needs, suggestions and preferences were incorporated in the design and evaluation of health information technology. The UCD approach transformed users into active contributors of the design process and allowed continuous refinement of the technology to fully develop the systems. In the Project I, members of a patient union for heart and pulmonary diseases were involved in the development of the collaborative telemedicine system that enabled COPD patients to report their symptoms and health status after hospitalisation to health care professionals at a telemedicine centre. The continuous report of symptoms for chronic patients throughout the whole health service chain, together with actively including patients in building the solution, are in line with the European Union (EU) Health Strategy, *"putting patients at the heart of the system and encouraging them to be involved in managing their own healthcare needs"* [109]. This EU strategy aims to help current health care systems by placing the patient at the centre of new treatments for chronic conditions that are included in the projections of global mortality for 2030 [110], such as ischemic heart disease and diabetes.

Further, throughout the PhD research study, the simulations in high fidelity laboratory settings and in the field trial were significant contributing factors to the ecological validity of the research here presented. In a world where human-computer interactions progressively increase in number and complexity, real-time evaluations in real-world settings become crucial to understand not only the successfulness of deployment, but also the efficient and continuous use of technological solutions.

Finally, the UCD process has been validated by deployment of the collaborative telemedicine system in the Project I, and successfully adopted by the EU FP7 project United4Health [45], focusing on technologies for support of remote monitoring of COPD patients after hospital discharge. As a result, 3 telemedicine centers covering 23 municipalities in Norway are currently using the final version of the application. This represents a significant contribution to the research community compared with related scientific literature where many telemedicine studies do not reach a final deployment stage. Despite the fact that the 4-year long Project II did not reach a final deployment stage, the data collection through a mixed methods approach meaningfully presented detailed information of all the phases of the UCD process, a relevant contribution to the scientific literature in health information technology.

7.2 Implications and Future work

The main contribution of the PhD research study to designers and researchers within health information technology are the experiences on the methodological approach used in two development projects based on UCD, available through the publications included in Part II.

The tested approach of UCD has been an inspiration to other projects at the Centre for eHealth and Health Care Technology, UiA. The tested UCD approach has been implemented into the project plan of the up-coming project Agder Living Lab (see Figure 6), which is a collaboration between the municipality of Grimstad [111] with an inter-municipal collaboration with another six municipalitiesot the region Østre Agder [112] and the Centre for eHealth and Health Care Technology, UiA [45], funded by the Norwegian Directorate of Health [113]. The aim of the project is to involve end-users in development and testing of eHealth technology in laboratory and long-term home settings.

In addition, the Centre for eHealth and Health Care Technology submitted a large research application together with several international partners for a Lighthouse project (in Norwegian *Fyrtårn*) called *Home2Health* to the Research Council of

Norway. The vision of *Home2Health* was to promote an innovative and reflective future society through the use of inclusively designed technologies empowering citizens in their understanding and management of health and disease. In the research application, the development of new ICT tools underpinned on user needs were proposed with the use of the UCD process, tested and verified in this PhD research study.
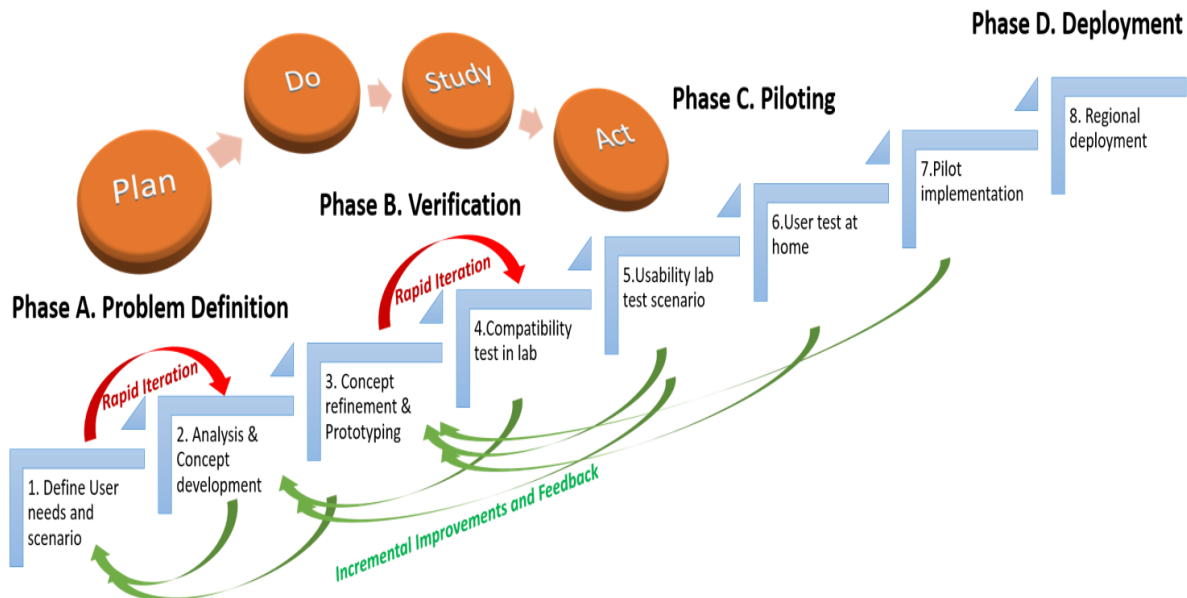
Figure 6 Methodological Approach for Agder Living Lab

Finally, the PhD research study with in particular the outcome of Project I and III (Paper VIII and IX), presents reflections and recommendations on a test infrastructure for usability evaluations of health information technology, as a contribution to designers, developers and researchers in the field.

The research outcome regarding test infrastructure for usability evaluations have inspired the research group at the Centre for the eHealth and Health Care Technology to do applied research on assistive technology and accessibility together with targeted end-user groups, to be shared with the research community. When relevant, eye tracking technology is suggested used for research purposes.

The proposal for future work addresses research on methodological approaches on mobile testing, inspired by the Project III, a relevant research field for the future of health information technology. Further suggestions are research work on appropriate identification and authentication methods for mobile technology, involving patients at home with user tests in both laboratory and in the field.

For the collaborative telemedicine system in Project I, recommended future work would include integration of more devices to the existing platform to support other patient groups and clinical pathways associated with chronic diseases, such as cardiac diseases, metabolic syndrome and diabetes, with the active involvement of end-user groups in a UCD process. Since the Project I was finished in June 2016, a continuation of the remote monitoring of COPD is already in progress through the project *TELMA*, Telemedicine Agder [114] for the years 2016-2019, funded by the Research Council of Norway.

For the Project II, proposed future work includes a field trial with a test implementation in an inter-municipal work context, before final deployment of the IS.

References

[1]   Norwegian Ministry of Health and Care Services, National Health and Care Services Plan 2011-2015, Meld. St. 16 (2010-2011) Report to the Storting (white paper). [retrieved: June 1, 2016]. Available from: https://www.regjeringen.no/contentassets/f17befe0cb4c48d68c744bce3673413d/no/pdfs/stm201020110016 000dddpdfs.pdf English summary available from: https://www.regjeringen.no/contentassets/f17befe0cb4c48d68c744bce3673413d/en-gb/pdfs/stm201020110016000en_pdfs.pdf

[2]   Norwegian Ministry of Health and Care Services, "The Coordination Reform, Proper treatment – at the right place and right time," Report No. 47 (2008-2009) to the Storting. [retrieved: June 1, 2016]. Available from: https://www.regjeringen.no/contentassets/d4f0e16ad32e4bbd8d8ab5c21445a5dc/en-gb/pdfs/stm200820090047000en_pdfs.pdf

[3]   Lazar, J, Feng J. H., & Hochheiser, H. (2010). *Research methods in human-computer interaction*. John Wiley & Sons Ltd.

[4]   Preece, J., Rogers, Y., Sharp, H., Benyon, D., Holland, S., & Carey, T. (1994). *Human-computer interaction*. Addison-Wesley Longman Ltd.

[5]   Myers, M. D. (1997). Qualitative research in information systems. *Management Information Systems Quarterly*, 21(2), 241-242.

[6]   Orlikowski, W. J., & Baroudi, J. J. (1991). Studying information technology in organizations: Research approaches and assumptions. *Information Systems Research*, 2(1), 1-28.

[7]   Venkatesh, V., Brown, S. A., & Bala, H. (2013). Bridging the qualitative-quantitative divide: Guidelines for conducting Mixed Methods Research in Information Systems. *MIS Quarterly*, 37(1), 21-54.

[8]   Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007). A design science research methodology for information systems research. *Journal of Management Information Systems*, 24(3), 45-77. doi:10.2753/MIS0742-1222240302

[9]   Hevner, A. R. (2007). A three cycle view of design science research. *Scandinavian Journal of Information Systems*, 19(2), 4.

[10]   Green, J., & Thorogood, N. (2013). *Qualitative methods for health research*. Sage Inc.

[11]   Berg, M. (1999). Patient care information systems and health care work: a sociotechnical approach. *International Journal of Medical Informatics*, 55(2), 87-101. doi:10.1016/S1386-5056(99)00011-8

[12]   Nordic Council of Ministers (2013). Nordic eHealth Indicators, Organisation of research, first results and the plan for the future. TemaNord 2013:522, ISBN 978-92-893-2526-4. doi:http://dx.doi.org/10.6027/TN2013-522

[13]   Nordic Council of Ministers (2015). Nordic eHealth Benchmarking. Status 2014. TemaNord 2015:539, ISBN 978-92-893-4165-3. doi:http://dx.doi.org/10.6027/TN2015-539

[14]   Martínez-Alcalá, C. I., Muñoz, M., & Monguet-Fierro, J. (2013). Design and customization of telemedicine systems. *Computational and Mathematical Methods in Medicine*, 2013. doi:10.1155/2013/618025

[15]   Dabbs, A. D. V., Myers, B. A., Mc Curry, K. R., Dunbar-Jacob, J., Hawkins, R. P., Begey, A., & Dew, M. A. (2009). User-centered design and interactive health technologies for patients. *Computers, Informatics, Nursing*, 27(3), 175. doi:10.1097/NCN.0b013e31819f7c7c

[16]   Ho, M., Luk, R., & Aoki, P. (2007). Applying User-Centered Design to Telemedicine in Africa. In *CHI 2007 Workshop on User Centered Design for International Development*.

[17]   Das, A., & Svanæs, D. (2013). Human-centred methods in the design of an e-health solution for patients undergoing weight loss treatment. *International Journal of Medical Informatics*, 82(11), 1075-1091. doi:10.1016/j.ijmedinf.2013.06.008

[18] Gulliksen, J., Göransson, B., Boivie, I., Blomkvist, S., Persson, J., & Cajander, Å. (2003). Key principles for user-centred systems design. *Behaviour and Information Technology*, 22(6), 397-409. doi:10.1080/01449290310001624329

[19] Hassenzahl, M., & Tractinsky, N. (2006). User experience-a research agenda. *Behaviour and Information Technology*, 25(2), 91-97. doi:10.1080/01449290500330331

[20] Karat, J. (1996). User centered design: quality or quackery?. *ACM Interactions*, 3(4), 18-20. doi:10.1145/234813.234814

[21] Vredenburg, K., Mao, J. Y., Smith, P. W., & Carey, T. (2002) April). A survey of user-centered design practice. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 471-478). ACM.

[22] Rogers, Y., Sharp, H., & Preece, J. (2011). *Interaction Design-beyond human-computer interaction*. John Wiley & Sons.

[23] Löwgren, J., & Stolterman, E. (2004). *Thoughtful interaction design: A design perspective on information technology*. MIT Press.

[24] Borchers, J. O. (2001). A pattern approach to interaction design. *AI & Society*, 15(4), 359-376. doi:10.1007/BF01206115

[25] Zimmerman, J., Forlizzi, J., & Evenson, S. (2007, April). Research through design as a method for interaction design research in HCI. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 493-502). ACM. doi:10.1145/1240624.1240704

[26] Bevan, N. (1995). Usability is quality of use. *Advances in Human Factors/Ergonomics*, *20*, 349-349. doi:10.1016/S0921-2647(06)80241-8

[27] Jakob, N. (1993). *Usability engineering*. Fremont, California: Morgan.

[28] Nielsen Norman group, 2015. [retrieved: June 1, 2016]. Available from: http://www.nngroup.com/articles/usability-101-introduction-to-usability/.

[29] The ISO standard ISO/DIS 9241-11 Ergonomics of human-system interaction, Part 11: Usability: Definitions and concepts. [retrieved: June 1, 2016]. Available from: http://www.iso.org/iso/catalogue_detail.htm?csnumber=63500

[30] Eysenbach, G. (2001). What is e-health?. *Journal of Medical Internet Research*, 3(2): e20. doi:10.2196/jmir.3.2.e20

[31] WHO Trade, foreign policy, diplomacy and health. Glossary of globalization, trade and health terms. [retrieved: June 1, 2016] Available from: http://www.who.int/trade/glossary/story021/en/

[32] Perednia, D. A., & Allen, A. (1995). Telemedicine technology and clinical applications. *Journal of the American Medical Association*, 273(6), 483-488. doi:10.1001/jama.1995.03520300057037

[33] Craig, J., & Patterson, V. (2005). Introduction to the practice of telemedicine. *Journal of Telemedicine and Telecare*, 11(1), 3-9.

[34] Bashshur, R. L. (1995). On the definition and evaluation of telemedicine, *Telemed Journal*, 1(1), p. 19-30. doi:10.1089/tmj.1.1995.1.19

[35] Bai, C. (2012). Cell phone based telemedicine-brief introduction. *Journal of Translational Medicine*, 10(Suppl 2), A47. doi:10.1186/1479-5876-10-S2-A47

[36] Celler, B. G., Earnshaw, W., Ilsar, E. D., Betbeder-Matibet, L., Harris, M. F., Clark, R., Hesketh, N. H., & Lovell, N. H. (1995). Remote monitoring of health status of the elderly at home. A multidisciplinary project on aging at the University of New South Wales. *International Journal of Biomedical Computing*, 40(2), 147-155. doi:10.1016/0020-7101(95)01139-6

[37] U.S. Department of Health and Human Services, The Health Resources and Services Administration (HRSA) [retrieved: June 1, 2016]. Available from:http://www.hrsa.gov/healthit/toolbox/oralhealthittoolbox/introduction/whatishealthit.html

[38] U.S. Department of Health and Human Services, Office of the National Coordinator for Health Information Technology. [retrieved: June 1, 2016]. Available from:https://www.healthit.gov/patients-families/basics-health-it

[39] Stanziola, E., Uznayo, M. Q., Ortiz, J. M., Simón, M., Otero, C., Campos, F., & Luna, D. (2015, August). User-Centered Design of Health Care Software Development: Towards a Cultural Change. In *MEDINFO 2015: EHealth-enabled Health: Proceedings of the 15th World Congress on Health and Biomedical Informatics* (Vol. 216, p. 368). IOS Press. doi:10.3233/978-1-61499-564-7-368

[40] Faxvaag, A., Johansen, T. S., Heimly, V., Melby, L., & Grimsmo, A. (2010). Healthcare professionals' experiences with EHR-system access control mechanisms. *Studies in Health Technology and Informatics*, 169, 601-605.

[41] Smáradóttir, B. F. (2009). *The Role of electronic nursing documentation for continuity of care in short-time wards.* Master's thesis in Telemedicine and eHealth, University of Tromsø, Norway.

[42] Creswell, J. W., & Clark, V. L. P. (2007). *Designing and conducting mixed methods research.* SAGE Publications Inc.

[43] United4Health, The European project.Transforming the patient experience with telehealth in Europe. [retrieved: June 1, 2016] Available from: http://www.united4health.eu/

[44] Regional Research Fund Agder, [retrieved: June 1, 2016] Available from: www.regionaleforskningsfond.no

[45] United4Health 2015, The Norwegian project contribution. [retrieved: June 1, 2016]. Available from: http://www.united4health.no

[46] Centre for eHealth and Health Care Technology. [retrieved: June 1, 2016]. Available from: http://www.uia.no/en/centres-and-networks/centre-for-ehealth-and-care-technology

[47] The 7th Framework Programme for Research and Innovation, European Union. [retrieved: June 1, 2016] Available from: http://ec.europa.eu/research/fp7/index_en.cfm

[48] Norwegian Health Network (NHN). [retrieved: June 1, 2016] Available from: https://www.nhn.no/english/Pages/default.aspx

[49] Gerdes, M., & Fensli, R. End-to-end security and privacy protection for co-operative access to health and care data in a telehealth trial system for remote supervision of COPD-Patients. In *Linköping Electronic Conference Proceedings: 13th Scandinavian Conference on Health Informatics,(SHI2015)*(pp. 25-32). ISSN(print): 1650-3686, ISSN(online): 1650-3740, ISBN: 978-91-7685-985-8

[50] Cisco Jabber Video for Telepresence. [retrieved: June 1, 2016] Available from: https://it.tufts.edu/sites/default/files/Jabber.pdf

[51] Lazar, J. (2006). *Web Usability- a user-centered design approach.* Pearson Education. ISBN-10 0321321359, ISBN-13 9780321321350

[52] Norwegian Social Science Data Services (NSD). [retrieved: June 1, 2016] Available from: http://www.nsd.uib.no/personvern/en/index.html

[53] Håland, J. *Blinde og berøringsskjerm- en brukerevaluering.* (2015). Master's thesis in Health and Social Informatics, University of Agder, Norway.

[54] Denzin, N. K., & Lincoln, Y. S. (1994). *Handbook of qualitative research.* SAGE Publications, Inc.

[55] Patton, M. Q. (1990). *Qualitative evaluation and research methods.* SAGE Publications, Inc.

[56] Berg, B. L., Lune, H., & Lune, H. (2004). *Qualitative research methods for the social sciences* (Vol. 5). Boston, MA: Pearson.

[57] Mays, N., & Pope, C. (2000). Assessing quality in qualitative research. *British Medical Journal*, 320 (7226), 50.

[58] Malterud, K. (2001). Qualitative research: standards, challenges, and guidelines. *The Lancet*, 358(9280), 483-488.

[59] Burns, R. B. (2000). *Introduction to Research Methods*, SAGE Publications Ltd. 4th edition.

[60] Pope. C., & Mays, N. (1995). Qualitative research: Reaching the parts other methods cannot reach: An introduction to qualitative methods in health and health services research. *British Medical Journal*, 1 (311), 42-45.

[61] Kuper, A., Reeves, S., & Levinson, W. (2008). An introduction to reading and appraising qualitative research. *British Medical Journal*, 337: a288. doi:http://dx.doi.org/10.1136/bmj.a288

[62] Teddlie, C., & Tashakkori, A. (2011). Mixed methods research. Denzin, Norman; Lincoln, Yvonna (eds.), *The Sage handbook of qualitative research*, 4, 285-300.

[63] Stoop, A. P., & Berg, M. (2003). Integrating quantitative and qualitative methods in patient care information system evaluation: guidance for the organizational decision maker. *Methods of Information in Medicine*, 42(4), 458-462.

[64] Johnson, R. B., Onwuegbuzie, A. J., & Turner, L. A. (2007). Toward a definition of mixed methods research. *Journal of Mixed Methods Research*, 1(2), 112-133. doi:10.1177/1558689806298224

[65] The University of Agder's Library. [retrieved: June 1, 2016] Available from: http://www.uia.no/en/library.

[66] The Norwegian Electronic Health Library. [retrieved: June 1, 2016] Available from: www.helsebiblioteket.no.

[67] Google Scholar. [retrieved: June 1, 2016] Available from: https://scholar.google.no

[68] The Norwegian government. [retrieved: June 1, 2016] Available from: https://www.regjeringen.no/en/id4/

[69] Directorate of Health. [retrieved: June 1, 2016] Available from: https://helsedirektoratet.no/English

[70] Jaspers, M. W. (2009). A comparison of usability methods for testing interactive health technologies: methodological aspects and empirical evidence. *International Journal of Medical Informatics*, 78(5), 340-353. doi:10.1016/j.ijmedinf.2008.10.002

[71] Ericsson, K. A., & Simon, H. A. (1980). Verbal reports as data. *Psychological Review*, 87(3), 215.

[72] Kushniruk, A. W., & Patel, V. L. (2004). Cognitive and usability engineering methods for the evaluation of clinical information systems. *Journal of Biomedical Informatics*, 37(1), 56-76. doi:10.1016/j.jbi.2004.01.003

[73] Svanæs, D., Alsos, O. A., & Dahl, Y. (2010). Usability testing of mobile ICT for clinical settings: Methodological and practical challenges. *International Journal of Medical Informatics*, 79(4), e24-e34. doi:10.1016/j.ijmedinf.2008.06.014

[74] Stiles, W. B. (1999). Evaluating qualitative research. *Evidence Based Mental Health*, 2(4), 99-101.

[75] QSR NVIVO v10. [retrieved: June 1, 2016] Available from: http://www.qsrinternational.com/products_nvivo.aspx

[76] Elo, S., Kääriäinen, M., Kanste, O., Pölkki, T., Utriainen, K., & Kyngäs, H. (2014). Qualitative Content Analysis. *SAGE Open*, *4*(1), 2158244014522633. doi:10.1177/2158244014522633

[77] Schreier, M. (2014). Qualitative content analysis. *The SAGE Handbook of Qualitative Data Analysis*, 170-183.

[78] Dingwall, R. (1997). Accounts, Interviews and Observations. In Miller, G., & Dingwall, R. (Eds.). (1997). Context and method in qualitative research. SAGE. doi:http://dx.doi.org/10.4135/9781849208758.n4

[79] Brooke, J. (1996). SUS-A quick and dirty usability scale. *Usability evaluation in industry*, *189*(194), 4-7.

[80] Bangor, A., Kortum, P., & Miller, J. (2009). Determining what individual SUS scores mean: Adding an adjective rating scale. *Journal of Usability Studies*,*4*(3), 114-123.

[81] Bangor, A., Kortum, P. T., & Miller, J. T. (2008). An empirical evaluation of the system usability scale. *International. Journal of Human–Computer Interaction*, 24(6), 574-594. doi:10.1080/10447310802205776

[82] Tullis, T. S., Stetson, J. N. (2004). A comparision of questionnaires for assessing website usability. Unpublished presentation at the UPA annual conference (2004). http://home.comcast.net-tomtullis/publications/UPA2004TullisStetson.pdf

[83] Adair, J. G. (1984). The Hawthorne effect: A reconsideration of the methodological artifact. Journal of Applied Psychology, 69(2), 334. doi:http://dx.doi.org/10.1037/0021-9010.69.2.334

[84] Norman, D. A., & Draper, S. W. (1986). *User centered system design*. Hillsdale, NJ.

[85] Ritter, F. E., Baxter, G. D., & Churchill, E. F. (2014). *Foundations for Designing User-Centered Systems*. London: Springer.

[86] Earthy, J., Jones, B. S., & Bevan, N. (2001). The improvement of human-centred processes—facing the challenge and reaping the benefit of ISO 13407. *International Journal of Human-Computer Studies*, 55(4), 553-585. doi:10.1006/ijhc.2001.0493

[87] Gulliksen, J., & Göransson, B. (2001). Reengineering the systems development process for user centered design. In *Proceedings of ACM INTERACT* (pp. 359-366).

[88] Karat, J. (1997). Evolving the scope of user-centered design. Communications of the ACM 40(7) (pp. 33-38). doi:10.1145/256175.256181

[89] Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). "Mini-mental state": a practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, *12*(3), 189-198.

[90] Directorate of Health and National Expertise Service for Ageing and Health. (2011). Etablering og drift av Demensteam, Demensutredning i primærhelsetjenesten. [retrieved: June 1, 2016]. Available from: http://www.aldringoghelse.no/ViewFile.aspx?ItemID=2824

[91] Norwegian Ministry of Health and Care Services. (2007). Dementiaplan, 2015. (Demensplan 2015 "den gode dagen" Delplan til omsorgsplan 2015). [retrieved: June 1, 2016]. Available from: http://www.regjeringen.no/upload/HOD/Vedlegg/Omsorgsplan_2015/Demensplan2015.pdf

[92] Wyatt, J. C., & Wyatt, S. M. (2003). When and how to evaluate health information systems?. *International Journal of Medical Informatics*, *69*(2), 251-259. doi:10.1016/S1386-5056(02)00108-9

[93] Bastien, J. C. (2010). Usability testing: a review of some methodological and technical aspects of the method. *International Journal of Medical Informatics*, *79*(4), e18-e23. doi:10.1016/j.ijmedinf.2008.12.004

[94] Fonteyn, M. E., Kuipers, B., & Grobe, S. J. (1993). A description of think aloud method and protocol analysis. *Qualitative Health Research*, *3*(4), 430-441. doi:10.1177/104973239300300403

[95] Nielsen, J. (1994). Estimating the number of subjects needed for a thinking aloud test. *International Journal of Human-computer Studies*, *41*(3), 385-397.

[96] Nielsen, J., Clemmensen, T., & Yssing, C. (2002, October). Getting access to what goes on in people's heads?: reflections on the think-aloud technique. In *Proceedings of the second Nordic conference on Human-computer interaction* (pp. 101-110). ACM.

[97] Hollin, I., Griffin, M., & Kachnowski, S. (2012). How will we know if it's working? A multi-faceted approach to measuring usability of a specialty-specific electronic medical record. *Health Informatics Journal*, *18*(3), 219-232. doi:10.1177/1460458212437008

[98] Horsky, J., McColgan, K., Pang, J. E., Melnikas, A. J., Linder, J. A., Schnipper, J. L., & Middleton, B. (2010). Complementary methods of system usability evaluation: surveys and observations during software design and development cycles. *Journal of Biomedical Informatics*, *43*(5), 782-790. doi:10.1016/j.jbi.2010.05.010

[99] Van den Haak, M. J., & De Jong, M. D. (2003, September). Exploring two methods of usability testing: concurrent versus retrospective think-aloud protocols. In *Professional Communication Conference, 2003. IPCC 2003. Proceedings. IEEE International* (pp. 3-pp). doi:10.1109/IPCC.2003.1245501

[100] Li, A. C., Kannry, J. L., Kushniruk, A., Chrimes, D., McGinn, T. G., Edonyabo, D., & Mann, D. M. (2012). Integrating usability testing and think-aloud protocol analysis with "near-live" clinical simulations in evaluating clinical decision support. *International Journal of Medical Informatics*, *81*(11), 761-772. doi:10.1016/j.ijmedinf.2012.02.009

[101] Borycki, E., & Kushniruk, A. (2005). Identifying and preventing technology-induced error using simulations: Application of usability engineering techniques. *Healthcare quarterly*, 8(Sp), 99-105. doi:10.12927/hcq..17673

[102] Tory, M., & Möller, T. (2005). Evaluating visualizations: do expert reviews work?. *IEEE Computer Graphics and Applications,* 25(5), 8-11. doi:10.1109/MCG.2005.102

[103] Shaikh, A. (2015). The impact of SOA on a system design for a telemedicine healthcare system. *Network Modeling Analysis in Health Informatics and Bioinformatics*, 4(1), 1-16.

[104] Bashshur, R. L. (2013). Guest editorial: Compelling issues in telemedicine. *Telemedicine and e-Health*, 19(5), 330-332. doi:10.1089/tmj.2013.9998

[105] Craft, R. L. (2005). Toward technical interoperability in telemedicine. *Telemedicine and e-Health*, *11*(3), 384-404. doi:10.1089/tmj.2005.11.384

[106] Nielsen, J., & Landauer, T. K. (1993, May). A mathematical model of the finding of usability problems. In *Proceedings of the INTERACT'93 and CHI'93 conference on Human factors in computing systems* (pp. 206-213). ACM. doi:10.1145/169059.169166

[107] Wade, V. A., Eliott, J. A., & Hiller, J. E. (2014). Clinician acceptance is the key factor for sustainable telehealth services. *Qualitative Health Research* vol. 24(5) 682-694. doi:10.1177/1049732314528809

[108] Acevedo, D., Jackson, C. D., Drury, F., & Laidlaw, D. H. (2008). Using visual design experts in critique-based evaluation of 2D vector visualization methods. *IEEE Transactions on Visualization and Computer Graphics*, 14(4), 877-884. doi:10.1109/TVCG.2008.29

[109] European Union. Official Journal of the European Union, vol. C 146, 22 June 2006, ISSN 1725-2423. [retrieved: June 1, 2016]. Available from: http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1446552106801&uri=CELEX:52006XG0622(01)

[110] Mathers, C. D., & Loncar, D. (2006). Projections of global mortality and burden of disease from 2002 to 2030. *Plos med*, *3*(11), e442. doi:https://dx.doi.org/10.1371/journal.pmed.0030442

[111] Grimstad Kommune, Agder Living Lab. [retrieved: June 1, 2016]. Available from: https://www.grimstad.kommune.no/tjenester/helse-omsorg-og-sosiale-tjenester/utviklingssenteret-og-velferdsteknologi/velferdsteknologi/agder-livinglab/

[112] Samarbeid på tvers i Østre Agder. [retrieved: June 1, 2016]. Available from: http://www.ostreagder.no/agder-living-lab/

[113] Directorate of Health. [retrieved: June 1, 2016]. Available from: https://helsedirektoratet.no/velferdsteknologi

[114] TELMA (Telemedisin Agder) Norwegian Research Council number 247929/O70.

Part II

Appendix A

List of Publications

The author of this dissertation has published in total 12 peer-reviewed scientific papers during the PhD programme with 10 publications as a first author and 2 as a co-author. The following list gives an overview of the published papers.

Papers Included in the Dissertation

Paper I B. Smaradottir, M. Gerdes Martin, S. Martinez, and R. Fensli, "The EU-project United4Health: user-centred design of an information system for a Norwegian telemedicine service," in *SAGE Journal of Telemedicine and Telecare*, 1357633X15615048, November 2015.

Paper II[1] B. Smaradottir, M. Gerdes Martin, R. Fensli, and S. Martinez, "User-Centred Design of a COPD Remote Monitoring Application-Experiences from the EU-project United4Health," in *IARIA International Journal on Advances in Software*, vol. 8, no. 3 & 4, December 2015.

Paper III B. Smaradottir, M. Gerdes Martin, R. Fensli, and S. Martinez, "Usability Evaluation of a COPD Remote Monitoring Application," in *Studies in Health Technology and Informatics*, 210, May 2015, pp. 845-849.

Paper IV B. Smaradottir, E. Holen-Rabbersvik, E. Thygesen, R. Fensli, and S. Martinez, "User-Centred Design of the User Interface of a Collaborative Information System for Inter-Municipal Dementia Team," in *Proceedings of the 8th International Conference on Health Informatics*, *HEALTHINF 2015,* Lisbon, Portugal, 12-15 January 2015, pp. 446-453.

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[1] This is an invited paper, extended from paper X.

Paper V   B. Smaradottir, E. Holen-Rabbersvik, E. Thygesen, R. Fensli, and S. Martinez, "Usability Evaluation of Electronic forms and Collaborative Assessment Report in an Inter-municipality Health Care team for Dementia Diagnose," in *Proceedings of the 12th Scandinavian Conference on Health Informatics*, *SHI2014*, Grimstad, Norway, 21-22 August 2014, pp. 45-54.

Paper VI   B. Smaradottir, S. Martinez, E. Holen-Rabbersvik, T. Vatnøy, and R. Fensli, "Usability Evaluation of a Collaborative Health Information System- Lessons from a User-centred Design Process," in *Proceedings of The 9th International Conference on Health Informatics*, *HEALTHINF 2016*, Rome, Italy, 21-23 February 2016, pp. 306-313.

Paper VII   B. Smaradottir, S. Martinez, E. Holen-Rabbersvik , and R. Fensli, "eHealth-extended Care Coordination: Development of a Collaborative System for Inter-municipal Dementia Teams- A research project with a user-centered design approach," in *Proceedings of IEEE Xplore 2015 International Conference on Computational Science and Computational Intelligence, CSCI, Symposium on Health Informatics and Medical Systems*, Las Vegas, USA, 7-9 December 2015, pp. 749-753.

Paper VIII   M. Gerdes Martin, B. Smaradottir, and R. Fensli, "End-to-end Infrastructure for Usability Evaluation of eHealth Applications and Services," in *Proceedings of the 12th Scandinavian Conference on Health Informatics*, *SHI2014*, Grimstad, Norway, 21-22 August 2014, pp. 53-59.

Paper IX   B. Smaradottir, J. Håland, S. Martinez Santiago, Å. Somdal, and R. Fensli, "Recommendations on a Test Infrastructure for Evaluation of Touchscreen Assistive Technology for Visually Impaired Users," in *Proceedings of the 13th Scandinavian Conference on Health Informatics*, *SHI2015*, Tromsø, Norway, 15-17 June 2015, pp. 41-46.

Papers Not Included in the Dissertation

Paper X[2]   B. Smaradottir, M. Gerdes, R. Fensli, and S. Martinez, "User Interface Development of a COPD Remote Monitoring Application- A User-centred Design Process," in *Proceedings of the Eighth International Conference on Advances in Computer-Human Interactions*, *ACHI 2015*, Lisbon, Portugal, 22-27 February 2015, pp. 57-62.

Paper XI   B. Smaradottir, M. Gerdes Martin, S. Martinez, and R. Fensli, "The EU-project United4Health: User-Centred Design and Evaluation of a Collaborative Information System for a Norwegian Telehealth Service," in *Studies in Health Technology and Informatics*, vol. 216, August 2015, pp. 892.

Paper XII   M. Gerdes Martin, B. Smaradottir, F. Reichert, and R. Fensli, "Telemedicine and Cooperative Remote Healthcare Services: COPD Field Trial," in *Studies in Health Technology and Informatics*, vol. 210, May 2015, pp. 455-457.

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[2] This papers received "Best Paper Award" from the ACHI 2015 Conference.

Appendix B

Paper I

Title:	The EU-project United4Health: user-centred design of an information system for a Norwegian telemedicine service
Authors:	**Berglind Smaradottir**, Martin Gerdes, Santiago Martinez and Rune Fensli
Affiliation:	University of Agder, Jon Lilletuns vei 9, N-4879 Grimstad, Norway
Published in:	*SAGE Journal of Telemedicine and Telecare*, 357633X15615048, 5 November 2015.

The EU-project United4Health: User-centred Design of an Information System for a Norwegian Telemedicine Service

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Abstract—

Introduction: Organisational changes of health care services in Norway brought to light a need for new clinical pathways. This study presents the design and evaluation of an information system for a new telemedicine service for chronic obstructive pulmonary disease patients after hospital discharge.

Methods: A user-centred design approach was employed composed of a workshop with end-users, two user tests and a field trial. For data collection, qualitative methods such as observations, semi-structured interviews and a questionnaire were used.

Results: User workshop's outcome informed the implementation of the system initial prototype, evaluated by end-users in a usability laboratory. Several usability and functionality issues were identified and solved, such as the interface between the initial colour scheme and the triage colours. Iterative refinements were made and a second user evaluation showed that the main issues were solved. The responses to a questionnaire presented a high score of user satisfaction. In the final phase, a field trial showed satisfactory use of the system.

Discussion: This study showed how the target end-users groups were actively involved in identifying the needs, suggestions and preferences. These aspects were addressed in the development of an information system through a user-centred design process. The process efficiently enabled users to give feedback about design and functionality. Continuous refinement of the system was the key to full development and suitability for the telemedicine service.

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I. INTRODUCTION

In Norway, the Coordination reform [1] focuses on strategies for increased continuity of care in the National Health Services. One key consequence is the need for effective technological solutions that support new clinical pathways and facilitate coordination, collaboration and information flow between health care providers across organisational borders. In this context, the EU funded project United4Health (U4H) [2], develops and evaluates telehealth solutions for chronic disease patients. The Norwegian contribution to the U4H project was the development of a collaborative telemedicine system for remote monitoring of chronic obstructive pulmonary disease (COPD) patients after hospital discharge. A municipal partner established a telemedicine service where COPD patients performed daily routines of self-reported symptoms at home, sending data measurements of pulse oximetry (SpO2, pulse and blood oxygen) and a questionnaire on self-reported symptoms on a tablet device [3] over a mobile network. For information management and communication efficiency, an information system (IS) was built to support the new telemedicine service, see Figure 7.
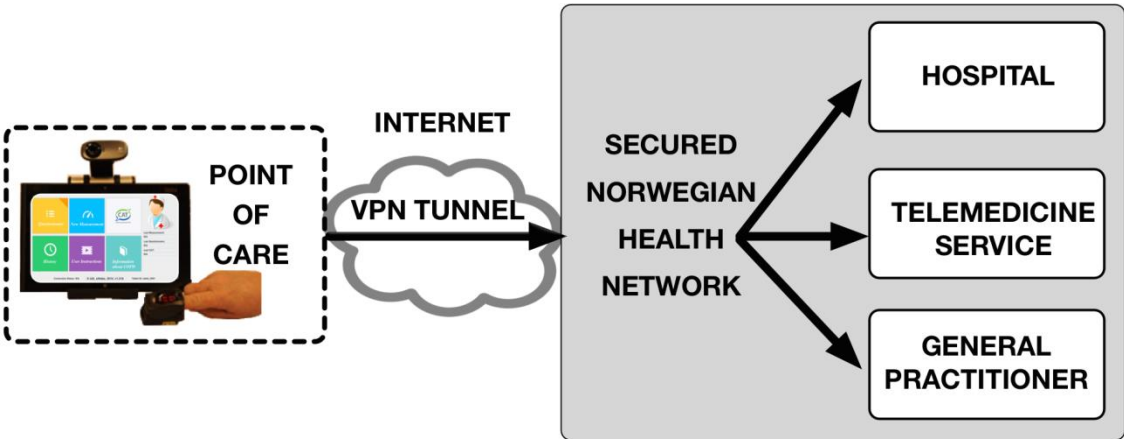

Figure 7 The telemedicine service information flow

The IS was designed for sustainable operation and implementation within the secured Norwegian Health Network (NHN) [4]. The details of privacy and security are further described in [5]. In order to achieve acceptable levels of effectiveness, efficiency, and satisfaction, a user-centred design (UCD) [6][7][8] process was employed for the development of the IS. This paper presents the results from the UCD process of the IS development, with the aim of validation from operational and qualitative usability perspectives.

The following research questions (RQ) were addressed:

RQ1: How can a functional collaborative information system be developed taking into account user needs and requirements of a telemedicine service?

RQ2: What lessons and methodological procedures from this study are transferable to the development of other clinical systems?

II. METHODS

Qualitative methods were used for data collection and analysis. The UCD process was divided into two phases: (1) workshop with representatives of the end-user groups to gather user requirements and (2) iterative development of the IS including user evaluations, interviews and a field trial. The UCD process had a total duration of 6 months during the years 2013-2014 and involved 24 end-users, see Table 1 for distribution of the participants.

Table 1 The end-user participation in the UCD process.

End-users n=24	Workshop n=7	User test 1 n=15	User test 2 n=9	Field trial n=11
Nurse 1	x	x	x	x
Nurse 2	x	x		
Nurse 3			x	x
Nurse 4-6 (n=3)		x	x	x
Nurse 7-12 (n=6)		x		
Patient 1	x		x	x
Patient 2	x		x	
Patient 3-7 (n=5)				x
Physician 1-2 (n=2)		x		
Project manager	x			
Technician 1-2 (n=2)	x	x	x	

The workshop, user evaluations and interviews were audio-visually recorded, with a total of 20 hours verbatim transcribed by the researchers. Transcripts were coded into categories and a qualitative content analysis [9] was made with the software QSR NVIVO v10.

A. *Workshop with End-users*

The workshop aimed to understand the context of use and gather user requirements for the design of the IS. Workshop attendees (n=7) were representative of the end-user groups: 2 nurses, 2 technicians, 2 members of the union for cardiac and pulmonary patients (average age of 69 years) and 1 project manager. During the workshop, attendees defined the optimal workflow for the telemedicine service, described their preferred way of interacting with the IS and suggested ideas for the user interface layout.

B. *Iterative Development*

The initial design of the IS was based on the outcome of the end-user workshop. An interaction designer created the initial graphical user interface (GUI), inspired by the results of the project eHealth-extended Care Coordination [10]. An industry partner (Devoteam AS in Grimstad, Norway) in the U4H project implemented the functionality of the IS. The security network infrastructure of the Centre for eHealth and Healthcare Technology at the University of Agder, Norway, was used as a test bed.

C. *User Test 1 and 2*

Two user tests based on a think aloud (TA) protocol [11][12][13][14][15], were carried out with end-users to evaluate the usability of the system and propose potential refinements for further development iterations. The user tests took place in the Usability Laboratory at the Centre for eHealth and Healthcare Technology, a facility with three separate test rooms and one observation room. The details of the infrastructure are described in [16]. In user test 1 (n=15), 11 nurses, 2 physicians and 2 technicians participated in the execution of a role-play scenario [17]. The scenario was designed by the research team and included a simulation of the proposed telemedicine service workflow using the developed technology where the interface design and functionalities were tested (see Table 1 for participant distribution). After user test 1, two weeks were spent refining the IS. In user test 2 (n=9), 5 nurses, 2 technicians and 2 members of the union for cardiac and pulmonary patients simulated the steps of the

telemedicine service workflow and tested the functionality of the second version of the IS. To complete the feedback, the questionnaire System Usability Scale (SUS) [18] was individually filled in after both user tests. In addition, two post-test semi-structured group interviews (n=15, n=9) were made with the aim of discussing the findings from the user tests regarding GUI and functionality of the IS. The participants were shown the IS on a large screen during the interview session, allowing to see the GUI in detail.

For the telemedicine service, nurses were assigned a key role regarding data management in the IS, which was reflected in the participant distribution in the user tests, shown in Table 1. The representatives for COPD patients had the key role as advisors regarding the patient role in the telemedicine monitoring scenario. In addition, they provided data for the test and transmission to the IS, which contributed to a realistic test scenario. Four people from the research team had roles as moderators and observers during the user tests. In addition, two developers from the company were present as observers in user tests and interviews.

D. Field Trial

The last step in the iterative development was to run a field trial for the continuous functioning of the IS and identification of usability issues. 5 nurses utilizing the service at a telemedicine centre established by a municipality partner participated in the field trial, see Table 1 for participation of the nurses in earlier phases. 6 representatives of voluntary COPD patients were enrolled and used a tablet application at home for a week to daily send data. Every day, nurses used the IS to evaluate the participants' data and, in addition, a videoconference call was made. During the field trial, a usability evaluation with a TA protocol evaluating the daily tasks of the nurses in the IS was conducted in the workplace environment followed by a post-test interview. At the end of the field trial, the COPD patient participants were visited at home for an evaluation and interview focusing on the tablet device in the telemedicine scenario, further presented in [19].

E. Ethical Considerations

This study was approved by Norwegian Social Science Data Services (project number: 35356). All participants received oral and written information about the project and confidential treatment of the collected data. Participation was voluntary and participants could withdraw at any time without reason. The participants representing COPD patients were informed that the main aim of the project was the

development and functional evaluation of the technology and not a medical follow-up. All participants signed up explicit written consent.

III. RESULTS

The results are presented following the stages of the UCD process: workshop with end-users; the iterative development divided into user test 1, user test 2, SUS questionnaire and field trial.

A. Workshop with End-users

The workshop results are categorised by context of use, telemedicine scenario workflow and user interface design.

1) Context of use

The overall aim of the new IS was to create a platform that supported the information flow and collaborative work between the user groups involved in remote monitoring of COPD patients; nurses at hospital; technical department at hospital for configuration of patient tablet devices for remote communication with the IS; telemedicine service nurses for management of patient data and patient follow up. In addition, patient's GP and hospital physicians would have access granted to IS data of those patients they were responsible for.

2) The workflow of the telemedicine scenario

The workflow for the telemedicine scenario contained two differentiated phases, the *administrative* and the *practical* ones. The administrative phase started at the hospital lung ward, where a COPD patient would soon be discharged for home and given consent to participate in telemedicine monitoring. The hospital nurse would register the new COPD patient and notify the technical department at the hospital. The technical department created a new user in the IS (with the data fields *name*, *birthday*, *address*, *mobile telephone number*, *tablet ID* and *JabberID* for videoconference external to the system; privacy and security details are described in [5] and prepared a suitcase with the remote monitoring equipment inside.

In the practical phase, a hospital nurse provided user training to the patient before hospital discharge. The patient was instructed how to connect the equipment and take physiological measurements for transmission to the IS. Later on, the hosptial nurse established the medical baseline reference values for calculation of triage with measurements made the day of discharge. In the triage, patient data were differentiated by a colour scheme: *green* colour for data within the pre-defined values, *yellow* colour

when data fell outside those values meaning "attention required", and *red* colour when data fell far from the values resulting in a "immediate attention and alert triggered" state. The cutoff values alerts were defined in the common U4H protocol for COPD and represented defined percentage deviations from the baseline reference values. In addition, three questions in the questionnaire related to dyspnea, sputum volume and sputum colour were filled in with values representing patient's own symptom sensing (*normal*, *worse*, *much worse*). These questions align with the recommended symptoms to be evaluated when deciding whether antibiotics should be given or not according to [20].

At the time of discharge from hospital, two documents were transferred to the IS by the hospital nurse: nurse's and doctor's discharge letters. After the patients went home, physiological measurements (SpO_2 and pulse) were daily sent together with the questionnaire on self-reported symptoms. A nurse used the IS for continuous management and evaluation of patient data for the patient follow-up. During the first 10 days, a daily videoconference initiated by the nurse was made. The next 20 days, patient data were transmitted and evaluated. In the case that any of these data alerted the professionals (e.g., yellow or red colour in the triage), the nurse would contact the patient.

3) User interface design

For the user interface design, support for certain administrative functions, such as creating a new user, establishing reference values for each patient and Personal Identification Number (PIN) management were requested. Related to the functionality of the IS, users requested to get an informed overview of patients' names and measurements related visible at one glance. Individual patient selection was assigned for accessing patient's health record with historical data, visualised on a line chart. Patient's overview had to distinguish between short-term and long-term follow-ups. According to information legal security and privacy requirements, all health care professional actions would need to be registered and logged in the system database.

B. User Test 1

User test 1 was executed with the first version of the implemented IS, the initial GUI is shown in Figure 8. The results are based on the findings in the user test in laboratory and group interview. They are presented divided into two subcategories: graphical user interface design and suggestions about functionality.
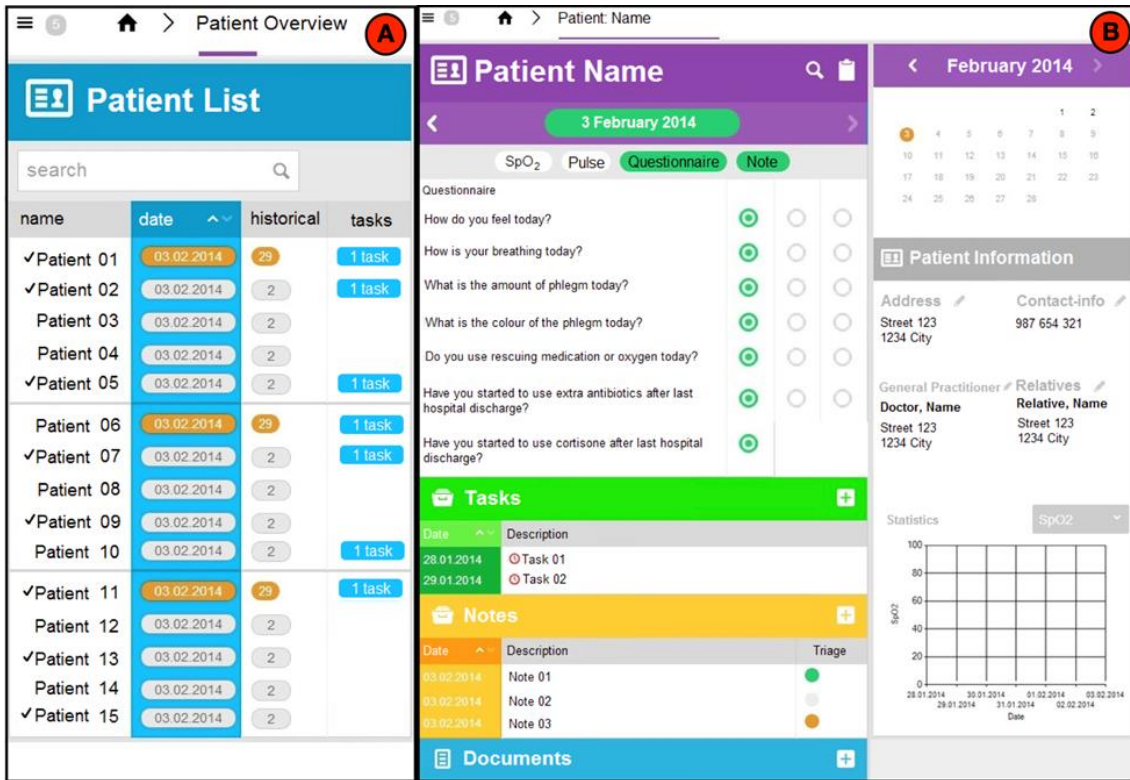
Figure 8 The GUI of the first information system (IS) implementation. A) Patient list overview. B) Individual patient's overview.

1) Graphical user interface design

Related to the GUI, 9 usability issues were identified. The major one was that the colour scheme selected for patient list overview and headings could interfere with the coloured evaluation of triage calculated from the patient data (e.g., colours yellow and green were used in the triage but also in patient list overview). A grey scale colour scheme for the GUI was instead suggested.

The patient overview presented was satisfactorily accepted by users because - as they argued - it showed the relevant information associated to each patient and only minor changes were required regarding element labeling. Patient names marked with a red triage value were suggested to be placed at the top of the patient overview and an additional column was needed to mark patients already followed-up in the current day. Clicking with the mouse anywhere inside the GUI in the patient's name row was suggested as a way of accessing the corresponding patient file. In the contact information section, patient's name had to be clearly visible on top of the record and there had to be sufficient space to include mobile telephone numbers of patient and relatives, being very useful, e.g., in case of a videoconference error.

2) Functionality of the IS

The user interaction with the IS during the performance of the tasks was generally successful, with minor technical problems related to transmission of patient data and videoconference's quality.

The users made 9 suggestions about the functionality. The triage was automatically calculated, but it should also incorporate the option to manually override it by a health care professional after patient follow-up (e.g., manually change the final triage colour from yellow to green after supervision). In this case, a journal note made with the new triage colour would automatically update triage colour in the patient view.

The nurses asked for an electronic appointment booking system, in order to set up videoconference sessions with patients and avoid overbooking. They requested an overview of all patient measurements of the same day when a certain day was selected because the IS did only show one measurement per day. A notitication was suggested when new patient data was received by the IS, instead of having to actively press the *refresh* button to see the latest measurement value. In the heading *Documents*, users requested to see by default the last 5 documents, with the possibility of maximizing the list to see the remaining ones. Search for a specific patient had to be possible by birthday and social security number, in addition to by name. Users suggested to have a unique storage for journal notes to sign at the end of the day, instead of having multiple journal notes from the same day. When users logged out, they asked for a notification, such as *You have unsigned journal notes,* as a reminder when there still were notes to be signed. The option to create a journal note should be always available even when having unsigned notes associated to the same patient.

In the group interview after the test, the users' comments about the IS use were overall positive: *We learned a lot about it, it was useful.* […] *It is a fantastic feeling to be able to come with feedback and know they can lead to changes. I miss that with other systems that we have*.

C. User Test 2

User Test 2 showed that most of the suggestions and problems from the previous evaluation were solved and incorporated to the IS. For instance, the transmission of patient data was successful in all cases and manual inserting of triage values as a coloured journal note was successfully tested. The new interface colour scheme, see Figure 9, was evaluated as appropriate providing a better overview in the patients' view. In the group interview, users highlighted their satisfaction with the functionality for inserting triage colour by making a correctly coloured journal note.
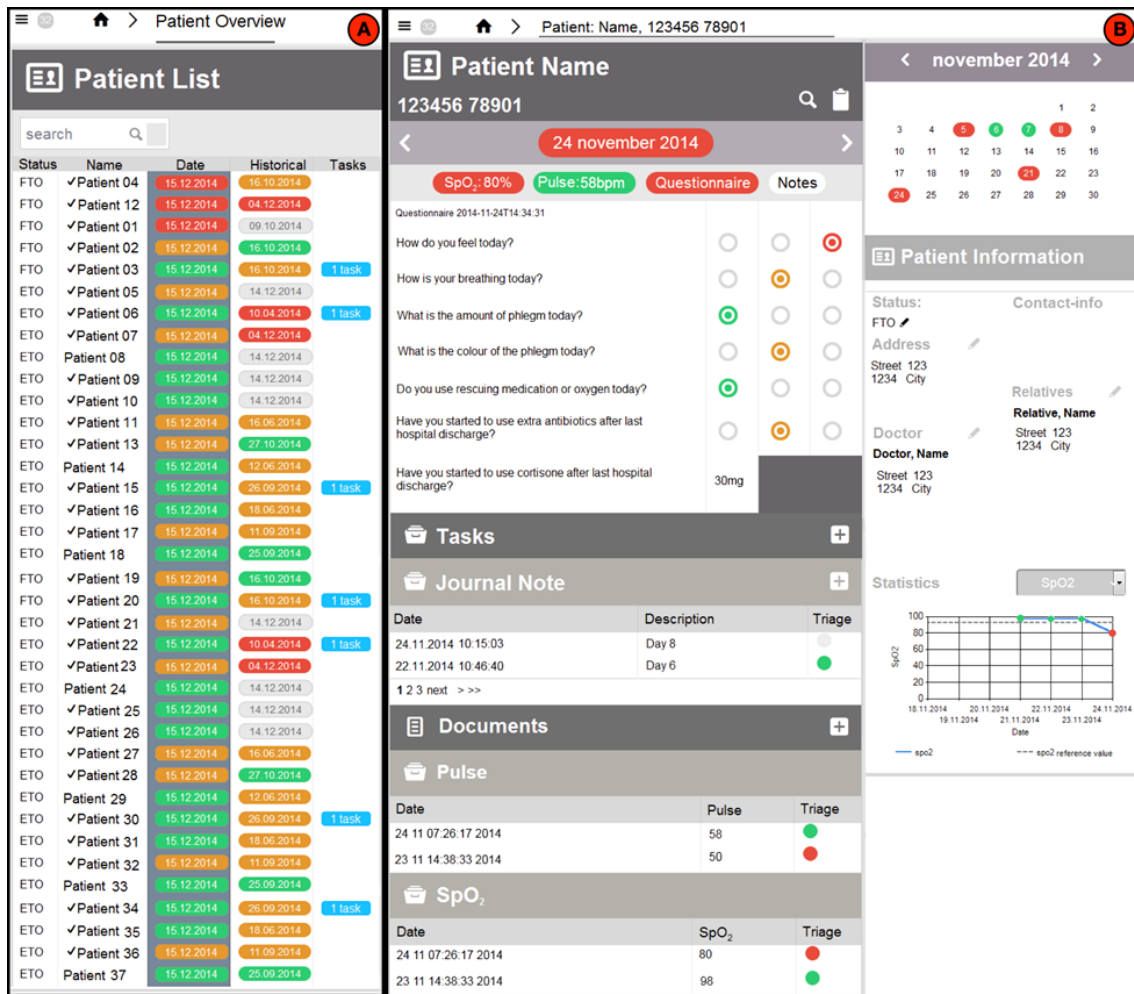
Figure 9 The GUI of second information system (IS) implementation. A) Patient list overview. B) Individual patient's overview.

D. The SUS questionnaire

The results of the SUS questionnaire [18][21][22] from the user tests are presented in Table 2. When comparing the SUS scores of user test 1 and user test 2, the scores improved in 9 out of 10 questions, and the other question kept the same score in both tests. The results of the second test showed that the median of satisfaction ratings were on the range of "Agree" or "Strongly Agree" for all the answers to the positively enunciated questions, and in the range of "Disagree" or "Strongly Disagree" for all the answers to the negatively enunciated questions.

Table 2 SUS Questionnaire Scores.

Question	User test 1		User test 2	
	M	*IRQ*	*M*	*IRQ*
1. I think that I would like to use this system frequently.	3	1.5	4.5	0
2. I found the system unnecessarily complex.	2	1.0	2.0	1.0
3. I thought the system was easy to use.	3.5	1.0	4.5	1.0
4. I think that I would need the support of a technical person to be able to use this system.	3.0	1.0	2.5	2.0
5. I found the various functions in this system were well integrated.	3.5	0.5	4.5	1.0
6. I thought there was too much inconsistency in this system.	2.5	1.5	1.5	0
7. I would imagine that most people would learn to use this system very quickly.	4.0	0.5	4.5	0
8. I found the system very cumbersome to use.	2.5	1.0	1.0	0
9. I felt very confident using the system.	3.5	1.0	4.0	2.0
10. I needed to learn a lot of things before I could get going with this system.	3.0	1.5	1.5	0

Strongly disagree   Strongly agree

| 1 | 2 | 3 | 4 | 5 |

Questionnaire responses in a 5-point Likert scale

M = median; IRQ= Interquartile Range

E. Field trial

In the field trial, the nurses' overall rating concerning the IS was satisfactory. Font size was evaluated as sufficient, the choice of colours as appropriate and the critical information was placed on top in patients' overview as requested. The patient's record provided a useful overview of patient's data, where historical data were represented as triage colour scheme drawed in the calendar. At the bottom of the interface there was a line graph representing pulse oximetry measurements. The navigation in the IS was reported as easy, even though there were some technical problems due to data transmission into the IS.

In the interviews nurses commented: *I think this system is easy to use. With small adjustments this will be a good tool to support the workflow.* […] *The IS seems to work well and gives a good overview, most of it is self-explained.* […] *The field trial has been very useful in order to identify errors that can occur when using the equipment.*

IV. DISCUSSION

In this paper, a UCD process of an IS for a collaborative telemedicine service has been presented. A UCD process involves end-users throughout the entire development cycle of an intended technological solution. Telemedicine services often involve

multiple user groups, what makes the user participation in the design and evaluation crucial in order to understand the clinical context and user interactions. UCD has proven to be an effective approach for gathering user requirements [23], increasing level of user acceptance [7] and reducing development time because usability problems can be identified before deployment [6].

The research questions were answered based on the results of this study. About the RQ1, which asked about how to take into account user needs and requirements in the new system, the study showed that the UCD approach successfully included user needs in the design and development. The workshop with end-users effectively outlined the clinical context of use and user requirements regarding GUI, interaction and functionalities. User evaluations during the iterative development were carried out both in laboratory and real settings of the telemedicine service. The evaluations in the laboratory were performed in a high fidelity simulation task environment, which enabled users to give useful feedback about GUI design and interactions with the system. These findings are in line with the use of a simulation laboratory in health for education [24], training [25] and research purposes [26], where the task environment provides controlled complexity to experimental task performed by human participants in research [27]. In addition, the field trial allowed analysing the IS in real settings, providing both real-time evaluation and continuous observation of long-term technology use in working environment.

Several lessons were learned during the UCD process that can be transferable for the development of other clinical systems (RQ2). Firstly, the creation of clinical systems requires active involvement of all target user groups in the design and continuous evaluation of the solution and, when possible, in a high fidelity simulation environment that realistically recreates the context of use. Due to the workshop with end-users, constructive comments were gathered regarding data visualisation, such as a historical overview of the triage using a line-graph that helped to detect trends in data.

In addition, the user evaluations between the iterations usefully informed IS refinements, such as using a grey-scale colour scheme to not interfere with the colours used in the triage. Secondly, interoperability problems [28][29] are common within clinical environments, so the execution of the field trial provided valuable insights into the interactions between the technologies involved, and a continuous long-term feedback of users' interactions with these technologies. There were some limitations associated to this study, such as a reduced number of end-users and a simulated test environment. However, the laboratory setting allowed creating realistic scenarios for the validation of the system under controlled conditions, and the field trial gave the

opportunity to test the system in real clinical settings and realistic conditions including mobile data transfer from patients in home environment. These tests were carried out with representatives of the end-user groups intended to use the telemedicine system. Based on the comments gathered from health professionals involved in the clinical workflow after system implementation and deployment, these factors were assumed to sufficiently compensate the limitations mentioned above.

This study was framed inside the EU FP7 project United4Health. The implemented IS has been deployed in 3 telemedicine centres that provide services to 23 municipalities of Norway, being ready to be adapted to other services within the secured Norwegian Health Network. Future research would cover increased complexity of autonomous reasoning and decision support and the inclusion of other clinical patient groups.

DECLARATION OF CONFLICTING INTERESTS

The Authors declare that there is no conflict of interest.

REFERENCES

[1]   Norwegian Ministry of Health and Care Services. The Coordination Reform – Proper treatment - at the right place and right time. Report No. 47 to the Storting (2008-2009), 19 June 2009.

[2]   United4Health Transforming the patient experience with telehealth in Europe. European Commission- ICT Policy Support Programme and Competitiveness and Innovation Framework Programme. Online Referencing, http://www.united4health.eu/ (2015, accessed 8 Sep 2015).

[3]   Smaradottir B, Gerdes M, Fensli R and Martinez S. User interface development of a COPD remote monitoring application- a user-centred design process. In: 8th International Conference on Advances in Computer-Human Interactions, Lisbon, Portugal 22-27 Feb 2015, pp.57-62.

[4]   Norwegian Health Network. Online Referencing, https://www.nhn.no/english/Pages/default.aspx (2015, accessed 8 Sep 2015).

[5]   Gerdes M and Fensli R. End-to-end security and privacy protection for co-operative access to health and care data in a telehealth trial system for remote supervision of COPD-Patients. In: Scandinavian Conference on Health Informatics, Tromsø, Norway, 15-17 June 2015, pp.25-32. ISSN(print): 1650-3686, ISSN(online): 1650-3740.

[6]   De Vito Dabbs A, Myers BA, Mc Curry KR, et al. User-centered design and interactive health technologies for patients. Comput Inform Nurs 2009; 27(3):175-183. DOI: 10.1097/NCN.0b013e31819f7c7c

[7]   Das A and Svanæs D. Human-centred methods in the design of an e-health solution for patients undergoing weight loss treatment. Int J Med Inform 2013; 82(11):1075-1091.

[8]   Årsand E, Tufano JT, Ralston JD, et al. Designing mobile dietary management support technologies for people with diabetes. J Telemed Telecare 2008; 14:329-332. DOI: 10.1258/jtt.2008.007001

[9]   Lazar J, Feng JH and Hochheiser H. Research methods in human-computer interaction. John Wiley & Sons Ltd; 2010.

[10]   Smaradottir B, Holen-Rabbersvik E, Thygesen E, et al. User-centred design of the user interface of a collaborative information system for inter-municipal dementia team. In: 8th International Conference on Health Informatics, Lisbon, Portugal, 12-15 Jan 2015, pp.446-453. DOI: 10.5220/0005222704460453

[11]   Bastien JM. Usability testing: a review of some methodological and technical aspects of the method. Int J Med Inform 2010; 79(4):e18-e23.

[12]   Kushniruk AW and Patel VL. Cognitive and usability engineering methods for the evaluation of clinical information systems. J Biomed Inform 2004; 37(1):56-76.

[13]   Jaspers MW. A comparison of usability methods for testing interactive health technologies: methodological aspects and empirical evidence. Int J Med Inform 2009; 78(5):340-353.

[14] Horsky J, McColgan K, Pang JE, et al. Complementary methods of system usability evaluation: surveys and observations during software design and development cycles. J Biomed Inform 2010; 43(5):782-790.

[15] Ericsson KA and Simon HA. Verbal reports as data. Psychol Rev 1980; 87:215-251.

[16] Gerdes M, Smaradottir B and Fensli R. End-to-end infrastructure for usability evaluation of ehealth applications and services. In: Scandinavian Conference on Health Informatics, Grimstad, Norway, 21-22 Aug 2014, pp.53-59. ISSN(print): 1650-3686, ISSN(online): 1650-3740

[17] Svanæs D, Alsos OA and Dahl Y. Usability testing of mobile ICT for clinical settings: Methodological and practical challenges. Int J Med Inform 2010; 79(4):e24-e34.

[18] Brooke J. SUS: a quick and dirty usability scale. Usability Evaluation in Industry. London: Taylor & Francis; 1996, p.189-194.

[19] Smaradottir B, Gerdes M, Martinez S and Fensli R. Usability Evaluation of a COPD Remote Monitoring Application. Stud Health Technol Inform 2015; 210:845-849.

[20] Anthonisen NR, Manfreda J, Warren CP, et al. Antibiotic therapy in exacerbations of chronic obstructive pulmonary disease. Ann Intern Med 1987; 106(2):196-204.

[21] Bangor A, Kortum P and Miller J. Determining what individual SUS scores mean: adding an adjective rating scale. J Usability Studies 2009; Vol. 4(3):114-123.

[22] MacLellan S, Muddimer A and Peres SC. The effect of experience on system usability scale ratings. J Usability Studies 2012; Vol. 7(2):56-67.

[23] Teixeira L, Ferreira C, and Santos BS. User-centered requirements engineering in health information systems: a study in the hemophilia field. Comput Methods Programs Biomed 2012; 106(3):160-174.

[24] Thoirs K, Giles E and Barber W. Use of simulated learning environments in radiation science curricula. University of South Australia, Adelaide, 2010.

[25] Beaubien JM and Baker DP. The use of simulation for training teamwork skills in health care: how low can you go? Qual Saf Health Care 2004; 13(1):i51-i56.

[26]   Venot A, Burgun A and Quantin C. Medical Informatics, e-Health: Fundamentals and Applications. Springer Science & Business Media, 2013.

[27]   Gray, WD. Simulated Task Environments: The Role of High-Fidelity Simulations, Scaled Worlds, Synthetic Environments, and Laboratory Tasks in Basic and Applied Cognitive Research. Cogn Sci Q 2002; 2:205-227.

[28]   Shaikh, A. The impact of SOA on a system design for a telemedicine healthcare system. Netw Model Anal Health Inform and Bioinforma 2015; 4(1): 1-16. DOI: 10.1007/s13721-015-0087-0

[29]   Craft, RL. Toward technical interoperability in telemedicine. Telemed J E Health 2005; 11(3):384-404.

Appendix C

Paper II

Title:	User-Centered Design of a COPD Remote Monitoring Application
	Experiences from the EU-project United4Health
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User-Centered Design of a COPD Remote Monitoring Application

Experiences from the EU-project United4Health

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Abstract— **Recent health reforms in Norway have produced changes at all levels of the health sector, bringing to light a need for technology solutions explicitly designed for enhancing end-user collaboration. Telemedicine technology can support in this context new services that enable communication across local borders, optimizing resources and increasing cost effectiveness. This study focuses on the user-centered design, iterative development and evaluation of the user interface of a mobile application for a new telemedicine service for remote monitoring of chronic obstructive pulmonary disease patients. The tablet device application was developed based on information gathered in a workshop and group interviews where the end-users, e.g., patients and health professionals, described their preferred way of interacting with the telemedicine technology. User evaluations showed positive results on the ease of use and user satisfaction regarding the interaction with the application. Application's user interface refinements were made iteratively through several end-users' evaluations, resulting in a fully developed system suitable for remote monitoring of chronic obstructive pulmonary disease patients. Furthermore, the process led to the deployment of a telemedicine system, adopted by the partners of the project United4Health as part of the 7th Framework Programme for Research of the European Union.**

Keywords—user-centered design; telemedicine; software development; usability evaluation

I. INTRODUCTION

Health care services involve heterogeneous user groups, such as health professionals, administrative employees and patients. However, these groups share a common need: easy-to-use systems that support collaboration and coordination between users. User-centered design (UCD) has proven to be an effective methodology to identify needs across different user groups and to include them in the implementation of information and communication technology (ICT) systems [1] while increasing the usability [2][3] and user satisfaction of clinical systems.

In Norway, a recent health reform [4] urged health organisations to implement structural changes and new pathways for citizens. Services that traditionally were offered by specialized national and regional health care institutions (e.g., follow-up of chronic diseases managed by hospitals) were transferred to primary health care managed by municipalities. This service responsibility shift brought to light the need for an effective coordination and improved communication across borders of health care services [5][6][7], where ICT could play an essential role.

The prevalence of chronic diseases is increasing and chronic obstructive pulmonary disease (COPD) is predicted to be the fourth most fatal disease globally in 2030 [8]. COPD patients suffer from exacerbations with frequent admissions to hospital, leading to a reduced quality of life [9] and an increase of medical expenses for the society [10]. In this context, the 7th Framework Programme for Research of the European Union (EU FP7) funded the research project United4Health [11], to develop technology for remote monitoring of chronic diseases and communication across the different levels of health care services. In particular, the Norwegian contribution to the United4Health project focused on the development of telemedicine technology that supported remote monitoring of COPD patients after hospital discharge [12]. Research evidence showed that COPD patients are at an increased risk of readmission to hospital within 12 months [13][14] after hospital discharge. In the Norwegian health system, municipal health care services are responsible for patients after hospital discharge, which requires a close collaboration with general practitioners (GPs) and specialists at hospital to provide continuity of care for patients with chronic conditions. The aim of the project was then to evaluate the benefits of using ICT for monitoring COPD patients that traditionally have not had the possibility of reporting their symptoms and health status after hospitalization. The potential benefits would include reduction of hospital readmission rates with their correspondent diminution in cost and benefits on quality of life.

Two developments were made connected with the U4H project: a mobile telemedicine application for continuous monitoring COPD patient's symptoms and an information system (IS) for the new telemedicine centre through which health professionals would remotely attend the patients [1][15]. This paper presents the development of the mobile telemedicine application on a tablet device for remote monitoring of blood oxygen saturation (SpO2) and pulse measurements. In addition, the application included a questionnaire for daily self-evaluation of COPD symptoms. Through the application, patients were able to take measurements at home that were wirelessly transmitted to the telemedicine centre. In order to achieve acceptable levels of effectiveness, efficiency, and satisfaction, a UCD process led by a multidisciplinary research group with ICT and health background was employed for the development and evaluation of the mobile telemedicine application. The application was designed with the active involvement of end-users: patients from the patient's union of cardiac and pulmonary patients and health professionals from the municipality and partner hospital. The results from the UCD and evaluation process of the mobile telemedicine application were validated from operational and qualitative usability perspectives. The following research questions (RQ) were addressed:

RQ1: How can a mobile telemedicine application for remote monitoring of COPD patients be developed with the contribution in the design process of patients and disease-related health professionals?

RQ2: What lessons from this study are transferable and applicable for the development of useful technology for other chronic disease clinical pathways?

Following this introduction, Section II gives an overview of the research background about UCD. Section III outlines the research methodology employed and Section IV describes the results of the mobile application development. In Section V, the results are discussed and, in Section VI, the conclusion and future work are presented.

II. RESEARCH BACKGROUND

Telemedicine can be defined as a remote electronic clinical consultation using technology for the delivery of health care and the exchange of information across distance. Telemedicine covers a diverse spectrum of technologies and clinical

applications [16][17][18]. Telemedicine has the potential to improve the equity of access to health care services and, therefore, the quality of the health care [17]. Mobile technology is used nowadays for multiple purposes in health, such as monitoring diseases and personalized management. Portable devices allow collection of data from patients and electronic data transmission over the Internet. Mobile networks support interactive communication between health care professionals and enable remote direct feedback to the patient. These uses are targeted at improving long-term cost-effectiveness, real time monitoring, shortening feedback's time and reducing the number of hospital visits [19].

Telemedicine systems often involve the interaction between multiple user groups through a digital system, e.g., a patient at home communicates using a device with nurse in a telemedicine or health centre, or with GP at their office. Communication in these use scenarios is usually multimodal, that is, synchronous (e.g., videoconference) and asynchronous (e.g., data transmission and dispatch); what makes it crucial to know between whom, how and when the information transmission and personal communication occur. Thus, an effective telemedicine application requires a detailed analysis of end-users' needs to inform system designers and the usability is necessary for the continuous, efficient and satisfactory use of an application. In system development, the approach of UCD [20][21][22][23] involves end-users in all the stages and helps to understand users' needs and the context of use, which are key elements for the construction of a system framed within a clinical workflow [24]. In addition, the usability evaluation allows to analyze user's interaction and user satisfaction with the system [25][26][27].

UCD has already been used in health contexts. For instance, Martínez-Alcalá et al. [28] presented a study of telemedicine systems' development based on UCD. The aim was to develop two intuitive and efficient systems, with an optimized design of the user interface (UI) according to users' needs. The eMental System and the e-Park System development was composed of four phases: analysis, design, implementation and evaluation. They concluded that researchers and system developers must work together to integrate the knowledge of UCD towards new systems customized to users' specific needs. Further, they identified 4 research lines: (1) deployment of other telemedicine systems based on their framework including other technology; (2) development of tailored versions of a telemedicine system for mobile devices; (3) implementation of their approach in the treatment and rehabilitation therapy file; (4)

incorporation of intelligent agents in telemedicine systems to support the patient and medical staff.

Ho et al. [29] described the application of a UCD process of a new remote consultation system for use in developing regions with methods such as semi-structured interviews, participant observation, and focus groups. Paper prototyping was used in the initial iterative design. De Vito Dabbs et al. [30] described the UCD of a Pocket PATH, a handheld PC that allowed lung transplant patients with data recording, messaging and decision-support to promote self-care and communication to their transplant team in hospital. The UCD process is described with the use of an interdisciplinary team in order to understand the patient users. Representative patients were recruited for meaningful selection of tasks and participation in platform for development. The evaluation was carried out in laboratory settings to measure usability, and afterwards, completed by an assessment of the functionality through a field study. Das et al. [31] used a co-design approach to involve users in the design process. Users were COPD patients that explored mobile technologies to support their health condition and disease. The examples listed above show the importance of user participation from the early stage of designing a technological solution. However, many studies like these did not reach final deployment stage. The contribution of this paper is a case study with a UCD process of a COPD remote monitoring application describing all the stages of design, whose final result has been deployed in real settings.

III. METHODOLOGY

Qualitative methods such as observations and group interviews were used for data collection and analysis during the UCD process of the telemedicine tablet application, which was framed within the research project United4Health [11][12]. The UCD process was executed in two phases with a total duration of 6 months during 2013 and 2014. The process is described in Figure 10: (A) workshop with representative end-users, such as patients and health professionals; (B) iterative design of the tablet application for COPD remote monitoring. Each sub-phase's output informed the input of the next.
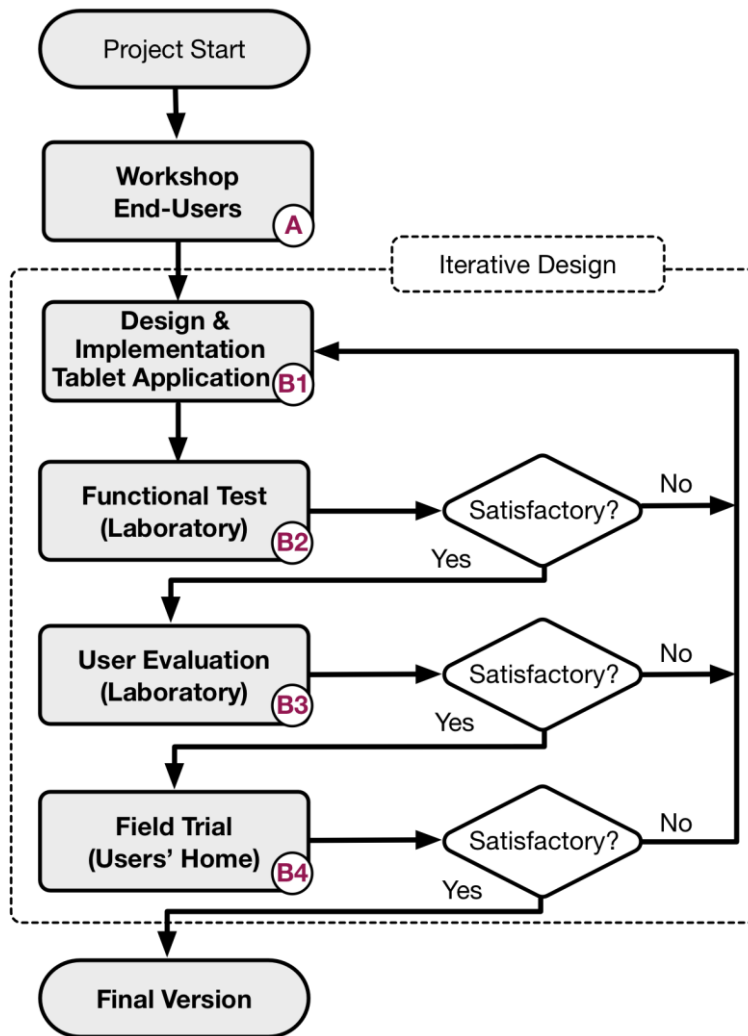
Figure 10 The User-centered Design Process.

The iterative system development included a sequence of four concatenated stages: design and implementation, functional test, user evaluation and field trial.

The running commentary gathered during the two phases of the UCD process resulted in 18 hours of audio-visually recorded data, verbatim transcribed by the researchers. Transcripts were coded into categories through a qualitative content analysis [27] with the software QSR NVIVO v10 [32].

A. Workshop with End-users

A one-day workshop with 7 end-user representatives (e.g., patients, health professionals and technicians) was hosted by the University of Agder, Norway. The aim was to understand the context of use and to work out the user requirements for the design of the tablet application for remote monitoring. In addition, the workshop was a source of information and familiarization for end-users with the research team and health professionals working in the project. The participants were 2 members of the

union of cardiac and pulmonary patients, mean age of 69 years; 2 nurses and 1 project-leader from the municipality and hospital, mean clinical experience of 6 years with COPD patients; and 2 technicians from hospital responsible for correct functioning and maintenance of the tablet devices, mean of 6 years of experience working with medical technical equipment.

The workshop lasted 5 hours and was divided into two parts. In the first part of the workshop, participants were given an introduction to the research project United4Health. A prototype demonstration of wirelessly transmitted measurements of SpO2 and pulse was shown to end-users on a tablet device to facilitate the understanding of the context of use of the system. Additionally, a videoconference between a patient and a health care professional was tested. The members of the union of cardiac and pulmonary patients described their preferred way of interacting with the application at home and suggested ideas for the UI's layout. The participants used colorful post-it notes and handmade sketches to describe application's functionalities and design.

In the second part of the workshop, participants described their suggestions for the procedure of remote monitoring of a COPD patient, such as taking measurements at home, transmitting measurements' values through the system to the telemedicine centre and illustrating the feedback given from telemedicine centre to a COPD patient at home.

B. Iterative Design

The design of the application was carried out through the iterative execution of the following stages: design and implementation, functional test, user evaluation and field trial. A development team supervised by one of the researchers developed the system. An interaction designer hired by the team was in charge of the initial graphical user interface and interaction design.

1) Design and Implementation

The results from the workshop led the initial design and implementation of a Java native application. Java includes libraries for several low-level application program interfaces (APIs), in particular for the Bluetooth connectivity and communication with sensor devices. In addition, using Java allowed the application to be used across different tablet devices. The outcome of the subsequent sub-phases informed additional user requirements included in the implementation of the user interface design (UID) and system's functionality.

2) Functional Test

The facilities of the Centre for eHealth and Health Care Technology of the University of Agder, Norway, were used as a test bed for a functional test of the implemented application. It allowed verifying whether the system matched the requested functionality determined by users in the workshop and in user evaluations from other iterations. Performance and scalability of the system were not within the scope of the functional test.

3) User Evaluation

Two evaluations of the application's prototype were carried out with end-users in the Usability Laboratory at the Centre for eHealth and Health Care Technology. The facilities had two separate test rooms (referred to as "test room 1" and "test room 2") and one observation room. The infrastructure is further described in [33]. The user evaluations had the aim to provide end-user's feedback to the development team about system's errors and potential refinements. They consisted of a series of tasks using a think aloud protocol [34][35][36]. Group interviews were made at the end of the evaluations to complete the feedback.

a) Evaluation 1

In total 15 end-users participated in the first evaluation. They were: 13 nurses and physicians from municipality and hospital partner and 2 technicians from hospital partner. During the test, the participants were involved in a role-play scenario. In the patient's home (represented by test room 1), health care professionals simulated the patient's use of tablet application (see Figure 11). At the same time, the telemedicine centre (represented by test room 2) contained the health care professionals that interacted with patient's home. The functionalities tested at a patient's home consisted of taking and sending patient's measurements (i.e., SpO2 and pulse), filling and sending a questionnaire to the telemedicine centre. In addition, a videoconference session between the patient and the telemedicine centre was evaluated. There were three repetitions of the scenario with different users. The overall duration of the evaluation was 6 hours.

Figure 11 End-user testing the tablet application during evaluation.

b) Evaluation 2

The second evaluation included another role-play with the new telemedicine application. It was carried out two weeks after the first evaluation and included 9 end-users: 2 members of the patient's union (who played the patient's role), 3 nurses from municipality (who played telemedicine centre health professional's role), 2 nurses from hospital and 2 technicians from hospital. The test simulated the following interactions with the application: (1) user training of COPD patient in hospital with instructions from a hospital nurse; (2) COPD patient at home taking measurements, filling in symptom self-evaluation questionnaire and sending it to the telemedicine centre; (3) videoconference between COPD patient at home and a health professional at the telemedicine centre. There were two iterations of the user evaluation, with a total duration of 5 hours.

4) Field Trial

A field trial was carried out with 6 diagnosed COPD patients (mean age 72.6 years). They tested the continuous functioning and interaction with the technology at home during a period of 7 days. The trial was performed across several weeks, lasting 5 weeks in total. Each participant was equipped with a suitcase including a pulse oximetry device (Nonin Onyx II, 2012) and a tablet device (Lenovo ThinkPad tablet 2, 2013, Windows 8.1) with the telemedicine application installed. In addition, an adjustable USB camera and a headset were included for the videoconference. Figure 12 shows the remote monitoring equipment.
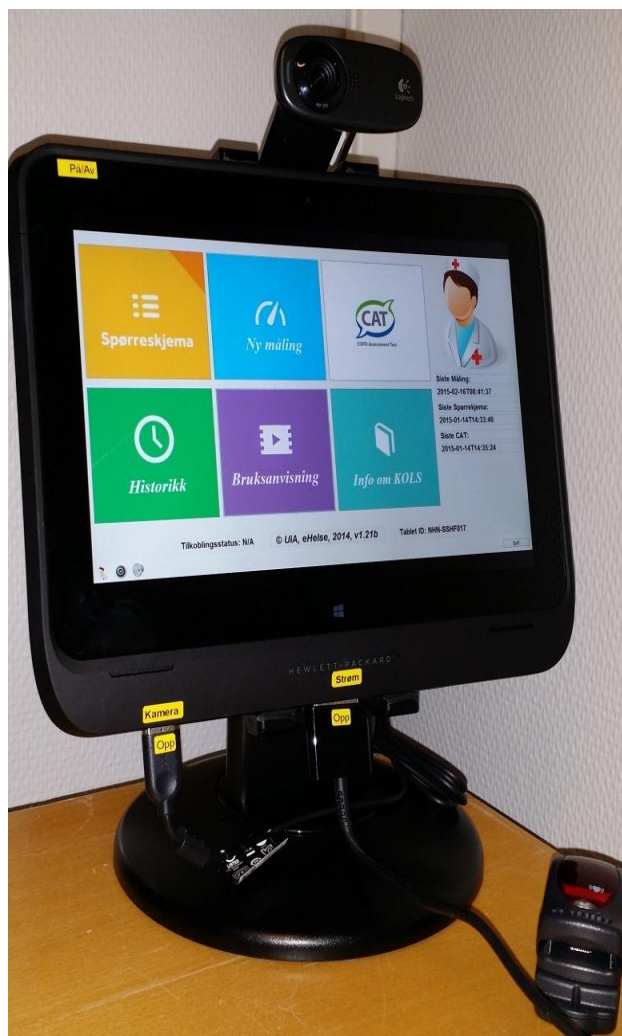
Figure 12 The remote monitoring equipment.

Every day, the participants used the tablet application for measurements with the pulse oximetry device filled in the symptoms' self-evaluation questionnaire. The data were sent over the mobile network to the telemedicine centre. A videoconference session between the participant at home and a health professional at the telemedicine centre was tested in addition.

All these tasks were performed using the tablet device. After each week of testing, the research team visited each participant at home and made a user evaluation of the application and an interview. The user evaluation entailed switching on tablet, logging in to the telemedicine application, taking measurements, filling in symptom self-evaluation questionnaire, sending the data to the telemedicine centre and answering a videoconference call from the telemedicine centre. The interviews focused on the user experience and suggestions for further improvements. The users' suggestions in the field trial were incorporated in the iterative refinements of the tablet application. More details on the field trial are presented in [37].

IV. RESULTS

The results were obtained from the content analysis of the transcripts of the audio-visually recorded data and annotations and observations during the UCD process. To ease the reading, the results of each phase are separately presented.

A. Workshop with End-users

The contributions from end-users in the workshop are grouped in 3 different categories: context of use, user interface design and procedure for remote monitoring.

1) Context of Use

Patient representatives explained that their individual's level of physical energy was regularly low and even simple actions, such as using a tablet device, might become unachievable. This issue underlined the importance of designing an easy-to-use application that did not require much physical effort and mental workload to be successfully used. Therefore, it was suggested that user interaction with the system must be minimal, with only the few necessary actions. One participant stated: *"Usability is extremely important for the interaction with this application since COPD patients have little energy left on bad days"*.

2) User Interface Design

Patients agreed with the authentication method through a personal identification number (PIN) mechanism, although they expressed having difficulties remembering numbers and they preferred to be able to choose their own PIN instead of using a pre-defined one. In addition, they requested to have the user's name at the top of the home screen after each successful login. Patients required seeing the results of their own measurements on the device's screen before sending them to the telemedicine centre. They asked for receiving immediate feedback when measurements were successfully delivered. A time-span visualization of several days of measurement results was also suggested where patients could see measurements from previous days. Another request was the possibility of seeing the health professional through a videoconference to simultaneously guide the patient through any of the tasks.

For the interface's layout, patients chose not to have nested menus (e.g., one patient representative said: "you cannot ask elderly people to remember what is inside each menu") and instead, only one touch area per action. Suggestions included 6 squared big-size touch areas, with readable and appropriate function's names. The 3 most important functions were placed at the top: "new measurements", "daily questionnaire" and "videoconference". The other 3 touch areas with less frequently

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used functions were placed at the bottom: "historical data", "information about COPD", and "user instructions", see Figure 13.

Figure 13 User's UI suggestions for tablet application main screen.

Further, it was concluded that the system was not to be used for emergency situations, so a written text was displayed that said "Call 113 for emergency" was suggested.

For the questionnaire, end-users suggested multiple touchable selections for the daily self-evaluation of symptoms. Specifically, to have six questions visible on the screen at the same time because patients were afraid they would get tired of reading the questions one by one (see Figure 14). The button to navigate to the next step, labelled "Next", had to visible at the bottom of the screen. The users requested to be able to review the questionnaire answers before sending the self-evaluation questionnaire.
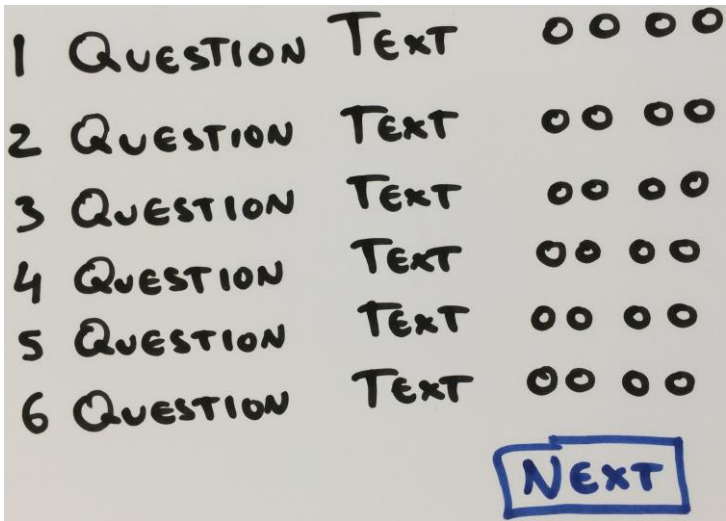
Figure 14 User's UI suggestions for daily questionnaire.

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3) Procedure for Remote Monitoring

One of the most important findings of the workshop was the description of the procedure for the use of the telemedicine application for remote monitoring of COPD patients.
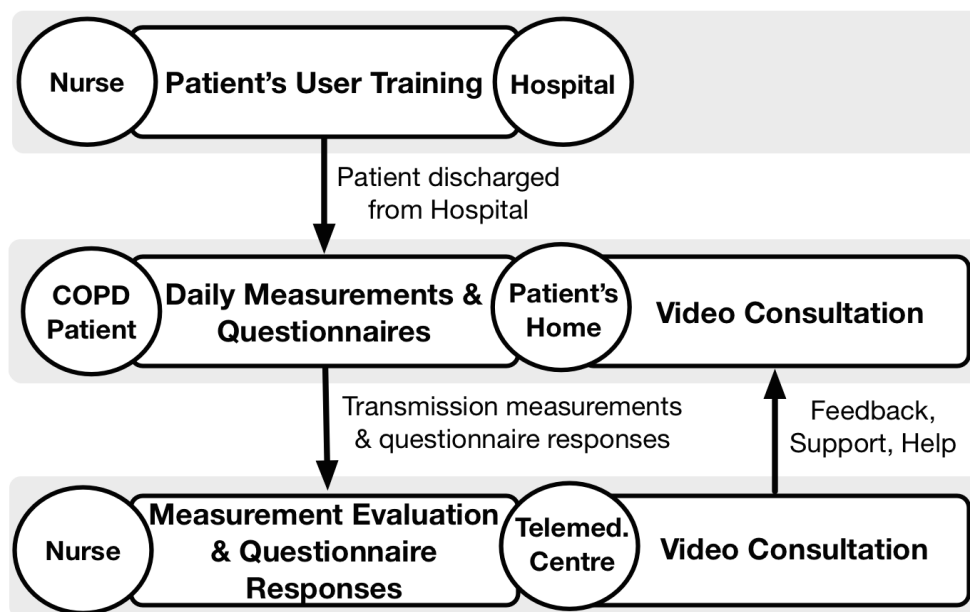

Figure 15 Procedure for remote monitoring.

Figure 15 shows the end-users' suggestion for the process and feedback in the remote monitoring scenario. In addition, instructions were required to be concise and to be additionally available on paper and through the system.

It is a common practice in a given telemedicine centre to differentiate patient status by an easy-to-interpret color scheme, called triage. Triage color was represented in this case by a green color for measurement values within the pre-defined cut-off values; yellow color for requiring attention and red one to trigger alert. Yellow and red colors were activated when measurement values were outside the predefined cut-off values. Patient representatives initially suggested that patients at home should be able to see the triage color related to their own measurements in order to have a feeling of control of their own health. However, a "false" red measurement (e.g., cold finger may alter measurement readings) could potentially increase patient's anxiety. At the end, patient representatives agreed with the option that only health care professionals could see the triage's color.

B. Iterative Design

The contributions from the iterative design are presented following the sub-phases of design and implementation, functional test, user evaluations and field trial.
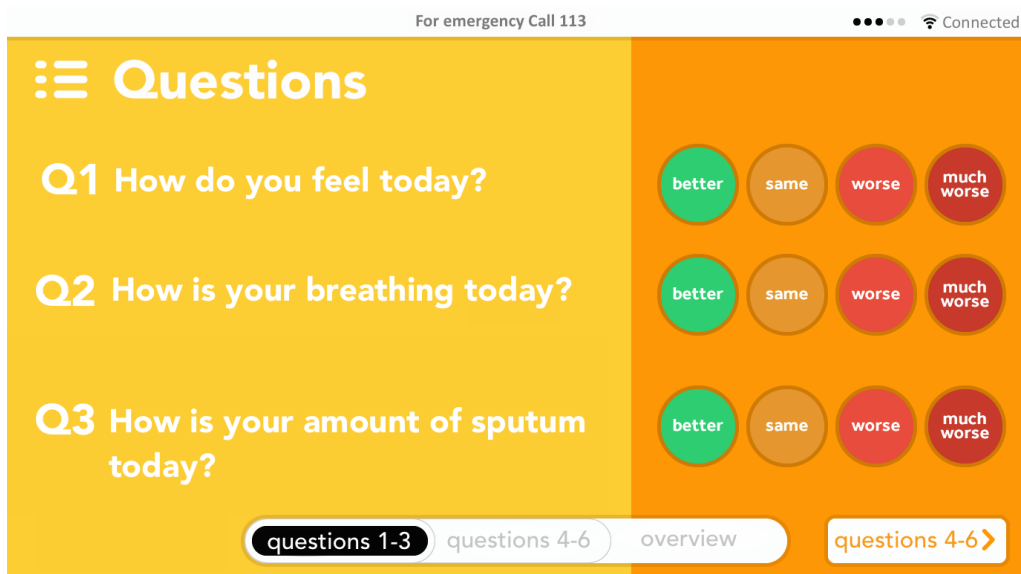
1) Design and Implementation

In the sub-phase design and implementation, the workshop's results were transformed into user requirements. The initial graphical user interface (GUI) for the main screen of the tablet application was outlined including the two functions "New Measurement" and "Questionnaire", which were placed at the top, see Figure 16.
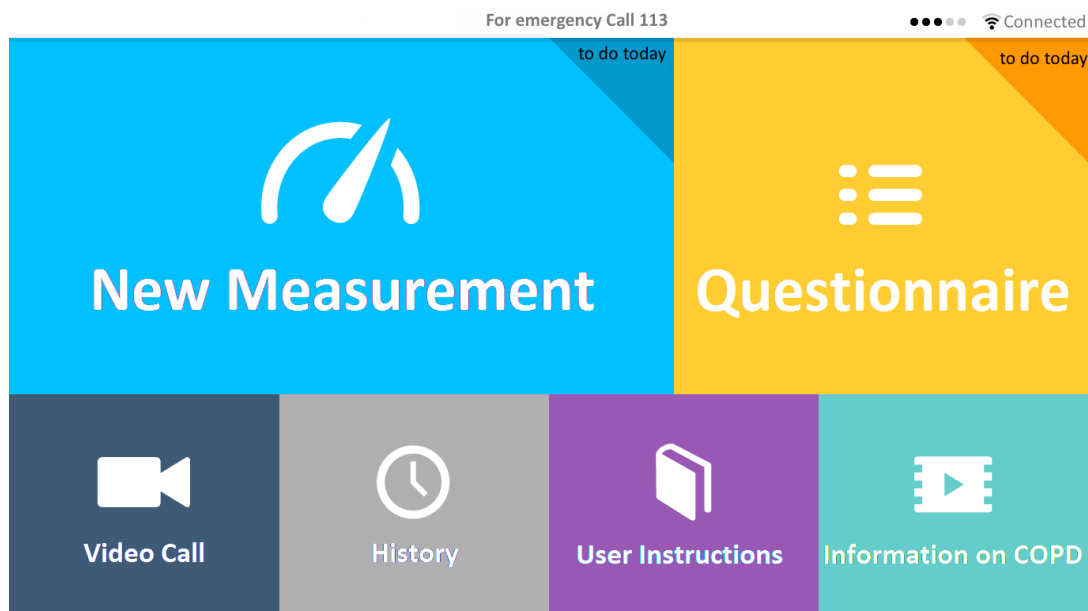
Figure 16 GUI of tablet application main screen.

For the GUI of the daily self-evaluation questionnaire, three questions with touch areas for answers were displayed with a legible text on a tablet device, see Figure 17.

**Figure 17 GUI of daily self-evaluation questionnaire**

Outcomes from further iterations' sub-phases contributed to refine the user requirements and improve the application implementation.

Based on the initial GUI, a first prototype version was created. Figure 18 shows the first prototype version of the measurements' screen with the buttons "Measure Pulse" and "Send Pulse Value". The readings of SpO2 and pulse are shown in the right column (e.g., pulse = 85 beats per minute, and SpO2 = 98%).

Figure 19 shows the initial prototype version of the questionnaire's UI, with one question per screen. The list of answers had to be touch-selected. A "Next" button to advance to the next question was placed under the list of answers.
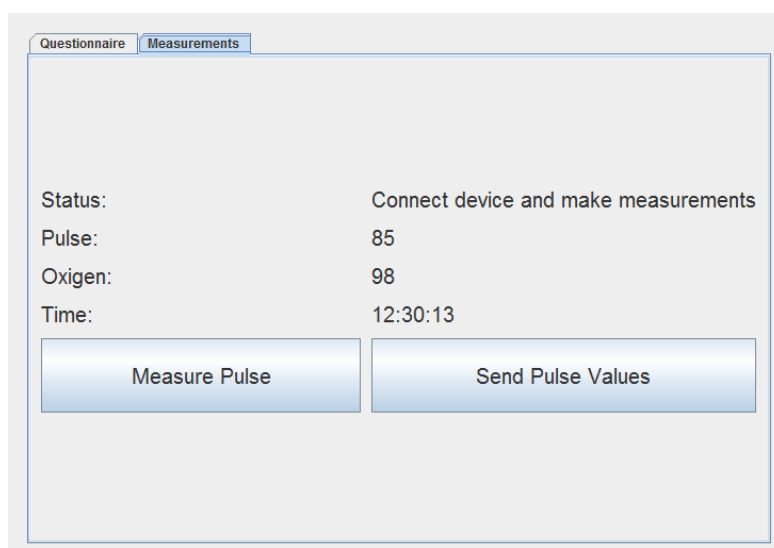
Figure 18 First prototype version of the measurement screen
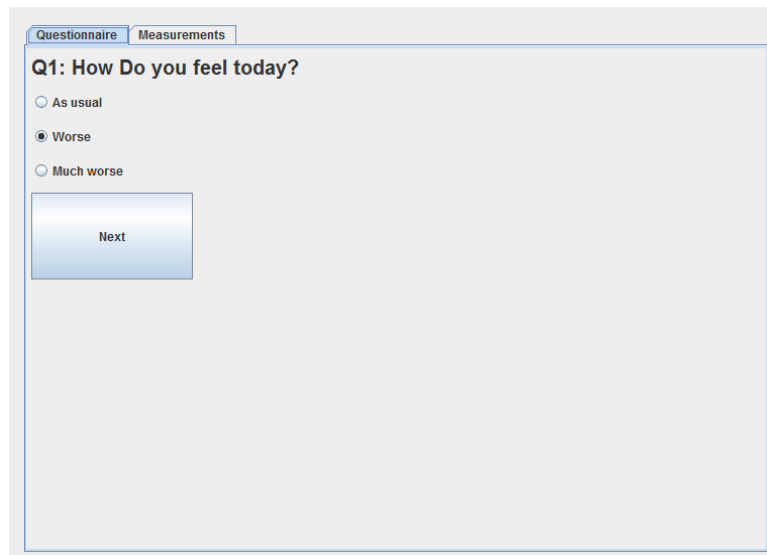
Figure 19 First prototype version of the measurement screen

2) Functional Test

In each iteration during the development of the application, a functionality test was run by the development team. The identification of errors at this stage proved to be relatively cost-effective to fix in terms of time and effort compared with further sub-phases.

3) User Evaluation

The user evaluations in laboratory settings comprised tasks to perform in the tablet application. An in-depth analysis of the observations revealed a number of usability issues. For the GUI, several problems were identified due to the insufficient text size in the UI of the measurement's screen and related to the progress bar. Some spelling errors were found in the UI wording. For the functionality, there were some technical issues related to transmission of data from the tablet device. The videoconference sound quality was insufficient, but the use of headset improved the communication. Further, while the measurement reader device showed correct measured values, wrong ones were displayed in the tablet screen and sent to the telemedicine centre. User evaluation helped to identify these issues.

In the group interviews after the evaluations, user comments about the tablet use were overall positive. They refer to the usability of the application and its functionalities: *"I think this will help us if we get worse; the tablet was easy to use with 5 or 6 functions and few things that should be touched to do measurements"*. Comments also addressed the feeling of safety after using the system for few days in a row: *"This is a fantastic procedure and a nice service for COPD patients. Initially I*

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was skeptical because I was afraid this would be too technical and little human, but now I think this will give patients a feeling of safety, especially the first 14 days after hospital discharge". Other comments referred to the need of user training: *"With some user training I think most people could use this, it was not complicated. If you forget how to do it, you can contact telemedicine centre"*. Patients also positively commented about the videoconference: *"It was a good feeling to have the videoconference with telemedicine centre. I think it is good to see and hear the nurse for users at home"*. About the interaction with the tablet device, one of the patients stated: *"I assume finger interaction will work well for most elderly people"*.

The tablet application went through several iterative refinements to implement the findings from the user evaluations. These refinements included the display of the questionnaire with the adequate number of questions per screen, reduced from 3 in the initial GUI design to finally 1 per screen in the final implementation to ease the individual reading A review of the questionnaire's answers was included to allow patient to double check the filled-in answers before sending them in. Initially, a progress bar notified data transmission but it was unclear for distinguishing between successful and unsuccessful data delivery. A feedback notification pop-up window was shown, displaying a round face with an associated color code (i.e., green smiley face for successful delivery and red sad face for unsuccessful one). In addition, the user manual with intuitive images to guide step-by-step how to handle the measurement devices was requested. In this line, the GUI corresponding to the new measurement was improved by reducing the information load to perform tasks.

4) Field Trial

The usability evaluations performed during the field comprised 4 tasks with associated sub-tasks and several usability problems were revealed. In the GUI of the measurements' screen, the text "New Measurement" was used twice, as a heading but also as an action bar, creating confusion on which was one had to be selected to start the action. When choosing the action bar, a pop-up window opened over the instruction text, impeding its reading. The size of the touch area to answer the videoconference call was too small. Regarding the interface design, the text size was evaluated as sufficient and the choice of colors as appropriate. The interface of the main screen, measurement and the symptom self-evaluation questionnaire were easy to understand and had sufficient contrast between the elements. In the questionnaire, the size of boxes was sufficient and the overview of filled-in answers before sending was evaluated as a positive feature. For the application's functionality, there was a lack of

notification to the user when there was a data transmission error. For instance, a progress bar showed on the screen an ongoing transmission, but without notifying whether the transmission was successful or not. In addition, the videoconference had problems with sound and video quality. Initially, the quality was rated as satisfactory, but it presented some minor sound and video problems. Only one participant rated as satisfactory the videoconference quality during the whole test. The touch area to answer videoconference call was too small.

Regarding users' interactions with the tablet device, the double touch action was problematic because users had to apply the correct touch speed and pressure. A stylus was required in some cases. One user had forgotten the correct action for starting the application and found a way around by touching another UI area. When adjusting the camera in the videoconference, one user accidently switched off the application twice before succeeding.

The interviews showed that all participants successfully connected the equipment by themselves at home. The instruction manual was evaluated as clear and instructive, but some mismatch between the content shown in the manual and the final text and layout shown in the system had to be resolved. The main frustration expressed by participants was the videoconference problem, which was related to mobile network coverage. For the interaction with the UI, most users stated that during one week they became familiar with the correct speed and pressure for touch actions.

Based on findings from the field trial, several refinements were made in the tablet application, such as the automatic start of the application because of problems with touch initiation of the program icon (i.e., equivalent to mouse double-click). It was found that, ideally, the tablet application should report the battery level of the measurement device to the telemedicine centre and patient. The videoconference image and sound quality was improved through software configuration changes. The sound quality was improved by the selection of optimal headphones and microphone setup for the users.

The participants' overall rating of the application was satisfactory concerning all interactions with the tablet (e.g., equipment setup, device connection, measurements, questionnaire filling, data transmission, and videoconference). Comments referred to the design, understanding and usability of the system: *I think the application is very well designed so you do not misunderstand anything. I consider this system user-friendly*; *This application was easy to use because even an old person like me without computer experience could use it*.

C. Final Version

The UCD process concluded the development of a final version of the tablet application, which was evaluated as "satisfactory" in all the sub-phases. Users started to operate the UI from the main screen of the application. The screen was divided into six differentiable touch areas with the daily functions at the top (e.g., "Questionnaire", "New Measurement" and "COPD Assessment Test". Figure 20 shows the final UI of the tablet application.
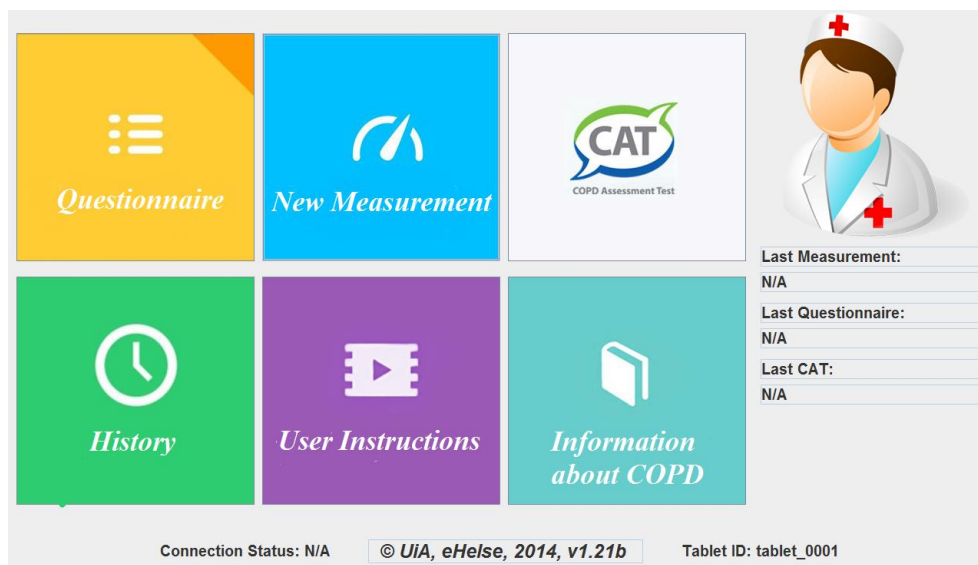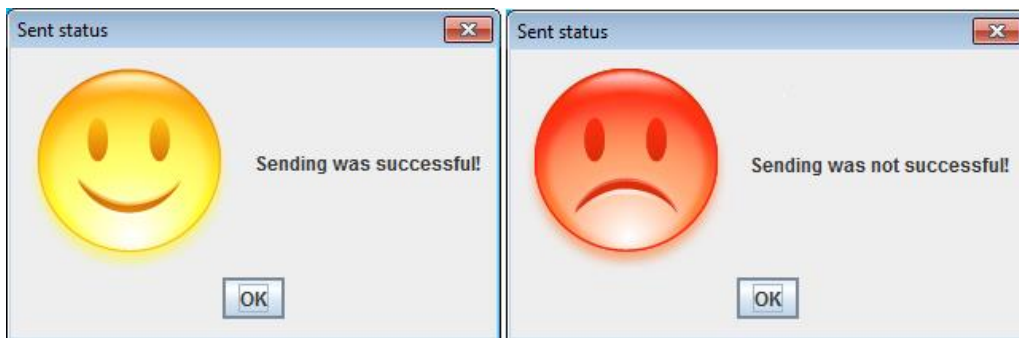

Figure 20 Final version UI's main screen

The series of steps related to the task of taking a new measurement is shown in Figure 21 and 22. The procedure included pressing the button "Start measurement" to start the operation (see Figure 21.1). When starting the measurement, a pop-up window opened and visually showed how to place the sensor on the finger (Figure 21.2). When successfully measured, the readings of SpO2 and pulse were shown in the two fields and the button with the label "Send" would become active to send the readings to the telemedicine centre (see Figure 21.3). When pressing the "Send" button, a progress bar showed the text "Sending", representing the ongoing transmission of data (see Figure 21.4).

Figure 21 (1) Final version UI's New Measurement screen. (2) Pop-up window with instruction. (3) Readings of SpO2 and pulse. (4) Progress bar.

When the data were transmitted, a feedback notification pop-up window opened to alternatively show successful or unsuccessful data delivery, see Figure 22.

Figure 22 (1) Final version UI's New Measurement screen. (2) Pop-up window with instruction. (3) Readings of SpO2 and pulse. (4) Progress bar.

The questionnaire for the daily self-evaluation of symptoms consisted of a sequence of 9 screens, 7 for the questions and 2 for reviewing and reset the answers when necessary. The question screen showed the possible answers to be touch-selected and a button with the text "Next" to continue with the remaining questions, see Figure 23 left.
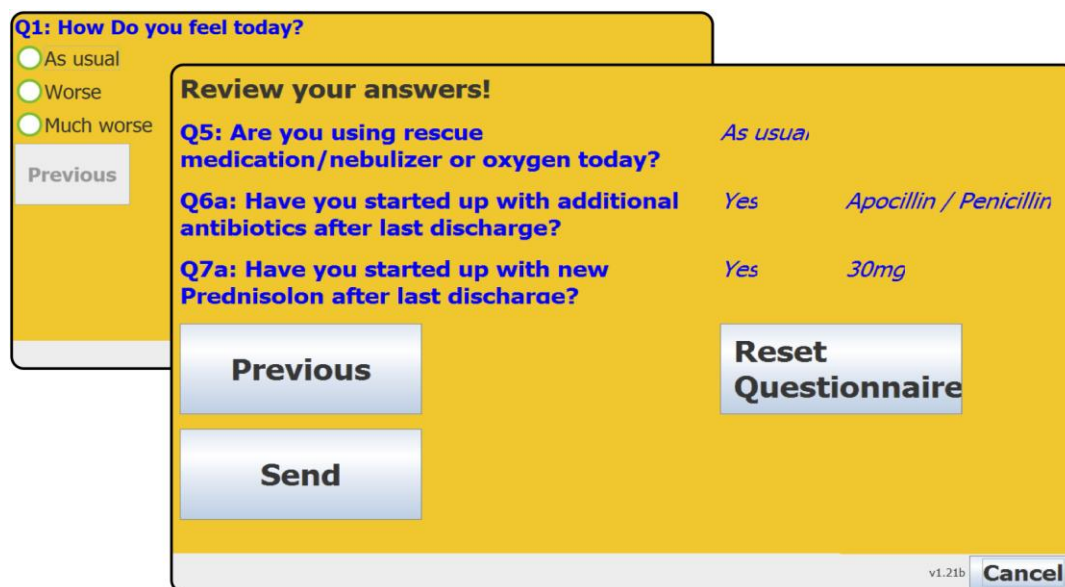

Figure 23 Final version UI's daily self-evaluation questionnaire, question 1 (left, Q1) and answer review (right).

The questionnaire review screen showed the answers selected and gave the possibility of resetting them when necessary. In addition, the button with the text "Send" would submit the answers to the telemedicine centre and the button labelled with "Cancel" would cancel the whole operation discarding the answers, see Figure 23 right.

V. DISCUSSION

This paper has presented the UCD process for the development of a tablet device application for remote monitoring of COPD patients in home environment. Telemedicine applications typically involve multiple users in number and type, such as patients, health professionals and administrative officers. This is why the involvement of those groups of end-users in the design of a new technical application is crucial to understand the clinical workflow where the solution will be deployed, its context of use and the interactions involved. The two research questions (RQs) formulated at the beginning of this paper are answered below based on the results from the study.

About the RQ1, which asked about the development of a telemedicine application for remote monitoring of COPD patients, it has been confirmed by end-users (i.e., COPD patients and health professionals) that the employed UCD approach included their needs in the development of the application. The workshop with end-users efficiently outlined user needs, context of use and helped the user groups involved to familiarize themselves with each other and the research team. Therefore, the workshop was the key to elicit users' requirements of the application, taking on board different aspects of GUI, interaction and functionalities.

The user evaluations were carried out both in a controlled laboratory environment and at COPD patients' homes. The early evaluations in laboratory environment simulated a realistic user scenario based on constructed role-play scenario where the patients and health care professionals interacted with the technology. In addition, the laboratory provided a test environment allowing controlling the variables studied and enabled users to give feedback about GUI design and the interactions following the remote monitoring process. The laboratory test was a necessary step where to evaluate the iterations for the refinement of the application. Finally, the controlled test provided the necessary safety for, as seen in other studies, afterwards running the field trial in an optimal way [30].

The field trial allowed studying the long-term and real-time usage of the technology by COPD patients at their home and provided useful information about the interactions between humans and technology, but also between the different technologies involved. This helped to address the common issues with interoperability [38], present nowadays in the deployment and use of telemedicine technologies [39][40].

Several lessons were learned during the study that can be transferable and applicable for technology development for other chronic clinical pathways (RQ2). In particular, intended solutions for medical environments necessarily need to firstly involve all the user groups in the creation of the solution. Secondly, the respective analysis of how this solution could best fit in an existing clinical workflow or, if non-existent, embedding the solution in a new workflow built up in collaboration with the end-user groups. Thirdly, the fact that chronic patients do not have the same levels of physical energy as healthy people underlines the importance of designing easy-to-use solutions that minimise physical effort and mental workload.

The research study of the UCD process had also some limitations such as: patient role-play by health professionals, user-scenarios tested in a simulated environment and reduced number of end-users. The health professionals took the role of the patient in the user evaluation 1 due to the low legibility of interface wording (as it can be seen in

Figure 9 and 10). This was improved in the user evaluation 2, where real patients tested the interface. The simulated test environment allowed creating highly realistic scenarios under controlled conditions, and the field trial gave the opportunity to test the system in real-world settings. The number of users, despite low, meaningfully represented all the end-user groups involved [41][42].

VI. CONCLUSION AND FUTURE WORK

This study has been developed including end-users' (i.e., COPD patients and health professionals) needs, suggestions and preferences, in the design and evaluation of a COPD remote monitoring application. Positive results were reported after the evaluation in the laboratory settings, regarding ease of use of the telemedicine solution and user satisfaction. The methodology employed, UCD, transformed the end-user into a contributor of the telemedicine service design and allowing continuous refinement of the application to fully develop the system suitable for remote monitoring of COPD patients.

The telemedicine service enabled COPD patients reporting their symptoms and health status after hospitalization. The system is interoperable with other concurrent systems, resolving the common issue of interoperability present in the deployment and use of telemedicine technologies. The continuous report of symptoms for chronic patients throughout the whole health service chain together with actively including patients in building the solution, are in line with the European Union (EU) Health Strategy, "putting patients at the heart of the system and encouraging them to be involved in managing their own healthcare needs" [43]. This EU strategy aims to help current health care systems placing the patient at the centre of new treatments for chronic conditions included in the projections of global mortality for 2030 [8], such as ischemic heart disease and diabetes.

The simulation in high fidelity laboratory settings and the field trial are significant contributing factors to the ecological validity of the research here presented. In a world where human-computer interactions progressively increase in number and complexity, real-time evaluations in real-world settings become crucial to understand not only whether deployment is successful, but the efficient and continuous use of technological solutions.

Finally, the proposed UCD process has been validated by the development of a telemedicine tablet application, successfully adopted by the EU FP7 project United4Health, which focused on technologies that support remote monitoring of

COPD patients after hospital discharge. As a result, 3 telemedicine centers covering 23 municipalities in Norway are currently using the final version of the application. This represents a significant contribution compared with related scientific literature where many telemedicine studies do not reach final deployment stage.

Future work will address research on appropriate identification and authentication methods for patients, more autonomous reasoning and decision support in the application, and integration of further devices to support other patient groups and clinical pathways associated with chronic diseases, such as hypertension and diabetes.

REFERENCES

[1]   B. Smaradottir, M. Gerdes, R. Fensli, and S. Martinez, "User Interface Development of a COPD Remote Monitoring Application, A User-centred Design Process," The Eighth International Conference on Advances in Computer-Human Interactions (ACHI 2015) IARIA Feb 2015; pp. 57-62, ISSN: 2308-4138, ISBN: 978-1-61208-382-7.

[2]   Web 3C- Web Accessibility Initiative [retrieved: November 3, 2015]. Available from: http://www.w3.org/WAI/redesign/ucd.

[3]   J. Chan, K. G. Shojania, A. C. Easty, and E. E. Etchells, "Does user-centred design affect the efficiency, usability and safety of CPOE order sets?," J Am Med Inform Assoc, 18, 276e281, 2011, doi:10.1136/amiajnl-2010-000026

[4]   Norwegian Ministry of Health and Care Services, "The Coordination Reform, Proper treatment – at the right place and right time," Report No. 47 (2008-2009) to the Storting. [retrieved: November 30, 2015]. Available from:

https://www.regjeringen.no/contentassets/d4f0e16ad32e4bbd8d8ab5c21445a5d
c/en-gb/pdfs/stm200820090047000en_pdfs.pdf

[5] Norwegian Ministry of Health and Care Services, "The Health&Care21 strategy," (HelseOmsorg21 Nasjonal forsknings- og innovasjonsstrategi for helse og omsorg) [retrieved: November 30, 2015]. Available from: https://www.regjeringen.no/contentassets/8ab2fd5c4c7746dfb51e3f64cd4d71aa /helseomsorg21_strategi_web.pdf?id=2266705

[6] Norwegian Ministry of Health and Care Services, "The Care of the Future," (Morgendagens omsorg), Report No. 29 (20012-2013) to the Storting. [retrieved: November 30, 2015]. Available from: https://www.regjeringen.no/contentassets/34c8183cc5cd43e2bd341e34e326dbd 8/no/pdfs/stm201220130029000dddpdfs.pdf

[7] Directorate of Health, "National strategy for e-ehealth (2014–2016)," (Nasjonal handlingsplan for e-helse). [retrieved: November 30, 2015]. Available from: https://helsedirektoratet.no/Lists/Publikasjoner/Attachments/12/Nasjonal-handlingsplan-for-e-helse-2014-2016-IS-2179.pdf

[8] C. D Mathers and D. Loncar, "Projections of global mortality and burden of disease from 2002 to 2030," PLoS Med, vol. 3(11), pp. 2011-2030, Nov 2006, doi: 10.1371/journal.pmed.0030442

[9] T. A. Seemungal, G. C. Donaldson, E. A. Paul, J. C. Bestall, D. J. Jeffries, and J. A. Wedzicha, "Effect of exacerbation on quality of life in patients with chronic obstructive pulmonary disease," Am J Respir Crit Care Med, vol. 157, No.5, pp. 1418-22, 1998, doi:10.1164/ajrccm.157.5.9709032

[10] S. D. Ramsey and S. D. Sullivan, "The burden of illness and economic evaluation for COPD," Eur Respir J, 21: Suppl. 41 29s–35s, 2003, doi:10.1183/09031936.03.00078203

[11] United4Health 2015, European Commission Competitiveness Innovation Programme, ICT Programme to Support Policy. [retrieved: November 3, 2015]. Available from: http://www.united4health.eu

[12] United4Health 2015, The Norwegian project contribution. [retrieved: November 30, 2015]. Available from: http://www.united4health.no

[13] G. Gudmundsson et al., "Risk factors for rehospitalisation in COPD: role of health status, anxiety and depression," Eur Respir J, vol. 26, pp. 414-419, 2005, doi:10.1183/09031936.05.00078504

[14] I. M. Osman, D. J. Godden, J. A. Friend, J. S. Legge, and J. G. Douglas, "Quality of life and hospital re-admission in patients with chronic obstructive pulmonary disease," Thorax, vol. 52, pp. 67-71, Jan 1997, doi:10.1136/thx.52.1.67

[15] B. Smaradottir, M. Gerdes, S. Martinez, and R. Fensli, "The EU-project United4Health: user-centred design of an information system for a Norwegian telemedicine service," J Telemed Telecare, 5 Nov 2015, doi:10.1177/1357633X15615048

[16] D. A. Perednia and A. Allen, "Telemedicine technology and clinical applications," JAMA, 273(6), pp.483-488, 1995, doi:10.1001/jama.1995.03520300057037

[17] J. Craig and V. Patterson, "Introduction to the practice of telemedicine," J Telemed Telecare, 11(1), pp. 3-9, 2005

[18] R. L. Bashshur, "On the definition and evaluation of telemedicine," Telemed J, 1(1), p. 19-30, 1995, doi:10.1089/tmj.1.1995.1.19

[19] C. Bai, "Cell phone based telemedicine – brief introduction," J of Transl Med, 10 (Suppl 2), pp. A47, 2012, doi:10.1186/1479-5876-10-S2-A47

[20] J. Gulliksen, B. Göransson, I. Boivie, S. Blomkvist, J. Persson, and Å. Cajander, "Key principles for user-centred systems design," Behav Inf Technol, 22(6), pp. 397-409, 2003, doi:10.1080/01449290310001624329

[21] K. Vredenburg, J. Mao, P. W. Smith, and T.Carey, "A survey of user-centered design practice," Conference on Human Factors in Computing Systems 2002 (SIGCHI 2002); p. 471-478, doi:10.1145/503376.503460

[22] J. Lazar, Web Usability- a user-centered design approach. Pearson Education, 2006, ISBN-10 0321321359, ISBN-13 9780321321350

[23] J. Nielsen, Usability engineering. Elsevier, 1993. ISBN-13: 978-0125184069, ISBN-10: 0125184069

[24] L. Goldberg et al., "Usability and accessibility in consumer health informatics current trends and tuture challenges," Am J Prev Med, Vol 40, Issue 5, Supplement 2, pp. S187–S197, May 2011, doi:10.1016/j.amepre.2011.01.009

[25] A. W. Kushniruk and W. L. Patel, "Cognitive and usability engineering methods for the evaluation of clinical information systems," J Biomed Inform, vol. 37, pp. 56-76, Feb 2004, doi:10.1016/j.jbi.2004.01.003

[26] M. W Jaspers, "A comparison of usability methods for testing interactive health technologies: methodological aspects and empirical evidence," Int J Med Inform, vol. 78(5), pp. 340-353, 2009, doi:10.1016/j.ijmedinf.2008.10.002

[27] J. Lazar, J. H. Feng, and H. Hochheiser. Research methods in human-computer interaction. Chichester, United Kingdom, John Wiley & Sons, 2010, ISBN 978-0-470-72337-1

[28] C. I. Martínez-Alcalá, M. Muñoz, and J. Monguet-Fierro, "Design and customization of telemedicine systems," Comput Math Methods Med, vol. 2013, doi:10.1155/2013/618025

[29] M. Ho, R. Luk, and P. M. Aoki, "Applying user-centered design to telemedicine in Africa," Conference on Human Factors in Computing Systems 2007 (CHI 2007) Workshop on User Centered Design for International Development.

[30] A. De Vito Dabbs et al., "User-centered design and interactive health technologies for patients," Comput Inform Nurs, vol. 27(3), pp. 175–183, May-June 2009, doi: 10.1097/NCN.0b013e31819f7c7c

[31] A. Das, S. Bøthun, J. Reitan, and Y. Dahl, "The Use of Generative Techniques in Co-design of mHealth Technology and Healthcare Services for COPD Patients," Design, User Experience, and Usability: Interactive Experience Design, pp. 587-595, Springer International Publishing, 2015.

[32] QSR NVIVO v10. [retrieved: November 30, 2015]. Available from: http://www.qsrinternational.com/products_nvivo.aspx

[33] M. Gerdes, B. Smaradottir, and R. Fensli, "End-to-end infrastructure for usability evaluation of eHealth applications and services," Scandinavian Conference on Health Informatics (SHI 2014) Aug 2014; pp. 53-59, ISSN(print): 1650-3686, ISSN(online): 1650-3740, ISBN: 978-91-7519-241-3

[34] J. Horsky et al., "Complementary methods of system usability evaluation: surveys and observations during software design and development cycles," J Biomed Inform, 43(5), pp. 782-790, 2010, doi:10.1016/j.jbi.2010.05.010

[35] K. A. Ericsson and H. A. Simon. "Verbal reports as data," Psychol Rev 87, pp. 215-251, 1980.

[36] J. Nielsen, T. Clemmensen, and C. Yssing, "Getting access to what goes on in people's heads?: reflections on the think-aloud technique," Nordic Conference on Human-Computer Interaction (NordicCHI, 2002) Oct 2002; pp. 101-110, doi:10.1145/572020.572033

[37]   B. Smaradottir, M. Gerdes, S. Martinez, and R. Fensli, "Usability Evaluation of a COPD Remote Monitoring Application," Stud Health Technol Inform, vol. 210, p. 845-849, 2015, doi:10.3233/978-1-61499-512-8-845

[38]   A.Shaikh, "The impact of SOA on a system design for a telemedicine healthcare system," Netw Model Anal Health Inform and Bioinforma, 4(1), p.1-16, 2015, doi:10.1007/s13721-015-0087-0

[39]   R. L. Bashshur, "Guest editorial: Compelling issues in telemedicine," Telemed E Health, 19(5), p. 330-332, 2013, doi:10.1089/tmj.2013.9998

[40]   R. L. Craft, "Toward technical interoperability in telemedicine," Telemed J E Health, 11(3), 384-404, 2005, doi: 10.1089/tmj.2005.11.384

[41]   J. Nielsen, "Estimating the number of subjects needed for a thinking aloud test," Int J Hum-Comput St, 41(3), 385-397, 1994, doi:10.1006/ijhc.1994.1065

[42]   J. Nielsen and T. K. Landauer, "A mathematical model of the finding of usability problems," Conference on Human factors in computing systems (ACM INTERCHI'93) May 1993, pp. 206-213, doi:10.1145/169059.169166

[43]   European Union. Official Journal of the European Union, vol. C 146, 22 June 2006, ISSN 1725-2423. [retrieved: November 30, 2015]. Available from: http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1446552106801&uri=CELEX:52006XG0622(01)

Appendix D

Paper III

Title:	Usability Evaluation of a COPD Remote Monitoring Application
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Usability Evaluation of a COPD Remote Monitoring Application

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Abstract—Telemedicine applications have the potential to enhance patient's safety at home by remote monitoring of chronic diseases. Telemedicine involves the interaction between multiple user groups through a system, making the usability aspect of such system crucial for the continuous, efficient and satisfactory use of the application. The main objective of this study was to carry out a usability evaluation in the field of a telemedicine application for remote monitoring of chronic obstructive pulmonary disease (COPD) patients to improve the application's user interface before system deployment. A field trial was performed with six COPD patients at their homes, continuously using the system's application on a tablet for seven days. The usability evaluation identified 23 usability problems related to users' interactions and system's functionality. These problems were solved with the refinement of the system through an iterative application development process. The outcome of the study was the improved telemedicine application that was adopted by the partners of the FP7 EU project United4Health.

Keywords—eHealth; remote monitoring; telehealth; usability evaluation; user-centred design

I. Introduction

The prevalence of chronic diseases is increasing and chronic obstructive pulmonary disease (COPD) is predicted to be the fourth most fatal disease globally in 2030 [1]. COPD patients suffer from exacerbations with frequent admissions to hospital, leading to a reduced quality of life [2] and an increase of medical expenses for the society [3].

In Norway, a health reform [4] urged health care providers to implement new clinical pathways. Hence, telemedicine technology was introduced to facilitate new services that support communication, optimize resources and increase cost effectiveness. In the FP7 EU project United4Health (U4H) [5], technology for remote monitoring of chronic diseases is being developed and the potential benefits of its use evaluated. In particular, the Norwegian contribution to the U4H project was to develop a telemedicine system that supported remote monitoring of COPD patients after hospital discharge.

The aim of this study was to specify usability requirements of the telemedicine application through a field trial, as a part of a User-centred Design (UCD) process [6]. The telemedicine application was validated from an operational and qualitative usability aspect.

II. Methods

In order to identify usability issues of the telemedicine application, a field trial was run in a home environment in March and April 2014. The field trial had 6 participants, 2 male and 4 female aged between 59 and 81 years (mean of 72), all diagnosed with COPD and living at home. They described their computer skills as "medium" or "low", and used the Internet for purposes such as sending e-mails, banking and reading newspapers. Two of them were experienced tablet PC users, one had minor experience and three had never used a tablet PC.

The field trial consisted of three phases: 1) participant's user training; 2) participant continuous use of the application for one week at home; 3) usability evaluation and interview at participant's home. In phase 1, individual user training was delivered by nurses at a telemedicine centre where participants were debriefed about the research project and demonstrated the daily tasks in the telemedicine application running on a tablet device. The daily tasks included: taking measurements of pulse and blood oxygen (SpO2) that were transmitted wirelessly from a measurement device to the tablet application, and filling in a questionnaire for self-evaluation of symptoms.

Readings and results were wirelessly transmitted to the telemedicine centre. In addition, the participants had to answer a videoconference call on the tablet device from a nurse in the telemedicine centre. At the end of the user training, the participants were asked to perform the tasks in the tablet application themselves. They were observed by the nurse and the research team. In phase 2, each participant performed the daily tasks in the tablet application at their home for a week. In phase 3, the research team visited participants at home and performed a usability evaluation of the user's interactions with the tablet application on daily tasks, based on a think aloud protocol [7]. Semi-structured interviews were carried out to complete participants' feedback.

Each participant was equipped with a suitcase including a pulse oximetry device (Nonin Onyx II, 2012), and a tablet device (Lenovo ThinkPad tablet 2, 2013, Windows 8.1) with the telemedicine application installed. In addition, an adjustable USB camera and a headset were included for the videoconference.

Observations and interviews were audio-visually recorded, with a total of 8.5 hours, where the mean duration was 45 minutes in user training (phase 1), 12 minutes for usability evaluation and 27 minutes for the interviews (phase 3). Recordings were transcribed verbatim and categorised based on a qualitative content analysis [8]. Patient's suggestions and feedback collected through the field trial were used to improve the system's user interface (UI) before its final implementation.

III. RESULTS

A. User Training

The user training comprised 4 tasks, with a total of 26 associated actions. An in-depth analysis of the observations revealed 10 usability problems that were categorised into 3 groups.

1) System's functionality

3 major problems were identified. 2 were related to transmission of data measurements.First, the results of previous measurements were sent instead of the current ones. Second, incorrect date and time configuration in one of the tablets made measurements be shown on the wrong date after data transmission to the telemedicine centre. The third problem was concerned with the videoconference's poor quality of video and sound due to insufficient mobile network coverage.

2) Users' interactions

5 problems were identified. The most important one was related to problems with the double touch action. Participants struggled to employ the appropriate speed when touching the starting icon of the application, e.g., participants had to try up to five times to succeed. Additionally, touching the UI was problematic in some cases due to finger low humidity skin. A stylus was used as a successful replacement in those cases. Regarding the videoconference, the USB camera and picture's size on the screen required a fine adjustment for optimal viewing. The use of headset increased perception of sound in the videoconference, especially for participants with hearing impairments. However, this introduced a new risk of user not hearing the call, because, when the headset was plugged in, the sound was off on the tablet's speakers and limited to the headset.

3) Graphical UI

2 problems were identified. One was related to the small size of UI's touch area for answering videoconference calls (especially for users with large fingertips), and the other with some spelling errors in the UI wording.

B. Usability evaluation

The usability evaluation comprised 4 tasks and 26 associated actions. It was conducted after one week of using the application. An in-depth analysis of the observations revealed 13 usability problems that were categorised into 3 different groups.

1) System's functionality

3 problems were identified. 2 were classified as major ones and were related to the lack of notification to the user when there was a data transmission error. For instance, a progress bar showed on the screen an ongoing transmission, but without notifying whether the transmission was successful or not. This led to situations where participants thought that the data transmission was successful because they could see the progress bar working, but on the other end the telemedicine centre did not receive the measurements. In addition, there was a time limit of 90 seconds for the action start measurement, where the measurement device had to make and send the measurement to the tablet application. If the action was unsuccessful (i.e. data was not received by the tablet application), then the measurement device had to be taken off user's finger to automatically switch off and repeat the action from the beginning. This led to some misunderstanding among users, who waited for too long without knowing that the time

allowed for measuring (90 seconds) ran out. In addition, the videoconference had problems with sound and video quality. Initially, the quality was satisfactory, but it was gradually reduced with some minor sound and video problems. Only one participant had satisfactory quality during the whole test.

2) Users' interactions

6 problems were identified. Double touch action was problematic for 3 of the users, who needed to try multiple times to succeed. The interaction with the UI screen required a stylus for 3 users, and for another, both stylus and finger. The difficulties associated with touch speed, correct pressure, low humidity finger skin or large fingertips were the reasons for using a stylus. One user had forgotten the correct action for starting the application, and found a way around by touching another UI area. When adjusting the camera for videoconference, one user accidently switched off the application twice before succeeding. Regarding the measurement device, one of the participants had problems with taking a measurement and was asked after 12 minutes to take the hand up from the table and hold the finger in the air. Then, the measurement succeeded, making the user aware that pressure influenced the measurement. Due to problems with the sound quality of the videoconference, around half of the users preferred to use a headset.

3) Graphical UI

4 problems were identified. 2 problems were related to the action of taking a new measurement. The text "new measurement" was used twice in the same screen, as heading and also as an action bar, creating confusion of which was the one to select to start the action. Another problem was that when choosing the same action bar, a pop-up window opened in the middle of the instruction text, impeding its reading. All participants commented on the small size of the touch area to answer videoconference call. In the questionnaire, the answer options of two questions regarding medication were misunderstood and some doubts were expressed about the answers.

C. Interviews

All participants had successfully connected the equipment by themselves at home, but one had a problem opening the camera's USB-cap and another forgot how to enter the PIN the first time, because in the keyboard the numbers were not visible and an action for switching from letters to numbers had to be taken. The user manual was evaluated as clear and instructive, but one participant highlighted that the written text had to be exactly as on the screen as some mismatch was found. Due to transmission

errors, four participants received an unscheduled home visit by a nurse or technician during the field trial, in order to identify reasons for errors in the transmission and also to change the videoconference configuration to optimize its quality. The main frustration expressed was the videoconference problem, which was related to mobile network coverage.

Regarding the interface design, text size was evaluated as sufficient and the choice of colours was appropriate. The interface of the main screen, measurement and the symptom self-evaluation questionnaire were easy to understand and had sufficient contrast between the elements. In the questionnaire, the size of boxes was sufficient and the overview of filled-in answers before sending was evaluated as a positive feature. Two participants suggested including one more answer option, "feel better today", related to the symptom self-evaluation questionnaire. For the interaction with the UI, most users stated that during the week they got more familiar with the correct speed and pressure for touch actions, but a few still remained using the stylus.

The participants' overall evaluation of the application was satisfactory. Users stated: *Imagine that someone made such an easy program so that even I could understand it* [...] *I would call this user friendly and easy to use; if I can use this others can also since I am not a very technical person.*

IV. DISCUSSION

In this paper, a usability evaluation of a telemedicine application for COPD patient remote monitoring has been presented. The field trial was a part of a UCD process, and it studied the continuous usage of the telemedicine application implemented in a tablet device. The application was used at participants' home for a week and provided useful information about the interactions between users and technology, but also between the different technologies involved.

A total of 23 usability problems were identified related to the use of the tablet application, where 6 were classified as major ones and prioritised to be addressed. Most of the problems were corrected in several iterations in order to optimize system's functionality and to ensure a better support for user interactions.

The study showed that despite the fact that several participants had little or no experience using tablet devices, all reported that their use of the telemedicine application was satisfactory. Due to that, user training was described as a key factor for providing patients with the relevant information and necessary confidence to operate the application by themselves at home.

The usability evaluation performed at participant's home after a continuous use of the application for seven days allowed having a more complete understanding of how the system operated from user perspective. The period was found generally sufficient for users to explore the possibilities of the system and feel confident with it. It also gave enough time to report suggestions, possible application's errors and limitations when they were interviewed. In addition, the field trial showed the benefits of an evaluation carried out in a familiar environment for users.

This research study has some limitations, such as a reduced number of end-users and non-laboratory test settings, where the user's home environment provided less control to the research team of the possible variables studied when compared with laboratory settings.

However, the field trial was preceded by a laboratory user evaluation [6] and the home environment gave the opportunity to test the system in real-world settings, providing a familiar context of use for participants and, above all, the real scenario where the deployed system will run. This aspect might have a positive influence on the satisfaction levels reported by the participants in the interviews. Regarding the reduced number of users, there is research evidence that 5 participants are enough for qualitative usability studies [9].

Finally, the telemedicine tablet application has culminated with the adoption of the system by the FP7 EU project United4Health's partners [5] and, by this, hundreds of Norwegian citizens and residents across the country will be using the system. Future work will cover integration of further devices with the telemedicine application to support other patient groups and clinical pathways.

REFERENCES

[1]   C.D. Mathers, D. Loncar, Projections of global mortality and burden of disease from 2002 to2030. PLoS Med 3 (11) (2006), 2011-30: e442. DOI:10.1371/journal.pmed.0030442

[2]   T.A. Seemungal, G.C. Donaldson, E.A. Paul, J.C. Bestall, D.J. Jeffries, J.A. Wedzicha, Effect of Exacerbation on Quality of Life in Patients with Chronic Obstructive Pulmonary Disease, Am J Respir Crit Care Med, Vol.157, No.5 (1998), pp. 1418-22. DOI:10.1164/ajrccm.157.5.9709032

[3]   S.D. Ramsey, S.D. Sullivan, The burden of illness and economic evaluation for COPD, Eur Respir J; 21: Suppl. 41 (2003), 29s–35s. DOI: 10.1183/09031936.03.00078203

[4]   Norwegian Ministry of Health and Care Services. The Coordination Reform –
        Proper treatment - at the right place and right time. Report No. 47 to the
        Storting (2008-2009), 2009

[5]   United4Health [Internet].Transforming the patient experience with telehealth in
        Europe. European Commission- ICT Policy Support Programme and
        Competitiveness and Innovation Framework Programme; [cited 2015 Feb 9].
        Available from: http://www.united4health.eu/

[6]   B. Smaradottir, M. Gerdes, R. Fensli, S. Martinez, User interface development
        of a COPD remote monitoring application- a user-centred design process.
        Accepted for publication at the 8th International Conference on Advances in
        Computer-Human Interactions; 2015 Feb 22-27; Lisbon: Portugal.

[7]   M.W. Jaspers, A comparison of usability methods for testing interactive health
        technologies: methodological aspects and empirical evidence, Int J Med Inform,
        78(5) (2009), 340-53.

[8]   J. Lazar, J.H. Feng, H. Hochheiser, Research methods in human-computer
        interaction, John Wiley & Sons, 2010.

[9]   J. Nielsen, T.K. Landauer, A mathematical model of the finding of usability
        problems. Proceedings of ACM INTERCHI'93 Conference; 1993 Apr 24-29;
        Amsterdam: Netherlands:206-13.

Appendix E

Paper IV

User-centred Design of the User Interface of a Collaborative Information System for Inter-municipal Dementia Team

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Abstract—**In the Norwegian Health sector there are currently undergoing changes at local, regional and national level triggered by recent health reforms. Municipalities are facing for first time the duty of implementing new primary health services. Inter-municipal coordination (IMC) health care teams have been created to operate across borders to share costs, extend geographical range of operation and optimise resources. This study focuses on the development and evaluation of the user interface (UI) functional prototype of a collaborative information system for IMC dementia team in Norway. Employing a user-centred design approach, the interface prototype was built based on the information gathered on two workshops where the end-users described their current clinical workflow of dementia assessment and how the UI would best fit into their daily work. The outcome of the workshops creatively informed the design of a working prototype that was qualitatively usability tested. Results showed that the UI effectively and efficiently supported the work of the IMC dementia team, with a sufficient level of satisfaction among the end-users. The resulting prototype established the foundation for the system implemented in the FP7 EU project United4Health.**

Keywords—Dementia Assessment; Health Information System; Inter-municipal Coordination; User-centred Design

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I. INTRODUCTION

In Norway, the Coordination reform urged municipalities to implement new specialised health care services [1]. One key consequence is the need for an effective coordination and collaboration between professionals, organisations and end-users of the Norwegian Health National system. This could be achieved by a balanced combination of medical expertise, technology innovation and interdisciplinary research where new technological solutions can satisfactorily attend the demands of the health sector. In this context, the research project eHealth-extended Care Coordination evaluated the existing clinical workflow in an inter-municipal coordination (IMC) for dementia assessment. The ultimate goal of the project was to develop a Collaborative Information System (CIS) for assessment of dementia for patients from different municipalities. To accomplish acceptable levels of effectiveness, efficiency, and satisfaction, the creation of the final CIS was preceded by the essential phase of designing, evaluating and refining the implementation of a functional prototype. This paper presents the user-centred design (UCD) [2][3][4] and evaluation of the user interface (UI) of a CIS for IMC dementia team. The prototype was designed with the active involvement of the end-users and led by a research team with the essential participation of an interaction designer. The prototype was conclusively validated from operational and a qualitative usability perspective.
The research questions (RQ) of this study were:

RQ1: How can a functional prototype be developed for the collaborative evaluation and assessment of dementia taking into account the needs and the requirements of an IMC dementia team?

RQ2: What lessons from this study are transferable to real-world scenario and what methodological procedures are applicable to the development of technological solutions for other clinical workflows?

II. RESEARCH BACKGROUND

Research evidence shows that early assessment of dementia increases case findings [5][6][7][8]. However, negative attitudes towards assessment and diagnose represent barriers to efficiently diagnose cognitive deteriorations [9][10]. Due to the Coordination Reform [1] municipalities are encouraged to establish IMC in order to

carry out new specialised health tasks. For instance, IMC dementia teams have been established [11] for the assessment of dementia in neighbour municipalities. IMCs generally face the challenge of information flow across the different Information Systems. A CIS for IMCs can be a contributing factor to improve the information flow in the medical detection of dementia. The development of such system requires involvement of end-users to adapt system to the clinical workflow, taking into account that a qualitative usability evaluation can increase user satisfaction and improve operational procedures [12][13][14].

This research study focuses on one IMC for collaborative dementia assessment formed by six especially trained health care professionals.

III. MATERIALS AND METHODS

The UCD process for the CIS was divided into four phases: user workshops, development of prototype, usability evaluation and graphic user interface evaluation.

A. User Workshops

Two workshops with end-users were set up in April and May 2013. The participants were two members of an IMC dementia team (mean age of 40.5 years) with an experience of two years from IMC dementia team and 11 years of clinical systems' use. An interaction designer responsible for the prototype development participated in the workshops moderated by two research team members.

The workshops had the aim to analyse the current workflow of the IMC dementia team, provide understanding of the context of use and establish user requirements. The workshops were arranged as interactive sessions and had an average duration of 2.5 hours. In first part of workshop 1, a patient scenario was created to map the workflow in the IMC dementia team. The participants described how they would like to interact with the CIS, making suggestions about the User Interface Design (UID). Colourful post-it notes (see Figure 24) and hand-made sketches were used to describe ideas for the functionalities and design of the CIS.
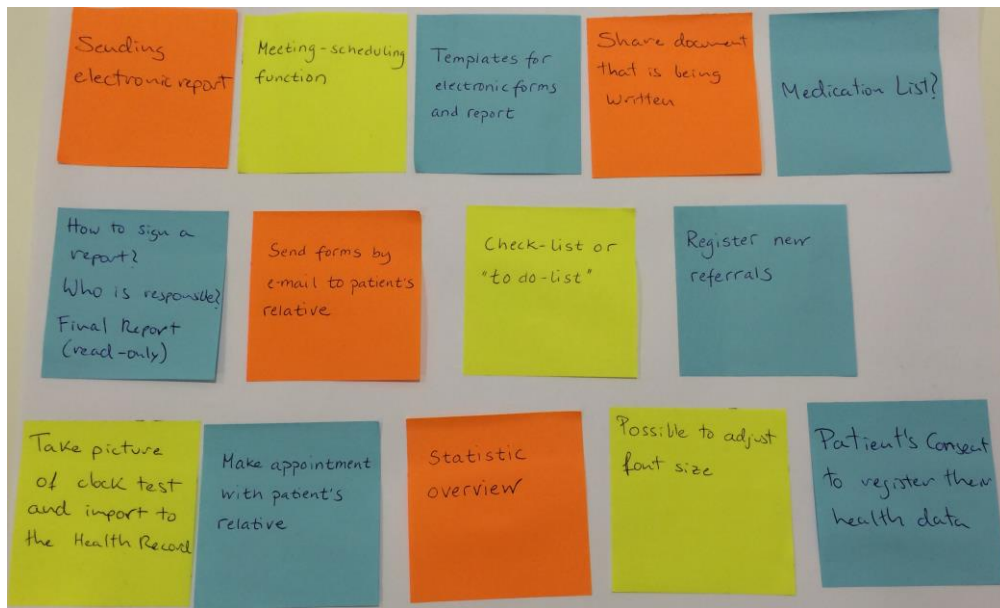
Figure 24 Post-it notes sample from user workshop.

In second part of workshop 1, the interaction designer presented wireframe sketches (see Figure 25) for the CIS, based on previous research in the project eHealth-extended Care Coordination. The participants gave feedback on sketches and made suggestions about the graphic user interface (GUI).
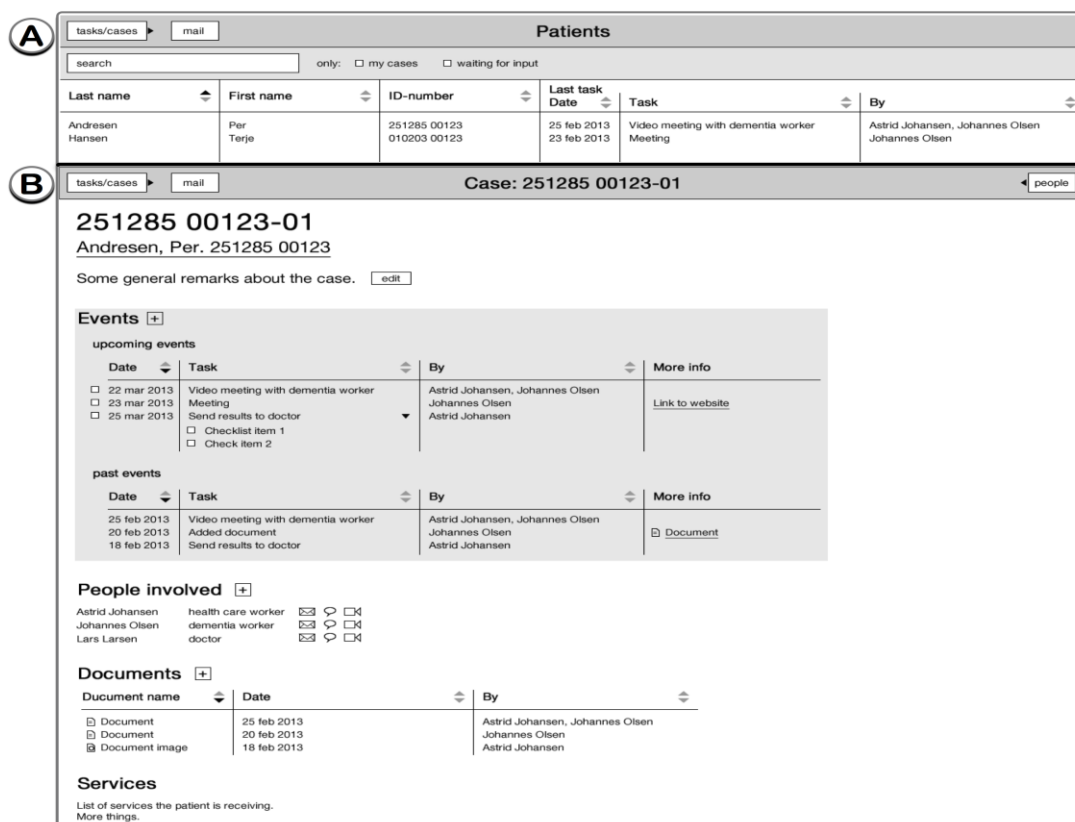

Figure 25 Wire frame sketches from user workshops. (A) Overview of patients' list. (B) Patient's information data.

In workshop 2, the interaction designer presented a graphical UI for the CIS, based on the patient scenario and the user suggestion from workshop 1 to demonstrate the proposed functionalities and interface design. The participants' evaluated and gave feedback on the proposed GUI.

B. Development of Prototype

Based on the user workshops, the interaction designer developed a prototype for the CIS. The prototype was developed as an interactive web application, implementing several of the proposed functionalities.

C. Usability Evaluation

As a part of the UCD process, usability evaluation was made with end-users performing representative tasks related to work in IMC dementia team.
The usability evaluation was carried out in the Usability Laboratory [15] at the Centre for eHealth and Healthcare Technology of the University of Agder in June 2013. The Usability Laboratory had a test room and observation room connected through an one-way mirror. The test room had a laptop and two video cameras and the observation room had monitors where the research team could follow in real time the evaluation being performed. The test participants were 5 IMC dementia team members, two male and three female, aged from 25 to 56 years (average of 45) and with an average of 13.6 years of experience using clinical systems. They evaluated their computer skills as 'medium'. The evaluation team had four members with health background and ICT background.

The test plan was based on the workflow description from the user workshops and followed a concurrent think aloud protocol (TA) [12][14][16][17][18]. The evaluation was run in five individual test sessions that started with informed consent and a pre-test interview. The test session were guided by a moderator and had the duration of 22 to 38 minutes (average of 27 minutes).

A post-test questionnaire, Scale of Usability Satisfaction (SUS) [19] was filled in individually and two post-evaluation group interviews (n=3, n=2) were conducted to qualitatively analyse the output of the test, with an average duration of 25 minutes.

D. Graphic User Interface Evaluation

A graphic user interface evaluation was made in December 2013 by teachers with graphic design expertise. There were 3 male participants, with average age of 45 years and average experience of 14 years in teaching web and interface design. They did not have previous experience with clinical systems. The evaluation was run in the

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Usability Laboratory as individual test sessions using a TA protocol with tasks related to graphic design and understanding of the user interface. The sessions had a length of 24 to 29 minutes (average of 26 minutes).

E. Data Collection

The user workshops, usability evaluation and graphic user interface evaluation were audio-visually recorded and transcribed verbatim and categorised based on qualitative content analysis [20]. In addition, the usability and graphic user interface evaluations used a screen capture tool.

This study was approved by Norwegian Social Science Data Services (project number 28027).

IV. RESULTS

The results of each phase in the UCD process are separately presented.

A. User Workshops

The results of the user workshops are categorised into three groups.

1) Workflow of Dementia Assessment

The participants described the workflow (see Figure 26) for dementia assessment in an IMC dementia team as consisting of three main parts: preparation of dementia assessment, visit to patient's home and creation and sending of assessment final report.
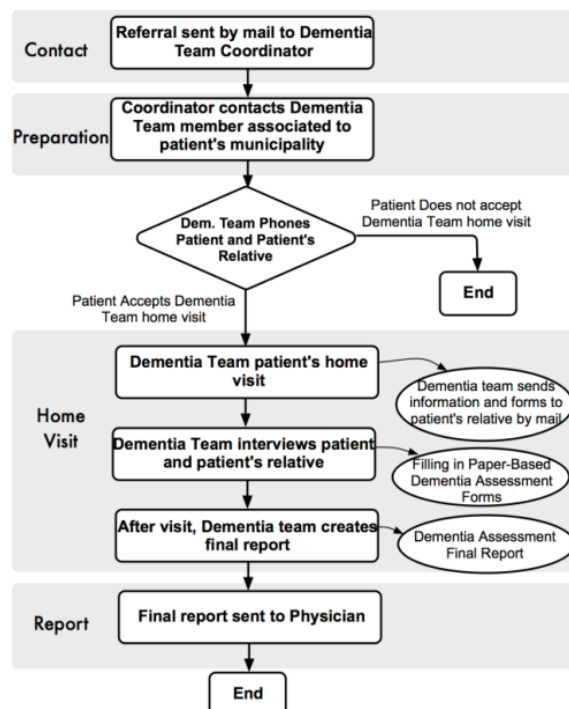

Figure 26 Inter-municipal dementia assessment workflow.

The information flow was mainly supported by phone and paper mail communication. The process started with a paper-based referral to dementia team coordinator, who established a dementia team for the individual patient by contacting dementia team member in patient's municipality and made an arrangement for visit to patient's home. In the home visit, paper-based dementia assessment forms were employed and afterwards the dementia assessment report was created by the dementia team and sent by paper mail to physician.

2) User Suggestions for Interaction with the System

The participants were asked in the workshops how the CIS could facilitate and improve work processes within the IMC dementia team. The main idea suggested was to provide a collaborative access to the system and improve the electronic information flow between the municipalities and ideally reduce phone and post mail communication.

3) User Suggestions for Interface Design

In terms of UID, users' suggestions referred to the visual organisation of the information on the screen. For instance, a typical "Log in" page with user name and password was mentioned as a mechanism to access the system. After entering the system, a "Home page" would allow to create a new patient record or find an existing one. When selecting an existing patient, a new page would show the health and administrative information related to the selected patient. In the same page, the patient's name should be clearly visible at the top: There should be no doubt what patient record you are dealing with. About the graphical layout, it was more important to have a good contrast than a wide range of colours: Good contrast instead of too strong colours. The users suggested having a design adaptable for both PC and tablet devices, since both would be used in the described scenario.

Users suggested electronic referral into system, with automatic transfer of name, birthday and address into CIS and also who referred the patient. In addition, a meeting scheduling function, check-list for tasks to do and video-conference and chat functionalities. They proposed SMS reminder or email before home visit to the dementia team members. Regarding dementia assessment forms, they proposed a digital version with pre-filled name from the system and the possibility of taking picture of relevant documents and information, e.g., clock test, paper referral and import them to CIS. They asked for remote access e.g., in patient's home, and also screen sharing for simultaneous report writing in two municipalities. A document had

to be un-editable after finalised and signed by liable person. Finally, statistics with a selection function was proposed.

B. Development

Based on the user workshops, the interface design of the prototype for CIS for IMC dementia team was developed. Figure 27 shows the home page divided in two sections. The section on the left side (blue colour), shows the "Overview of patients' list" presented after users logged in. The patients under dementia assessment were placed at the top of the list. The patients earlier assessed were placed below the line. The right side (green colour) includes the statistical data. It contained information visualisation of data, such as age and gender.

Figure 27 Overview of patients' list.

By selecting one patient's name on the patients' list, the individual patient's data was presented as seen in Figure 28. Four sections were differentiated by colours: Tasks

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(purple), People involved (turquoise), Documents (red) and Patient's personal information (yellow). The goal was to satisfy user requirements by maximising the amount and usefulness of information showed at one glance that could be easily distinguishable and understandable without overloading the interface.

Figure 28 Patient's information data.

C. Usability Evaluation

The overall evaluation was positive, although not all the aspects of the system were optimally developed. Some of the issues were caused by the fact that the assessment was made of a prototype instead of a fully implemented system. The usability

evaluation entailed 3 tasks, with a total of 15 subtasks and the analysis revealed 9 usability problems that were categorised into 3 groups. In addition, the scores of the Satisfaction Usability Score (SUS) questionnaire and post-test group interviews are presented.

1) Graphic Design

7 problems were identified. There were problems related to understanding of the meaning of icons, especially the external message icon and its size. The UI should have to entirely fill the screen in order to minimize user scrolling. For the task-list, it was not obvious whether tasks were done or had to be done, and that the meeting scheduling function and some numbers beside patient name in overview of patient list could be misunderstood. In addition, there was poor visibility of written text in overview of patients' list which needed for better colour or contrast. One stated: *The colours are very good because each theme has its own colour. So you can know, just by the colour, what you are choosing.*

2) Interaction with the System

In general the interaction during task solving was successful, but 2 problems were identified. For the interaction it was not clear how to switch view on the screen (three stripes in the left up corner) and not all participants understood how to add information to system ("+" symbol on each heading).

3) Functionality of System Related to Work Processes

The possibility to communicate between municipalities through the CIS, instead of via phone or post mail as it is currently done, was greatly appreciated by participants. They were unanimously satisfied about the statistics function and stated that the video-chat function would provide the opportunity to collaboratively write a final dementia report at distance. Some added features were suggested, such as displaying patient distribution by municipality and the capacity of reporting different diagnoses to the government. The visualisation of the patient's information data was rated as useful and important, providing a good overview of key information visually separated by colours and where the patient's name was clearly visible and indicating which patient's record was opened. One participant of the usability evaluation stated: *I got a lot of important information at one glance: patient's general and contact information and about his relatives.*

Table 3 Satisfaction Usability Scale (SUS)

Question	P1	P2	P3	P4	P5	M	SD
Q1	4	5	4	5	5	4.6	0.5
Q2	2	4	1	2	1	2.0	1.2
Q3	3	3	4	3	5	3.6	0.9
Q4	1	1	2	4	1	1.8	1.3
Q5	4	4	3	4	5	4.0	0.7
Q6	1	1	2	1	1	1.2	0.4
Q7	4	4	5	4	4	4.2	0.4
Q8	1	1	2	3	1	1.6	0.9
Q9	3	4	3	2	4	3.2	0.8
Q10	2	4	5	3	1	3.0	1.6
P*i* = participant *i;* M = mean; SD = Standard Deviation							
	Positive Response: Agree or Strongly Agree for positive questions; Disagree or Strongly Disagree for negative questions						
	Neutral: neither Agree nor Disagree						
	Negative Response: Agree or Strongly Agree for negative questions; Disagree or Strongly Disagree for positive questions						

4) Scores of Satisfaction Usability Scale

The scores of the SUS questionnaire are presented in Table 3 (modified version of [21][22]. Overall, the mean of the satisfaction ratings were on the range of "Agree" or "Strongly Agree" for the majority of answers to the positive questions (except one mean rating with neutral value), and in the range of "Disagree" or "Strongly Disagree" for the majority of answers for the negative questions (except two mean ratings with neutral values).

5) Post-test Group Interviews

Participants' comments gathered during the interviews expressed a need for user-training and self-exploration of the interface in order to learn more about how to use the system. One participant stated: *The system realistically fits in our current workflow; however I would need some user training.*

For evaluation of the final version of the system they suggested a test plan that followed the task scenario associated with a real patient case. In addition, performing an individual evaluation followed by a group one to analyse the system from a multi-personal perspective was proposed. For the UID, it was suggested that when placing the mouse cursor over an icon, its name should be displayed on the screen, which was also pointed out by the graphical specialists' evaluation. Readability and notification of new messages were relevant for the participants.

For the functionality of the system, interoperability with other existing systems was highlighted, which could ideally eliminate the need for transferring information between them. Participants also assumed that the chat function was a time efficient

way to effectively communicate between colleagues (e.g., asking questions and getting the answers in a quick way).

D. Graphic User Interface Evaluation

The overall evaluation of graphic user interface of the prototype was positive, but there were some recommendations for design changes. The evaluation entailed 2 tasks, with a total of 13 subtasks and revealed 7 usability problems.

1) Graphic Design

4 problems were identified. The text in overview patients' list had poor visibility, were the contrast between the background colour and text white font could be improved by including a visible cell border between the rows. The icon for external messages and the 'x' for closing up patient information were confusing and could be replaced with more intuitive ones. Using lines instead of bars in the statistical charts improved the visual clarity and distinguished finished tasks from undone ones in the task list.

2) Interaction with the System

The interaction with the CIS during the task solving was generally successful, but 3 problems were identified: when mouse hovers over icon text should be shown related to the associated action; a mechanism to navigate backwards should be inserted for avoidance of using browser back-oriented arrow; a confirmation notification window was lacking when adding a new team member

3) Overall Evaluation

The test participants positively agreed that the system was designed using validated methods for designing interfaces. One of them stated that: *The system is clear, easy to read and understand.*

The abundance of colours was justified because they visually informed users about the section's functionality in which they were currently working on. It helped to distinguish different sections at one glance. Monochromatic or black and white set of colours would have probably blurred the different section functionality. This was expressed during the evaluation: *From the design point of view, the colours are used to separate elements, which works well to get the overview of the screen. This would diminish user training.* However, it was reported an insufficient system structure overview because the different sections of the system could be only accessed by scrolling down. Instead, providing redundant access through a menu with the same colours at the top would probably be more effective giving a direct access to the

sections eliminating scrolling action. On the "Home page", the information load was rated as "too high" but the overall rating was balanced by the correctly structured sections, placing the most relevant at the top.

V. DISCUSSION

The elaboration of a CIS to be used by IMC dementia teams was developed following a UCD process. The aim was to support and ease the existing workflow with a technological solution that allowed electronic access, storage of patient data and served as a communication tool.

For the RQ1 that enquired about the prototype development for IMC dementia team, it was found that a UCD approach effectively took on board users' needs regarding the current workflow of operation. In addition, a test of such workflow incorporating the prototype in simulated clinical settings together with a qualitative usability evaluation was decisive in the development and refinement of the prototype.

For the RQ2 about the lessons applicable in real-world scenarios, the study has shown that a fully-implemented system based on the prototype presented, potentially avoids the risks associated to paper-based procedures. Lessons learned throughout this study are three. Firstly, the workshops with representative users became essential to gathering the system requirements. Secondly, through the same workshops it was possible to acquire the understanding of the current workflow of operation of an IMC dementia team. Thirdly, the evaluation of the prototype tested was performed from a usability and graphical expert perspectives.

The end-users' and graphic professional's evaluations of the system were generally positive. The workshops provided a key insight in the dementia assessment workflow and how the interaction with the CIS functionality would best fit the existing work processes. The suggestions about the UID were made in line with the need to visualise useful information at one glance at the same time that the functionalities of the system were clearly differentiated, for instance, by colours.

In the qualitative usability evaluation the graphic design and colour scheme used was generally approved and some features were pointed out as potentially confusing, such as icons and heading wording. This is consistent with the development of prototypes in early stages of UID [23][24]. The iteration process expected in future work precisely refines these types of potentially problematic findings. One of the most acclaimed features was the possibility of communication through the system by

messages and chat. The statistical summary offered by the system was unanimously satisfactory because of its contribution to the workflow.

Finally, the graphic interface evaluation was made by professionals in the field [25][26] and valuable recommendations were incorporated into the design of the next iteration of the prototype.

There were some limitations associated to this research study. Firstly, although the laboratory facilities realistically represented the work environment, the study was performed in a simulated environment. Therefore, caution is required in the direct transferability of the results to a real-world scenario. Instead, this study might be seen as a necessary step for the validation of the controlled conditions that should be carried out before the use of the system in real clinical settings. Secondly, the reduced number of participants in the UCD process might be seen as an impediment of the applicability of the findings in a larger scale. However, in qualitative usability studies a small number of participants can be sufficient for having valid results [27]. Thirdly, the prototype was not completely operative compared to a fully implemented system. Nevertheless, the prototype provided a satisfactory simulation of how users could hypothetically interact with the system in a real scenario.

VI. CONCLUSIONS

This work was framed inside the project *eHealth-extended Care Coordination*, which revealed a need for improving communication processes with efficient technology within IMCs. In this study, a UCD process was employed in the development of a working prototype. The CIS would ideally be the core for a fully-implemented system potentially adaptable for any health IMC's team. The end-users' participation in workshops allowed gathering key information to build the prototype based on user needs and requirements. The usability evaluation together with graphical assessment of the prototype led to the positive refinement of the functionality, effectiveness and look and feel of the solution. In addition, the resulting UI established the foundation for the technological solution implemented in the FP7 EU project United4Health, [28] currently being successfully used in IMC in Norway.

Future research will include a full implementation of the system, with its corresponding evaluation in the field from a usability and operational perspective.

REFERENCES

[1]   Norwegian Ministry of Health and Care Services. 2008-2009. Report No. 47. The Coordination Reform, Proper treatment – at the right place and right time. [cited 2014 Sept 1]. Available from: http://www.regjeringen.no/upload/HOD/Dokumenter%20INFO/Samhandling% 20engelsk_PDFS.pdf

[2]   De Vito Dabbs, A., Myers, B.A., Mc Curry, K. R., Dunbar-Jacob, J., Hawkins, R. P., Begey, A., Dew, M. A. 2009. User-centered design and interactive health technologies for patients. Computers Informatics Nursing; 27(3): 175–83. doi: 10.1097/NCN.0b013e31819f7c7c

[3]   Rogers, Y., Sharp, H., Preece, J. 2011. Interaction Design: Beyond Human Computer Interaction, Wiley. ISBN : 978-0-470-66576-3

[4]   Nielsen, J. 1994. Usability engineering. Elsevier.

[5]   Borson, S., Scanlan, J. M., Watanabe, J., Tu, S. P., Lessig, M. 2006. Improving identification of cognitive impairment in primary care. International Journal of Geriatric Psychiatry, 21(4), 349-355.

[6]   Harvan, J. R., Cotter, V. T. 2006. An evaluation of dementia screening in the primary care setting. Journal of the American Academy of Nurse Practitioners, 18(8), 351-360.

[7]   Boustani, M., Callahan, C. M., Unverzagt, F. W., Austrom M. G., Perkins, A. J., Fultz, B. A., Hui, S. L., Hendrie, H. C. 2005. Implementing a screening and diagnosis program for dementia in primary care. Journal of General Internal Medicine, 20(7), 572-577.

[8]   Callahan, C. M., Hendrie, H. C., Tierney, W. M. 1995. Documentation and evaluation of cognitive impairment in elderly primary care patients. Annals of Internal Medicine, 122(6), 422-429.

[9]   Connolly, A., Gaehl, E., Martin, H., Morris, J., Purandare, N. 2011. Underdiagnosis of dementia in primary care: variations in the observed

prevalence and comparisons to the expected prevalence. Aging & Mental Health, 15(8), 978-984.

[10]   Borson, S., Scanlan, J., Hummel, J., Gibbs, K., Lessig, M., Zuhr, E. 2007. Implementing routine cognitive screening of older adults in primary care: process and impact on physician behavior. Journal of General Internal Medicine, 22(6), 811-817.

[11]   Directorate of Health and National Expertise Service for Ageing and Health 2011. Etablering og drift av Demensteam, Demensutredning i rimærhelsetjenesten. [cited 2014 Sept 1]. Available from: http://www.aldringoghelse.no/ViewFile.aspx?ItemID=2824

[12]   Jaspers, M. W. 2009. A comparison of usability methods for testing interactive health technologies: methodological aspects and empirical evidence. International Journal of Medical Informatics, 78(5), 340-353.

[13]   Bastien, J. M. 2010. Usability testing: a review of some methodological and technical aspects of the method. International Journal of Medical Informatics, 79(4), e18-e23.

[14]   Kushniruk, A. W., Patel, V. L. 2004. Cognitive and usability engineering methods for the evaluation of clinical information systems. Journal of Biomedical Informatics, 37(1), 56-76.

[15]   Gerdes, M., Smaradottir, B., Fensli R. 2014. End-to-End Infrastructure for Usability Evaluation of eHealth Applications and Services, Scandinavian Conference on Health Informatics; pp. 53-59, ISSN(print): 1650-3686, ISSN(online): 1650-3740.

[16]   Nielsen, J., Clemmersen, T., Yssing, C. 2002. Getting access to what goes on in people's heads?- Reflections on the think-aloud technique. NordiCHI, October 19-23, p101-110.

[17]   Fonteyn, M. E., Kuipers, B., Grobe, S. J. 1993. A Description of Think Aloud Method and Protocol Analysis. Qualitative Health Research, 3: 430.

[18]   Ericsson, K. A., Simon, H. A. 1980. Verbal reports as data. Psychological Review, 87(3), 215.

[19]   Brooke, J. 1996. SUS: a quick and dirty usability scale. In P. W. Jordan, B. Thomas, B. A. Weerdmeester & I. L. McLelland, Eds. Usability Evaluation in Industry, pp. 189-194. London: Taylor & Francis.

[20] Lazar, J., Feng, J. H., Hochheiser, H. 2010. Research methods in human-computer interaction. John Wiley & Sons.

[21] MacLellan, S., Muddimer, A., Peres S. C. 2012. The Effect of Experience on System Usability Scale Ratings. Journal of Usability Studies , Vol. 7, Issue 2, 56-67.

[22] Bangor, A., Kortum, P., Miller, J. 2009. Determining What Individual SUS Scores Mean: Adding an Adjective Rating Scale. Journal of Usability Studies, Vol. 4, Issue 3, pp. 114-123.

[23] Snyder, C. 2003.Paper prototyping: The fast and easy way to design and refine user interfaces. Newnes.

[24] Nielsen, J. 1993. Paper Prototyping: Getting User Data Before You code. NN/g Nielsen Norman Group http://www.nngroup.com/articles/paper-prototyping/

[25] Acevedo, D., Jackson, C. D., Drury, F., Laidlaw, D. H. 2008. Using visual design experts in critique-based evaluation of 2D vector visualization methods. IEEE Transactions on Visualization and Computer Graphics, 14(4), 877-884.

[26] Tory, M., Moller, T. 2005. Evaluating Visualizations: Do Expert Reviews Work?. IEEE Computer Graphics and Applications, 25(5), 8-11.

[27] Nielsen, J., Landauer, T. K. 1993. A mathematical model of the finding of usability problems. Proceedings of ACM INTERCHI'93 Conference. Amsterdam, The Netherlands, 24-29 April, 206-213.

[28] United4Health. European funded project United4Health 2014. Available from: http://www.united4health.eu/

Appendix F

Paper V

Title:	Usability Evaluation of Electronic forms and Collaborative Assessment Report in an Inter-municipality Health Care team for Dementia Diagnose
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Usability Evaluation of Electronic forms and Collaborative Assessment Report in an Inter-municipality Health Care team for Dementia Diagnose

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Abstract—**Despite that paper-based medical procedures have historically been the most common way of registering and exchanging patient data, it does not avoid the potential risks of unauthenticated access, unregistered data loss, legibility and difficulty to share the data with third parties. The Coordination Reform 2009 (Samhandlingsreformen) has demanded from municipalities to implement health services for citizens based on electronic messaging that eases the access to and sharing of patient data. In the context of the Research project "Collaboration without borders" (Samhandling uten grenser), in this study electronic forms and collaborative assessment report by videoconference have been usability tested in order to evaluate the potential application of these electronic tools in an inter-municipality workflow of dementia assessment. The results showed that electronic forms helped to reduce the paper load of the process, allowing repeated access to the forms for retrospective amendments and reviews. The videoconference with document sharing was reported to be a very effective and satisfactory tool to cooperatively work on the final report of the assessment between the members of the dementia team.**

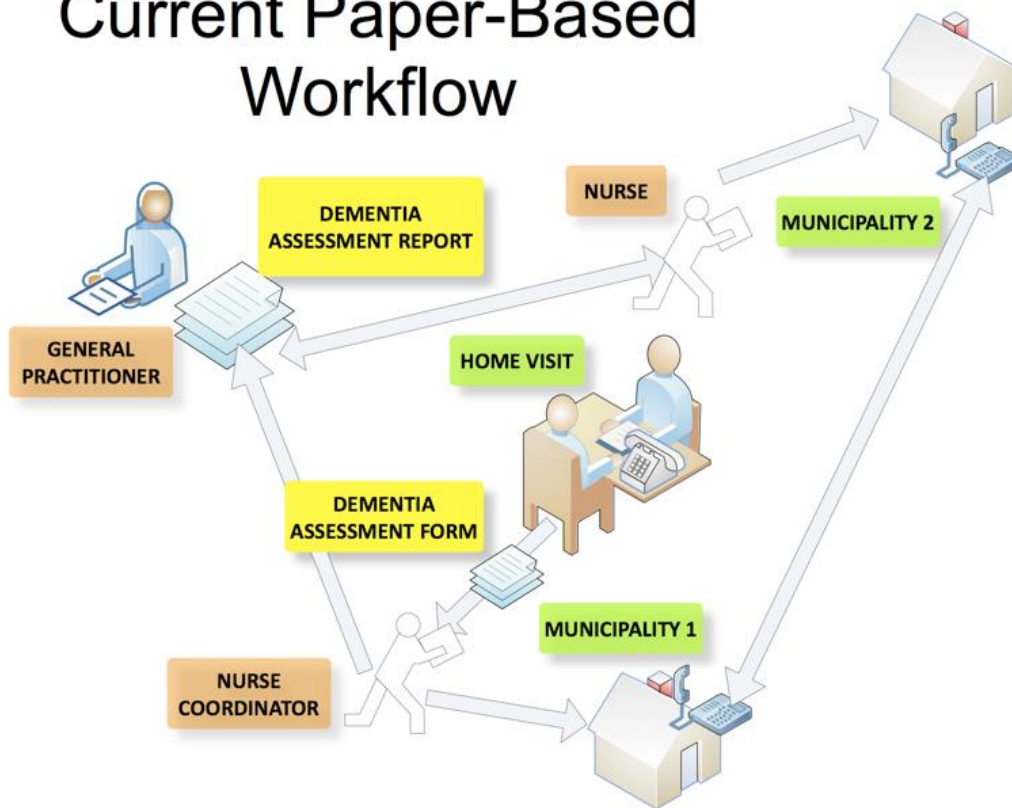*Keywords*—eHealth; dementia; health care team; health information technology; videoconference; collaboration

I. INTRODUCTION

The Norwegian Coordination Reform [1] demanded from municipality health care services to implement structural changes and facilitate the increasing use of ICT solutions to improve collaboration and coordination services. In addition, the Norwegian Association of Local and Regional Authorities (KS) [2] pointed out the need for effectively coordinated services that combine medical expertise with the experience from other sectors such as technology, research and innovation. In this context, the research project *Collaboration without borders* (*Samhandling uten grenser*), aimed to evaluate new opportunities for interaction and development of technological solutions that facilitates electronic sharing of information between the municipal care service professionals, users and relatives. One of the objectives of the project was to investigate whether the introduction of electronic communication through the establishment of inter-municipal professional teams required changes at an organisational level. Thus, the introduction of electronic communication presents inherent challenges for municipality health professionals who are used to work on paper-based procedures. The intrinsic benefits of the progressive transformation of physical documentation into digital documents that are electronically available have to be validated from a usability, operation and satisfaction perspective of the health professionals and patients involved.

This usability evaluation is preceded by a qualitative case study [3], which analysed work procedures and workflow regarding documentation practices in inter-organisational care teams in four small municipalities in Southern Norway. In that study, the workflow of a Dementia team was analysed (see Fig. 29) and revealed a need for improving communication processes, especially those paper-based, which lack of secure data storage and limited availability. The study specified user requirements and proposed the use of electronic tools that could support access and exchange of medical information of inter-municipality care teams.

Figure 29 Scheme of the current paper-based workflow in the inter-municipality dementia team in Southern Norway.

This paper presents the usability testing of two electronic communication tools, electronic dementia assessment forms and videoconference with shared document visualisation, to support the assessment of potential dementia patients, reduce the paper-based load and introduce digitally stored documents in their workflow.

The research questions of this study were:

RQ1: Does the replacement of paper-based dementia assessment evaluation forms by electronic versions impact on clinical practice and workflow in inter-municipality dementia teams?

RQ2: Does a collaborative tool such as videoconference with a shared visualisation document impact on the workflow of a dementia assessment report creation by the members of an inter-municipality dementia team?

II. Research Background

Underdiagnose of dementia has been demonstrated in research [4][5][6][7][8][9], with as few as 50% of dementia cases being diagnosed by physicians [10]. From there, the importance of early assessment and diagnose mechanisms that could improve the medical detection on patients, with evidence of increasing case finding [5][7][11][12].

However, negative attitude towards assessment and diagnose and, especially, added visit time, still represent barriers for physicians to efficiently diagnose cognitive impairment [4][10]. During their patient visit, physicians document and store the information related with dementia assessment and diagnose with a great variance in their methods: from personally written or dictated paper notes to templates with fill in boxes [13]. After the information collection, physicians have to work in collaboration with other staff members to summarise, evaluate and enter patient data from paper charts into final assessment reports [13].

Workflow improvements in the information gathering and/or the collaborative final assessment could produce tangible benefits such as productivity increase, reduced paper usage, time saved and quick completion time [14]. Usability improvements in any of these processes could also produce intangible benefits such as increased user satisfaction, e.g., on physician, ease of use and improved institutional image [14].

III. Materials and Methods

The usability evaluation was carried out as a follow up of the research project Collaboration without borders. In the evaluation, end-users performed representative tasks related to dementia assessment. The test included two scenarios: 1) a visit to a patient's home to conduct a dementia assessment using electronic dementia assessment form replicating existing paper forms provided by the *National Expertise Service for Ageing and Health* (Aldring og Helse Nasjonalt Kompetansesenter) and *Directorate of Health* (Helsedirektoratet) [15]; 2) a collaborative writing of the dementia assessment report supported by videoconference with shared document visualisation. A post-evaluation group interview was conducted to qualitatively analyse the output of the test.

A. Test environment settings

The usability evaluation was run in the Centre for eHealth and Healthcare Technology of the University of Agder, Norway. The facilities were the Usability Laboratory and the Smarthouse. The Usability Laboratory had two rooms: the Test

room and the Observation room, connected through one-way mirror (visualisation from the Observation room towards the Test room). The Smarthouse was a large room that simulated firstly a potential patient's home and secondly a municipality office. The test was run in two separated days in May 2014, Day 1 and Day 2.

B. *Participant selection*

Four people formed the Dementia team: one nurse coordinator and three nurses. They were one male and three female participants aged from 26 to 58, with a mean of 45 years. They had an average of 10.5 years of experience using clinical systems. All had experience using laptop, and using tablet and videoconference for working purposes.

The patient and patient's relative were healthy elderly people (average age of 79 years), who acted as patient and relative. The acting was merely figurative, meaning that their answers and behaviours were freely decided. The use of actors was based on the recommendations of usability evaluation in clinical settings where the tests were run as role-plays with multiple stakeholders as participants, e.g. physicians, nurses, and patients [16]. Their role was relevant for the simulation process because the Dementia team had somebody similarly aged to a real dementia patient to direct the questions to.

C. *The Research Team*

Four members, two with health professional background and two with health and ICT background formed the Research team. All had experience in working in health and technological environments with real patients.

D. *Test Procedure*

The test plan for the usability evaluation was adapted to the workflow description of an inter-municipality dementia team in Southern Norway collected in a series of workshops in April and May 2013. The usability evaluation was run in three sessions.

Each session started giving information to participants about the subsequent test and filling in a pre-test questionnaire (with questions about computer skills, experience with specific technological devices and videoconference systems). Each session followed the same test plan running on an average total duration of 120 minutes. A total of three sessions were run across two days, one session in Day 1 and two sessions in Day 2. For each session, two members of the Dementia team (the coordinator alternating one different nurse at a time) went through the two evaluation scenarios: patient's home dementia team visit and videoconference with shared dementia

assessment report. A group interview was conducted at the end of each day as a part of the evaluation method of the two scenarios.

The sequence of the two scenarios, participants involved and the distribution of the rooms used are described in Table 4. Both scenarios were performed in each session of the test and audio-visually recorded in the Observation room. The nurse of the Dementia team was replaced across the sessions and the nurse coordinator participated in all of them.

Table 4 Usability Testing Settings

Scenario	Task	Participants	Input Device	Room[3]
Dementia team visit to patient's home	Dementia assessment form filling in for patient	Nurse coordinator, Nurse, Patient	Laptop	Patient's Home
Dementia team visit to patient's home	Dementia assessment form filling in for relative	Nurse coordinator, Nurse, Relative	Tablet	Patient's Home
Dementia team Videoconference with shared document visualisation	Dementia assessment report writing	Nurse coordinator and Nurse	Laptop	Municipality offices

The three rooms were used in a realistic way, replicating the part of the dementia team workflow where they interacted with the patient, relative and technology (i.e., patient's home visit), and the final writing of the dementia assessment report with communication between long-distance municipality offices.

The Scenario 1 represented a home visit by the Dementia team to assess the potential dementia of a patient. The home visit was simulated in the Smarthouse as a dementia patient's home. Two elderly people played the roles, one as the dementia patient and the other as the patient's relative. During the home visit, the Dementia team represented by a nurse coordinator and a nurse alternatively used a laptop and a tablet to fill in the electronic version of the dementia assessment forms (see Materials section for more details on the specific forms).

The Dementia team had not used or seen the electronic version of the dementia assessment forms before. A member of the Dementia team interviewed the patient

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[3] The Smarthouse first simulated a patient and relative's home, afterwards the municipality office and at the end the meeting room for the interview group; the Test room only simulated the municipality office.

reading the questions of the electronic forms in a tablet, while the other team member filled in the questionnaire answers in a laptop (see Table 5).

Table 5 Scenario 1 Dementia team interactions during

Electronic Dementia Form	Nurse Coordinator Activity / Device	Nurse Activity / Device	Actor
Mini Mental State Examination (MMSE)	Filling in form answers / Laptop	Reading out loud form questions / Tablet	Patient
Dementia Patient's Relative Questionnaire	Reading out loud form questions / Tablet	Filling in form answers / Tablet	Relative

In the next step of the same scenario, roles were swapped within the Dementia team so a member asked questions to the patient's relative reading from the tablet and the other member was writing the answers in a tablet too. Therefore, two types of input device were used: laptop and tablet. The average time of the Scenario 1 was 45 minutes.

There was a moderator present from the Research team whose role was to guide throughout the scenario, reminding the way of proceeding when necessary.

In the Scenario 2, the same two members of the Dementia team from the Scenario 1 wrote a dementia assessment report based on the answers gathered during the patient's home visit. The report writing was performed in a simulated environment, where the participants had a long-distance collaboration, such as between two municipalities. In Scenario 2, the Smarthouse and the Test room represented Dementia team members' offices in different municipalities (see Table 6).

Table 6 Scenario 2 Dementia team videoconference with shared document visualization

Participant	Activity	Device	Room
Member 1 of Dementia team	Writing dementia assessment template report	Laptop	Municipality office[4]
Member 2 of Dementia team	Reading dementia assessment template report writing by nurse coordinator	Monitor	Municipality office[5]

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[4] The Test room simulated the municipality office for the report writing.
[5] The Smarthouse simulated the municipality office for the report reading.

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A videoconference communication system (see Materials section for further details) was used together with a shared document visualisation of the dementia assessment report simultaneously seen on both offices' screens. The dementia assessment report was written in a MS Word 2010 template provided in advance by the Dementia team. The visualisation of the screen from the Dementia team member in charge of writing the dementia assessment report was directly recorded in the Observation room through the Desktop Presenter software. This screen was also shared with the other Dementia team member office (Smarthouse) via the same software. The average time of the Scenario 2 was 40 minutes. There were moderators in the Smarthouse and in the Test room.

In the group interview at the end of Day 1 and Day 2, the Dementia team was asked to give feedback of the two scenarios of each test session: the interaction with the electronic dementia assessment forms and the videoconference with shared document visualisation as a supportive tool for collaboration. The group interview followed the steps defined in an interview guide. The guide included questions relative to the benefits and disadvantages of bringing electronic forms into the home visit stage of the dementia assessment workflow. In addition, questions relative to use of the videoconference with shared document visualisation, as a collaborative tool for writing the dementia assessment report, were included. Finally, questions about usability and graphic User-Interface Design were made during the interview. Suggestions from the Dementia team about further development of the electronic dementia assessment forms were also annotated. Two group interviews were performed with the average time of 35 minutes and moderated by members of the Research team.

E. Material

For replicability and information purposes, the technological material used during the study is presented below grouped by rooms.

Smarthouse:

-PC: HP Compact Elite 8300 ultra-slim desktop.
-Monitor: 46'' Samsung 460tsn-2.
-Laptop: HP EliteBook 8440p, Intel Core i7 CPU @ 2.67GHz, 4GB RAM, Windows 7 Enterprise SP1 64 bit.
-Tablet: 2x Elite Pad 900, Intel Atom @1.80GHz, 2GB RAM, Windows 8 32 bits.
-Tablet keyboard: HP ElitePad Case H4R88AA.

-Camera: SONY BRCZ330 HD 1/3 1CMOS P/T/Z 18x Optical Zoom (72x with Digital Zoom) Colour Video Camera.

Observation room:

-PC: HP Z220 CMT Workstation, Intel Core i7-3770. CPU@3.4 GHZ, 24GB RAM, Windows 7 Professional SP1 64 bit.

-Monitor: 3x HP Compaq LA2405x.

-Remote controller: SONY IP Remote Controller RM-IP10.

-Streaming: 2x Teradek RX Cube-455 TCP/IP 1080p H.264.

-Software Wirecast 4.3.1.

Test room:

-Laptop: HP EliteBook 8460p, Intel Core i7 CPU @ 2.70GHz, 4GB RAM, Windows 7 Enterprise SP1 64 bit.

-Monitor: 19'' Dell 1908 FPT.

-Tablet: Elite Pad 900, Intel Atom @1.80GHz, 2GB RAM, Windows 8 32 bits.

-Camera: SONY BRCZ330 HD 1/3 1CMOS P/T/Z 18x Optical Zoom (72x with Digital Zoom) Colour Video Camera.

-Software Cisco Jabber v9.7.1.

-Software Telestream Desktop presenter v2.0.4.

For the electronic dementia assessment forms creation, the software packages Adobe Acrobat X Pro 10.0.1 and Adobe InDesign CS6 8.0.2 were used. These electronic forms replicated the standardized dementia's assessment A4 paper-based form versions from standardized dementia's assessment A4 paper-based form versions [15]: *Mini Mental State Examination* (MMSE) (Mini Mental Status Evaluering) and *Dementia Patient's Relative Questionnaire* (Spørsmål Til Pårørende). The electronic forms were designed and electronically made at the University of Agder, Norway.

F. Data Collection

Scenarios 1 and 2 (3 sessions x 2 scenarios) and the two group interviews were all audio-visually recorded in the Observation room of the Usability Laboratory, resulting in 8 data recordings in total. Annotations of the recording visualizations by the Research team were included in the analysis. The group interview recordings were transcribed verbatim. Pre-test questionnaire participants' answers and notes from the Research team were also included. The analysis was based on qualitative content analysis [17] and made with the software QSR NVIVO 10 [18].

G. *Ethical Considerations*

This study was approved by the Norwegian Social Science Data Services [19] (NSD), project number 37920. All participants received oral and written information about the project, informed that participation was voluntary and the data collection, storage and access was confidential. All participants signed a written informed consent before the evaluation.

IV. RESULTS

The results were obtained from the annotations, observations and transcripts of the audio-visually recorded data. To ease the reading, the results of each scenario are separately presented.

A. *Scenario 1: Dementia team visit to Patient's Home*

The Dementia team argued that the use of electronic forms did not substantially save time for the dementia assessment form filling. The time consumed in information input to the devices (via physical keyboard or touch screen), based on the Dementia team answers, did not improve when compared with the traditional pen and paper.

The use of a device with a vertical screen and physical keyboard (e.g., laptop or tablet with external keyboard) resulted in a physical barrier that interfered in the communication between Dementia team members and the patient. When filling in the questions, it was found more appealing by the Dementia team to have the tablet in the lap covered by the table they were sitting around, removing any technological device from the visual field of the interviewed and reducing distractions. This resulted in a unanimous preference for tablet built-in keyboard input than through an external one.

The primary outcome of the electronic form evaluation was the immediate paper load reduction of the process. Instead of having to carry out and store the dementia assessment forms, the answers were electronically kept in the tablet, occupying no extra physical space nor introducing potential problems related with data loss or uncontrolled access.

The most highlighted benefit of the electronic form use was its impact in the Dementia team workflow after the home visit. It allowed repeated access to the forms for retrospective amendments and reviews. In addition, it introduced the possibility of electronically sharing the form answers with other professional colleagues, with a potential systematic treatment of the data.

The usability of the electronic assessment forms was subjectively evaluated as "clear, self-explained and little need for user training". The text size was sufficient in term of legibility, although there were some problems with the page scrolling.

Several errors were found during the test relative to the form filling. Initially, the arrow keys were used to navigate through the questions. However, once a question was answered, the arrow keys changed their functionality for question answer navigation, which impeded the normal navigation across questions and could potentially affect the final answer of a question (e.g., changing from Yes to No, instead of jumping to the next question). Another critical error was the miscalculation of the summarisation of the form answers, making the Dementia team members to manually summarise the question answers. The last main error was an occasional problem with storing the electronic form after filling in. This required having the tablet permanently switched on until the dementia assessment report was filled in.

The disadvantages were referred to the amount of visualisation of information on the form. It was stated that in the device, the information at one glance was smaller than when compared to the paper version form. The navigation through the document also presented some problems. For the Dementia team members, it was easier to physically navigate through the document pages than to scroll one by one the pages in the device. This also affected the notion of where the user was in the document at a given time, point especially relevant when they wanted to check out answers or information from other questions than the one currently visualised. It was expressed a fear of unexpected technology failure (e.g., device run out of battery before or in the middle of the form fill in, fatal error of device Operative System or unable to open/save document form), which reinforced the idea of having the paper-based form at hand as a back-up. In the hypothetical scenario of technology failure and having to fill in the paper-based form, the presumed benefit of paper load reduction would not apply.

The Dementia team members suggested that an automatic summarisation and result transfer into the dementia assessment report in order to reduce human errors in manually calculating and transferring the data from the forms to the report. In addition, the possibility of making comments for each question (e.g., in a text box beside the answer options), instead of only in one section at the end of the form, would help to refine the assessment and reflect the nuances of the answers (e.g., if a potential patient wrongly answers to the question of "What is today's date?" with years of difference instead of days, then it would worsen the evaluation of that answer compared with the current case where the only accepted answers are right or wrong). In this context, one

nurse of the Dementia team asked for the possibility of using a stylus to insert the answer by hand in the device using text boxes.

Other suggestions were made related to link the filled form with patient's health history; the document should be seamlessly stored in the patient's electronic Health Record (EHR) directly from the device, and allowing temporary and final versions of the document. This interoperability feature will ensure the long-term impact in the Dementia team workflow.

B. Scenario 2: Collaborative Dementia Assessment Report Writing

The use of a videoconference system with a shared document visualisation was evaluated as positive way of collaborative work by the Dementia team. In terms of work efficiency, sharing the report document visualisation allowed to see and collaboratively work on the same document by Dementia team members working from long-distance municipalities. The ability of finishing the document in one session, instead of requiring several sessions that would require additional tasks such as physically printing out the report, sending it by post or communicating the information through phone call to the other colleague, as it was stated in one of the group inter-views:

The videoconference with shared document was a positive experience today. It functioned quite well. My colleague sees what I write at once, instead of me having to read aloud what I have written.

In addition, a good sound quality was found more important for communication than the on-screen visualisation of the other Dementia team member. The average duration of the Scenario 2 was 40 minutes.

Several potential disadvantages were described by the participants that might affect the collaborative work, such as bad sound quality or difficulties to establish the communication between the two remote systems.

V. DISCUSSION

A. Use of electronic dementia assessment forms

The use of electronic dementia assessment forms generally received favourable comments from the Dementia team members in all the sessions. When comparing the electronic functionality of the form in the tablet with the traditional paper form filling in, the result was evenly ranked. However, the digital form offered several features that the paper form lacked. For instance, the electronic form gave the opportunity to

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retrospectively amend the results filled in by the professionals, which sometimes needed to be revisited. In addition, they reduced the amount of paper produced in each visit and the wide availability of the electronic format (i.e., PDF), made potentially easier to digitally interoperate with other electronic systems (e.g., EHR). These advantages confirmed the findings of the project Collaboration without borders that revealed a need for improving communication processes, especially those paper-based. The use of electronically stored data improves the availability of the data, reduces the hand-made transference of data between sources (e.g., from paper to EHR) and can automatically summarise the results. In addition, the use of devices with external keyboard was unanimously seen as a non-optimal, because the Dementia team members argued that the device's vertical screen could create a physical barrier in the communication with the patient and relative.

There were some additional non-tested features that were suggested by the Dementia team members and could easily be incorporated in the electronic form fill in that could enhance the interaction and the home visit outcome. For instance, the possibility of writing comments for each question would help to refine the information used for the dementia assessment outcome. The use of a stylus was also suggested for handwriting device input, as a more natural way of interacting with the technology.

In conclusion, the use of electronic dementia assessment forms could impact the workflow home-visit stage of an inter-municipality team when compared with traditional paper-based procedures. The main impact are benefits after the home visit, where added functionalities such as paper-load reduction, retrospective access for amendments and reviews and electronic availability and storage, are now included.

B. Videoconference with shared document visualisation

The videoconference with shared dementia assessment report visualisation also received positive evaluations from the Dementia team members. The tested system no longer relied on manual procedures that lacked optimal visualisation and sound quality for the collaboration. It allowed collaboratively completing the dementia assessment report in one operation in contrast with the paper-based workflow where printed forms sent by post and/or physical meetings are used for mutual agreement between the Dementia team members in the dementia assessment report writing. This collaborative component can save time to the team members involved in the report writing and provide information at earlier stage to the other professionals included in the next step of the workflow, such as General Practitioner.

Limitations of the study are related with the reduced number of participants (one nurse coordinator, three nurses and two actors), which might influence the generalisability of the findings. However, in qualitative usability studies a small number of participants can be sufficient for having valid results (e.g., 3 users from each category if testing three or more groups of users [20]). Another limitation could be that the electronic assessment forms were not completely operative which impeded the full exploration of the form functionalities. However, their operativeness provided a satisfactory simulation of how they could work in a real scenario.

VI. CONCLUSIONS

The study presented is a follow up of the project Collaboration without borders, which specified user requirements and proposed the use of electronic tools that could support access and exchange of medical information of inter-municipality care teams. Two electronic tools have been usability tested, in order to evaluate their impact in an inter-municipality workflow of dementia assessment. The evaluation was carried out in realistic clinical settings: patient's home for the interaction with the electronic version of dementia assessment paper-based forms; municipalities' offices for collaborative writing of a dementia assessment report; and role-play with multiple stakeholders such as nurse coordinator, nurse, potential dementia patient and patient's relative.

The main findings reported several benefits of the use of electronic forms, such as digital storage that allowed a later access for reviewing the written information and reduced paper load. These results are congruent with the use of electronic tools to facilitate efficient, accurate and controlled information flow, in a wide range of scenarios such as emergency care [21], medical homes [22] and for sharing data with patients, professionals, providers and government [23]. Research evidence shows that identified communication process gaps can be partly or fully covered by the use of effective electronic tools [22] and workflow operational improvements [24]. The potential of electronic forms for data collection has been demonstrated in data sharing and reporting quality measures between multiple actors [23].

The evaluation of a videoconference system with shared document visualisation provided a synchronization component to the workflow, where both professionals of the Dementia team could collaboratively work on the same dementia assessment report. Based on the findings of this simulation, a new dementia assessment workflow is proposed below as an alternative for the current paper-based one (se Fig. 30).
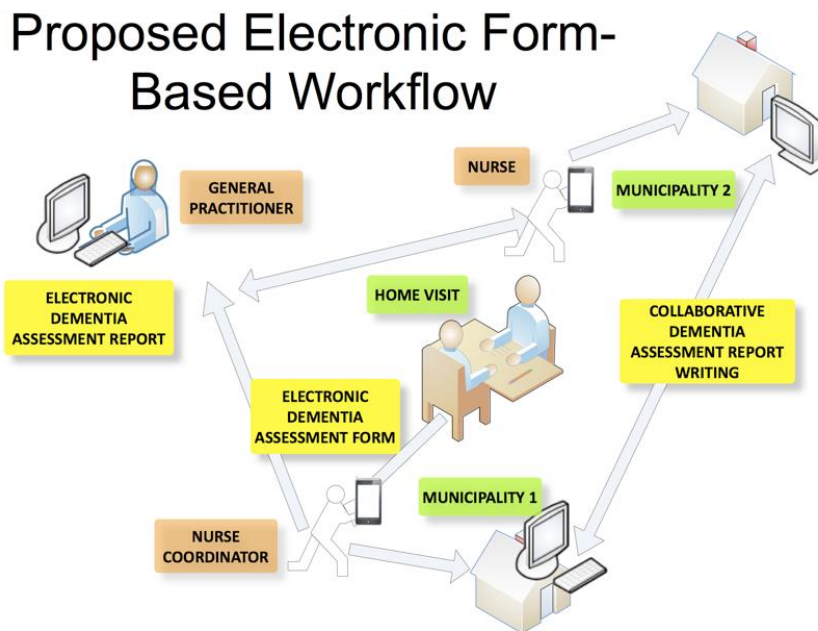
Figure 30 Scheme of the proposed electronic form-based workflow for an inter-municipality dementia team

Future work would include usability evaluation of the implementation of fully operative electronic dementia assessment form and its interoperability with other electronic health services, such as the Electronic Health Record within simulated and real clinical settings.

REFERENCES

[1]   Report No. 47 (2008-2009) to the Storting. (2009). The Coordination Reform, Proper treatment – at the right place and right time. Oslo: Norwegian Ministry of Health and Care Services Retrieved from: http://www.regjeringen.no/upload/HOD/Dokumenter%20INFO/Samhandling%20engelsk_PDFS.pdf

[2]   Kommunesektorens organisasjon (NO). ARTE-Arbeidskraft og teknologi i KS 2009. 2009 Feb [cited 2014 Jul 4]. Available from: http://www.ks.no/PageFiles/43061/ARTErapport.pdf

[3]   Fensli R, Holen-Rabbersvik E, Thygesen E. Shared Access to Electronic Health records for Inter-organisational Care Teams using a Treatment Pathway Health Record. A case study. (Submitted for publication).

[4]   Borson S, Scanlan J, Hummel J, Gibbs K, Lessig M, and Zuhr E. Implementing routine cognitive screening of older adults in primary care: process and impact on physician behavior. Journal of general internal medicine 2007, 22(6), 811-817.

[5]   Borson S, Scanlan JM, Watanabe J, Tu SP, and Lessig M. Improving identification of cognitive impairment in primary care. International journal of geriatric psychiatry, 2006, 21(4), 349-355.

[6]   Bush C, Kozak J, and Elmslie T. Screening for cognitive impairment in the elderly. Canadian Family Physician, 1997, 43, 1763.

[7]   Callahan CM, Hendrie HC, and Tierney WM. Documentation and evaluation of cognitive impairment in elderly primary care patients. Annals of internal medicine, 1995, 122(6), 422-429.

[8]   Evans DA, Funkenstein HH, Albert MS, Scherr PA, Cook NR, Chown MJ, Hebert LE, Hennekens CH, and Taylor JO. Prevalence of Alzheimer's disease in a community population of older persons: higher than previously reported. Jama 262, 1989, no. 18, 2551-2556.

[9]   Valcour VG, Masaki KH, Curb JD, and Blanchette PL. The detection of dementia in the primary care setting. Archives of Internal Medicine, 2000, 160(19), 2964-2968.

[10]   Boise L, Camicioli R, Morgan DL, Rose JH, and Congleton L. Diagnosing dementia: perspectives of primary care physicians. The Gerontologist, 1999, 39(4), 457-464.

[11]   Boustani M, Callahan CM, Unverzagt, FW, Austrom MG, Perkins AJ, Fultz BA, Hui SL, and Hendrie HC. Implementing a screening and diagnosis program for dementia in primary care. Journal of general internal medicine, 2005, 20(7), 572-577.

[12]   Harvan JR, and Cotter VT. An evaluation of dementia screening in the primary care setting. Journal of the American Academy of Nurse Practitioners, 2006, 18(8), 351-360.

[13]   Miller RH, and Sim I. Physicians' use of electronic medical records: barriers and solutions. Health affairs, 2004, 23(2), 116-126.

[14]   Rao M, Teran N, Savard M, and Medtronic AVE.. Improving workflow in home healthcare industry: A case study. Journal of International Technology and Information Management, 2004, 131, 61-72.

[15]   Aldring og helse. Nasjonalt kompetansesenter. Demensutredning i kommunehelsetjenesten. Helsedirektoratet, 2011 [cited 2014 Jul 4]. Available from: http://www.aldringoghelse.no/ViewFile.aspx?ItemID=1492

[16]   Svanæs D, Alsos OA, and Dahl Y. Usability testing of mobile ICT for clinical settings: Methodological and practical challenges. International journal of medical informatics 2010: 79(4), e24-e34.

[17]   Lazar J, Feng JH, and Hochheiser H. Research methods in human-computer interaction. John Wiley & Sons 2010.

[18]   QSR NVIVO: http://www.qsrinternational.com/products_nvivo.aspx

[19]   NSD: http://www.nsd.uib.no/personvern

[20]   Nielsen J, and Landauer TK. A mathematical model of the finding of usability problems. Proceedings of ACM INTERCHI'93 Conference. Amsterdam, The Netherlands, 24-29 April 1993, pp. 206-213.

[21]   Laxmisan A, Hakimzada F, Sayan OR, Green RA, Zhang J, and Patel VL. The multitasking clinician: decision-making and cognitive demand during and after team handoffs in emergency care. International journal of medical informatics, 2007, 76(11), 801-811.

[22]   Bates DW, and Bitton A. The future of health information technology in the patient-centered medical home. Health Affairs, 2010, 29(4), 614-621.

[23]   Blumenthal D. Launching HIteCH. New England Journal of Medicine, 2010, 362(5), 382-385.

[24]   Bowens FM, Frye PA, Jones WA. Health information technology: integration of clinical workflow into meaningful use of electronic health records. Perspect Health Inf Manag 2010, 7:1d.

Appendix G

Paper VI

Title:	Usability Evaluation of a Collaborative Health Information System- Lessons from a User-centred Design Process
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Usability Evaluation of a Collaborative Health Information System

Lessons from a User-centred Design Process

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Abstract—**In Norway, a recent health reform urged municipalities to implement new primary health care services for their citizens. In order to optimise resources, municipalities have established inter-municipal coordination (IMC) to collaborate across organisational borders. Information systems become a necessary tool to support collaboration and shared access to information in an IMC. In this context, the research project eHealth-extended Care Coordination identified a specific need for a collaborative information system for the process of evaluation and assessment of dementia in IMC teams. This paper presents the usability evaluation of a collaborative information system for dementia assessment built using a user-centred design approach. Mixed methods such as observations, semi-structured interviews and a questionnaire were used for data collection. The results showed that the new information system supported the collaborative work of the inter-municipal dementia team with a sufficient level of satisfaction among the end-users. The prototyped solution established the foundations for the system implemented in the Norwegian trials of the FP7 EU project United4Health, dedicated to Point-of-Care Services.**

I. INTRODUCTION

In Norway, the Coordination reform [1] addressed the continuity of care in national health and care services. Services that traditionally were carried out by specialised health care were transferred to primary health care provided by municipalities. Small and medium size Norwegian municipalities faced the challenge of providing specialised services to their citizens, accomplishing the need for structural, organisational and technological changes. This brought to light the need for an effective coordination and collaboration across organisational borders.

In this context, the research project eHealth-extended Care Coordination (Samhandling uten grenser) 2011-2015, focused on information flow in inter-municipal cooperation (IMC) health care teams. In the first phase of the project, a field study identified the need for a collaborative information system (CIS) to improve the information flow in IMC health care teams. In the second phase, an IMC dementia team participated in a user-centred design (UCD) process entailing user workshops, laboratory evaluations and interviews for developing a functional prototype for a CIS for dementia assessment [2]. In the third phase, a usability evaluation of electronic dementia assessment forms for home visits and a videoconference solution for collaborative report writing were performed with the participation of an IMC dementia team [3].

This paper reports from the fourth phase of the project. The final version of the CIS was developed and a usability evaluation was carried out together with end-users in order to validate whether the system accomplished acceptable levels of effectiveness, efficiency and satisfaction. In addition, reflections from the UCD process that involved the IMC dementia team are presented.
The research questions (RQs) of this study were:

RQ1: How can an information system be evaluated taking into account the needs and requirements of the end-users for collaborative access and information sharing by an inter-municipal team of dementia assessment?

RQ2: What lessons and methodological procedures from this study are transferable and applicable to development of technological solutions for other clinical assessment workflows?

II. Research Background

Dementia is a clinical syndrome with deterioration of mental abilities and cognitive skills [4]. For assessment of the cognitive aspects of dementia, a widely used method is the cognitive mental status examination, the Mini-Mental State (MMS) [5]. The MMS is a set of questions whose scored answers result in a category of cognitive mental status.

A dementia plan was implemented in Norway in 2007 [6], aiming at improving capacity, competence and quality in dementia care and enhancing the need for qualified competence in primary care. However, due to the small or medium size of many Norwegian municipalities, specialised IMC dementia teams have been established [7] to collaboratively carry out the assessment of people with dementia in neighbour municipalities.

Recently, a Delphi study with experts in coordination and IMC in health services reached consensus about the challenges concerning electronic communication. Specifically, the lack of tools impeded the collaboration of IMCs [8]. Therefore, IMC dementia teams face challenges generated by their nature of operation, such as limited information flow across the municipalities and interoperability problems between different information systems (IS).The aim of developing a CIS for IMC dementia teams was to provide a platform that supported the information flow and collaborative work across municipal borders.

An effective IS requires a detailed analysis of end-users' needs to inform system design. In addition, the usability of such application is crucial for the continuous, efficient and satisfactory use of the system. In system development, the approach of UCD involves end-users throughout the each stage of the development cycle [9][10] [11]. UCD considers the needs of the end-users through field studies, evaluations and task analysis, helping to understand context of use and workflow, which are key elements for the construction of an IS for a clinical workflow [12][13]. In addition, usability evaluation is necessary to analyse user's interaction and user satisfaction with the system [14][15][16].

III. Materials and Method

The prototype from the earlier phases of the eHealth-extended Care Coordination project was further developed by an industry partner as a full functioning version of the CIS which was implemented within the secure Norwegian Health Network [17]. The evaluation of the CIS was executed during two days in June 2015 and entailed

three steps: (1) test in usability laboratory with end-users, (2) individual questionnaire and (3) group interview. A mixed methods research approach was used including observations, interviews and a questionnaire.

A. Usability Evaluation

The usability evaluation was made with end-users in a laboratory. The facilities had two rooms (test and observation) connected through one-way mirror (described in [18]). In the test room, the system was accessed and used on a laptop connected to an external screen and keyboard. In the observation room, the evaluation was followed by the research team in real-time through four monitors connected to two stationary computers.

5 participants (4 female, 1 male; aged 41-57, average 55.6 years) with the professions nurse, nurse coordinator and social educator, took part in the tests. They were all members of an IMC dementia team from 4 municipalities. They reported an average of 16.8 years of experience using clinical systems and evaluated their computer skills as medium.

Each test session started with a pre-test interview with questions about background and experience with clinical systems. A member of the research team moderated each session. Participants were asked about their first impression of the graphical user interface (GUI). A concurrent Think Aloud protocol [14][15][19] was employed. The task list included 9 differentiated tasks to perform within the system. After each task, the participants were asked to score the task solving into five categories: very easy, easy, medium, difficult and very difficult. The tasks were based on the IMC dementia team workflow description from the UCD workshops [2]. The test sessions had duration of 39 to 62 minutes (average 47 minutes).

B. System Usability Scale

In order to evaluate the user satisfaction, the participants individually answered the post-test questionnaire System Usability Scale (SUS) consisting of with 10 questions [20].

C. Group Interviews

In order to complete the feedback, two post-test semi-structured group interviews (n=2, n=3) were conducted to qualitatively analyse the output of the test (average duration 37 minutes). The CIS was shown on a screen during the interviews, allowing the participants to follow in detail the GUI and comment on its functionality. The main findings from the usability evaluations were also discussed.
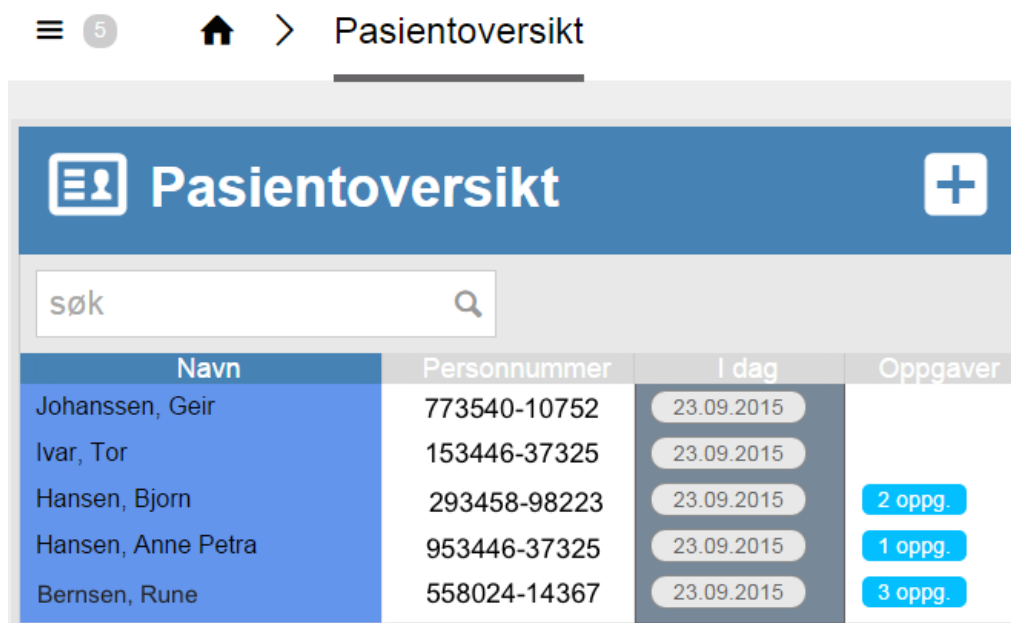
D. Data Collection

Audio-visual recordings were made with two cameras (1 fixed and 1 portable) and a screen capture tool (in usability evaluation) merged into one single video file using the software Wirecast v.4.3.1. The recordings (*.mov* format) were imported into QSR NVIVO 10 for transcription and a qualitative content analysis [16]. This study was approved by Norwegian Social Science Data Services [21] with project number: 37920. All participants signed a consent form.

IV. RESULTS

A. Usability Evaluation

The test started with the screen patients' overview (see Figure 31) and questions about the first impression of the GUI. Participants generally stated that the screen was useful to get a fair overview of patients. Three participants positively commented on the search function used to find a specific patient. About the GUI, comments highlighted the appropriate choice of colours, with the exception of poor readability and contrast of black text over blue background in patients' overview screen.

Figure 31 GUI of patients' overview.

It was pointed out that it could be difficult to read white text sections, especially in rooms with bright light. In addition, the insufficient font size both in text and headings was stated recommending to adapt the GUI to the full screen size. Suggestions

included being able to run a search writing only 3 letters and increasing the speed of the search results.

On each individual patient's view, comments of the GUI (see Figure 32) confirmed the abundance of colours, intended to visually inform about the sections' functionality. In this line, participants commented: *I liked the choice of colour and graphic design. Very clear and easy to read. When you are working on a patient, the colours can tell you where you are.* Patient's key information was coloured as a yellow section and placed at the top right.
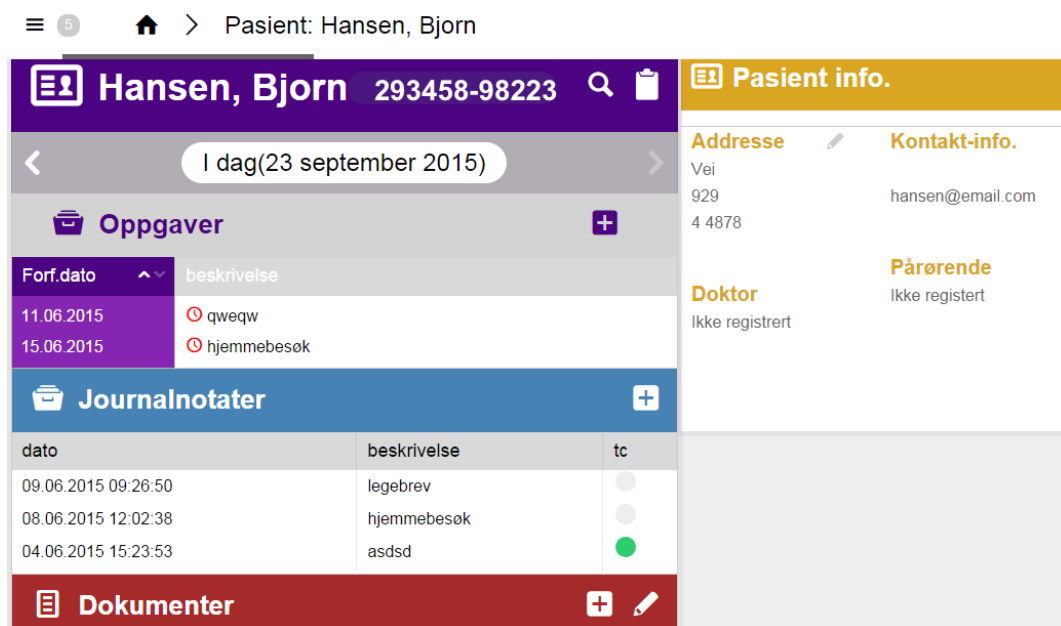

Figure 32 Individual patient's view.

1) Task Performance

All 5 participants successfully solved all the tasks, with different degrees of help from the moderator.

Task 1: Add a new patient to CIS

Participants had to click the '+' sign to access administrative functionalities and be able to register a new patient into the system (see Figure 33). The task was unanimously scored as *easy*. 2 participants had errors with the input format while registering patient's birthdate, having to try few extra times. Suggestions were made about having text boxes with the exact format of the field to avoid errors. Error messages would have to be written in colour to improve readability. When typing a post code, the city would have to automatically appear. The labelling of the button to register a new patient was suggested as save instead of create as a more intuitive

description The list of patients was suggested to be sorted either alphabetically or chronologically; for the chronological order, the newest patients would be placed at the top.

Figure 33 Individual patient's view.

Task 2: Add General Practitioner into system

To solve the task, the administrative functionality of the GUI had to be accessed and *health care professional* be chosen as action for data input. All participants needed help to solve the task, one participant needing up to nine attempts. Task was scored as *difficult* and finding administrative functionality was tagged as *problematic*. 2 system errors were identified relating to repetition of information: 1) when clicking twice on *create*. In this case, patient was stored twice with the same name without notifying the user. 2) when typing a long email address the phone number field became invisible due to of lack of space.

Comments on navigation issues in the GUI: *Information input was ok, but the navigation was difficult. The task was difficult to solve, because the problem was navigation.*

Task 3: Add relative into system

To solve the task, the administrative functionalities of the GUI had to be accessed. Then, *health care professional* had to be chosen and change the role to *relative* for data input. 4 participants successfully solved the task without help; one of them tried few times before succeeding and another asked for help. 3 participants scored the task as *eas*y, 1 as *medium* and 1 as *difficult*. Participants suggested being able to add different types of relatives such as *closest relative, friend, guardian* or *other*. They also

suggested that it would have been preferable to be able to make a priority list of whom to contact in case of multiple relatives registered. Comments related to understanding how the roles were interpreted in CIS: *I found health care professional but did not understand that it was the right one, and the role had to be changed to relative. It is difficult when I have not seen the system before… Difficult to navigate, the input was easy.*

Task 4: Navigate to patient's view in the system

To find the new patient's view, firstly the icon *home* had to be selected and then selecting patient's name in order to enter patient's view. 4 participants successfully solved the task and one needed help after two incorrect actions.

Task 5: Add a task into the Patient's View

It was necessary to click on '+' symbol in the section *Tasks* to solve the task. 3 participants successfully solved the task, although 2 needed help: *I did not see the heading Tasks… I did not see tasks, did not understand to watch on top*. 2 participants scored the task as *easy*, 1 as *medium* and 1 as *difficult*. One word regarding who to perform an action was misunderstood and that led to confusion.

Task 6: Upload a referral into the system

Participant had to click the '+' symbol in *Documents* section and upload a document to solve the task. 2 participants successfully solved the task and 3 needed help. 2 participants evaluated the task *as easy*, 1 as *medium* and 1 as *difficult*.

Task 7: Upload a dementia assessment report into the system

The task was similarly solved as task 6, adding a document and uploading it. All participants successfully solved the task and graded it as *easy*: *Now I have tried this once before*.

Task 8: Upload the clock-test into the system

The task was solved similarly as task 6 and 7, adding a document and uploading it. All participants successfully solved the task and graded it as *easy*: *Now I start to understand how the program is organised*.

Task 9: Write a journal note into the just-registered patient's view

Participants had to click on the '+' symbol in the *Journal note* section to solve the task. All 5 participants successfully solved the task and graded it as *easy*.

B. System Usability Scale

The scores of the SUS questionnaire are presented in Table 1. The colour visualisation scheme presented is a modified version of [22] and [23]. Overall, the mean of the satisfaction ratings were on the range of *Agree*, *Strongly Agree* or *Neutral* for the majority of answers to the positively enunciated questions and in the range of *Disagree*, *Strongly Disagree* or *Neutral* for the majority of answers for the negatively enunciated questions.

Table 7 Responses of System Usability Scale (SUS)

Question	P1	P2	P3	P4	P5	M	SD
Q1	3	3	4	4	3	3.4	0.5
Q2	4	2	1	3	3	2.6	1.1
Q3	3	4	4	3	3	3.4	0.5
Q4	1	2	1	3	1	1.6	0.9
Q5	4	4	5	4	3	4.0	0.7
Q6	2	2	1	3	2	2.0	0.7
Q7	5	4	4	4	4	4.2	0.4
Q8	2	5	1	2	2	2.4	1.5
Q9	3	4	3	3	3	3.2	0.4
Q10	2	4	1	3	2	2.4	1.1

P*i* = participant *i;* M = mean; SD = Standard Deviation

■ (green)	Positive Response: Agree or Strongly Agree for positive questions; Disagree or Strongly Disagree for negative questions
■ (yellow)	Neutral: neither Agree nor Disagree
■ (red)	Negative Response: Agree or Strongly Agree for negative questions; Disagree or Strongly Disagree for positive questions

C. Post-test Group Interviews

The group interview results are presented in four categories.

1) Test scenario and procedure

The test participants defined the test experience as exciting and similar to the earlier tests. They found the questions after each task to grade the difficulty of the task accomplishment a bit hard to answer.

A participant commented on it: *I did not find everything, but still I don't think this was a complicated program. When you receive help once, then you learn how to do it and it is easier next time. If I had used longer time during each task I would have probably found it by myself*. One participant had not participated earlier and commented: *This*

system was completely new for me and it was unusual to be in the test situation, with one person sitting beside you.

2) User training

Participants suggested that having user training in advance would have been useful, and, in addition, would help them to provide more feedback. They commented that in their daily basis, they have user training when new functions and updates are implemented in the systems. One participant commented: *If I had been allowed to sit 10 minutes by myself to explore the system, the test would have been much easier.* […] *If we had been instructed in advance about the three main elements, I would have understood the structure earlier.*

3) Navigation

Participants found the data input for all tasks *easy* with good visibility of the displayed information. Participants found difficult how to access patient's journal from the administrative section (task 4). In this line, one participant commented: *It was not obvious; I would not have found it without help.* In general, they suggested as few clicks as possible, but some information could be displayed only in request (e.g., email address, contact information to GP) using icons.

4) Municipal EHR versus new collaborative information system

The IMC dementia team used a municipal electronic health record (EHR) system in their daily work. Even though participants were positive earlier in the research project towards the new collaborative information system, in this evaluation they expressed some scepticism about the co-existence of the new system with the ones previously used by the team: *I would find it a bit cumbersome to have two different systems, one system for the inter-municipal dementia team, and one for everything else.* […] *I would not like to change the system we have now, since we would have two systems to use. I don't think that is smart and would be more difficult to work.*

One of the reasons argued was that the initial circumstances when the project started have changed throughout the project period. One participant commented: *We get new tasks all the time and that demands more from us. We need to ease the working processes as much as possible. We should not have too many programs to use. I am afraid that this system will cause double work, instead of having one single system. Four years ago, I was much more positive, because then, we did not have e-messages or access to EHR systems in other municipalities. Some of the problems we had at that time are now solved. The implementation of e-message (1.5 years ago) did*

revolutionise our daily work. The dementia report is now sent as e-message. In addition, we are now used to the tablet and to take a picture of the clock test to upload into the municipality EHR, instead of scanning as we did earlier. So there are fewer papers involved now.

Another participant stated: *Instead of implementing a new system, I would suggest a collaborative space in the* [municipal EHR]. *That would be helpful, with collaborative access for the inter-municipal dementia team to the patients undergoing dementia assessment.*

Another reason was that, when the project started, the IMC dementia team was recently established and they were inexperienced as a collaborative team. Since then, they have had over a 100 dementia assessments. Routines have been improved and less time is now used on each home visit and in the report writing. In addition, the laws regarding shared access to medical information across health organisations have been changed during the project period, and the nurse coordinator now had acquired legal access to the EHR systems in the involved municipalities (even though with separate username and passwords for each system to log in). Although the participants expressed a sceptical attitude towards implementation of the CIS, it was stated: *I like this new system and would find it helpful. In* [municipal EHR] *there are too many clicks and the information input is much more complicated.* Another participant commented: *Anyhow, I think this system would be useful. In* [municipal EHR], *I need to search a lot for information. I liked the visibility of the key information.*

Overall, participants positively commented the participation in the research project: *The participation in this project has been interesting.* They received the news that the outcome of the earlier phases of this project informed the creation of another IS for remote monitoring of COPD patients: *Nice to hear that what we have participated in has been used in another system, living its own life.* […] *So our contribution already has come to use.*

V. DISCUSSION

In this paper, the usability evaluation of a collaborative information system for an IMC dementia team has been presented. The aim of the IS was to provide a platform that supported the information flow and collaborative work across municipalities' borders. An effective IS requires a detailed analysis of end-users' needs, preferences and suggestions to inform system design. For this reason, a UCD process was

employed involving end-users in design and evaluation throughout the entire development cycle.

The two research questions presented at the beginning of the paper were answered based on the results of this study. About the RQ1, which asked about how to take into account user needs and requirements in the evaluation of a new IS, the study showed that the mixed methods approach efficiently considered user needs in the evaluation of the system. The approach was divided in three stages. The first stage was the evaluation in the usability laboratory, were participants performed a series of tasks based on the IMC dementia team workflow description provided by the users in earlier UCD workshops. This test enabled users to give useful feedback and first impressions about the GUI, functionality and interactions with the system. The second stage included a questionnaire (SUS) with 10 questions related to user satisfaction after task solving. It showed that, overall, participants were generally satisfied with the use of the system. The third stage included post-evaluation semi-structured group interviews that allowed participants to discuss the main findings with the research team and spontaneously make any suggestions. This stage gave the opportunity to participants to make comments and exchange impressions in a group, rather than individually, what presented the research team with new situations to learn from and which were not previously considered (e.g., slight reluctance to final implementation due to potential integration problems with coexisting systems and user work overload).

Several lessons were learned during the UCD process that can be transferable for the development of solutions for other clinical assessment workflows (RQ2). Firstly, the creation of clinical systems requires active and continuous involvement of the end-users in the design and evaluation of the solution. Secondly, the circumstances for the context of use may change over the study's time span. The nature of this research was linked to a Norwegian research project with the time duration of four years. The key requirements for the system that were gathered in a field study and several user workshops in an early project phase changed as the project evolved. For instance, new functionalities provided and included in the collaborative information system were, during the project time, also implemented in parallel in existing systems. At the end of the project, this resulted in a reduction of end-user interest in using the new system because they reported that improvements were already in place in existing systems. In addition, due to recent law changes, shared access across municipal borders was now allowed improving information flow and electronic communication. Thirdly, new system integration with existing systems is vital to, at least, not increase user workload. This is a logical consequence of the previous lesson.

There were some limitations associated to this study, such as the use of a simulated test environment and a reduced number of end-users. Firstly, although the laboratory setting realistically simulated the work environment and representative end-users carried out the tests for validation of the system, the study was performed in a simulated instead of real environment. This should be seen as a first step in the validation, complemented by a test of the system in real clinical settings through a field trial would be recommended before final implementation. Secondly, the reduced number of participants in the usability evaluation might be seen as an impediment of the applicability of the findings in a larger scale. However, the participants meaningfully represented the end-users of the system and in qualitative usability studies, a small number of participants can be sufficient for having valid results [24][25].

VI. CONCLUSION

This study was framed inside the project eHealth-extended Care Coordination, which aimed to develop a collaborative information system to be used in dementia assessment to improve the information flow between the members of an inter-municipal team. The system would ideally be the core for IMC health care teams, potentially adaptable for other clinical workflows. A UCD process was employed throughout the whole duration of the project, in which all the versions of the system were evaluated and tested. The usability evaluation, together with graphical assessment and group interviews of the system, identified refinements in order to improve the functionality and effectiveness of the solution before implementation. The SUS questionnaire showed a high score of user satisfaction.

The time span of the project, to which this study belonged, was four years. This period represents a substantial amount of time in clinical environments, usually associated with an increased demand for technological solutions that quickly and easily adapt to continuously evolving workflows, requirements and existing systems. Therefore, when implementing a new system, functionality should not duplicate the one from existing systems. In addition, there is a need of rapid development of new ICT capable of integration with other parallel activities and systems. These systems are typically used within organisations facing continuous changes as in the health care services.

The initial GUI of the CIS for dementia assessment established the foundation for the user-centred design and development of an information and management system

for remote telemedicine monitoring of COPD patients at home [26], which has been implemented in the FP7 EU project United4Health [27], currently being successfully used in 3 inter-municipal telemedicine centers in Norway.

Future research would include a full implementation of the system, with its corresponding evaluation in the field from a usability and operational perspective. In addition, a comparison of the new and the already existing system would provide useful results.

REFERENCES

[1]   Norwegian Ministry of Health and Care Services, 2008-2009. Report No. 47. The Coordination Reform, Proper treatment – at the right place and right time. [cited 2015 Dec 10]. Available from: https://www.regjeringen.no/contentassets/d4f0e16ad32e4bbd8d8ab5c21445a5d c/no/pdfs/stm200820090047000dddpdfs.pdf

[2]   Smaradottir B., Holen-Rabbersvik, E., Thygesen, E., Fensli, R., Martinez, S., 2015b. User-centred design and usability evaluation of the user interface of a collaborative information system for inter-municipal dementia team. Proceedings of International Conference on Health Informatics, Lisbon, Portugal January 12-15, 446-453. doi: 10.5220/0005222704460453, ISBN 978-989-758-068-0

[3]   Smaradottir B., Holen-Rabbersvik, E., Thygesen, E., Fensli, R., Martinez, S., 2014. Usability evaluation of electronic forms and collaborative assessment report in an inter-municipality health care team for dementia diagnose. Proceedings of Scandinavian Conference on Health Informatics, Grimstad, Norway, August 21-22, 45-54. ISSN(print): 1650-3686, ISSN(online): 1650-3740, ISBN: 978-91-7519-241-3

[4]   Gustafson, L., 1996. What is dementia? Acta Neurologica Scandinavica, Volume 94, Issue Supplement s168, 22–24. doi: 10.1111/j.1600-0404.1996.tb00367.x

[5]   Folstein, M. F., Folstein, S. E., McHugh, P. R., 1975. "Mini-mental state": A practical method for grading the cognitive state of patients for the clinician. Journal of Psychiatric Research, Vol 12, Issue 3, 189-198. doi:10.1016/0022-3956(75)90026-6

[6]   Norwegian Ministry of Health and Care Services, 2007. Dementiaplan 2015 (Demensplan 2015 "Den gode dagen" Delplan til omsorgsplan 2015). [cited 2015 Dec 10]. Available from: http://www.regjeringen.no/upload/HOD/Vedlegg/Omsorgsplan_2015/Demenspl an2015.pdf

[7]   Directorate of Health and National Expertise Service for Ageing and Health, 2011. Etablering og drift av Demensteam, Demensutredning i primærhelsetjenesten. [cited 2015 Dec 10]. Available from: http://www.aldringoghelse.no/ViewFile.aspx?ItemID=2824

[8]   Holen-Rabbersvik, E., Eikebrokk, T. R., Fensli, R. W., Thygesen, E., Slettebø, Å., 2013. Important challenges for coordination and inter-municipal cooperation in health care services: a Delphi study. BMC health services research, 13(1), 451. doi: 10.1186/1472-6963-13-451

[9]   Lazar, J. 2006. Web Usability- a user-centered design approach. Pearson Education. ISBN-10: 0321321359 ISBN-13: 9780321321350

[10]   Gulliksen, J., Göransson, B., Boivie, I., Blomkvist, S., Persson J., Cajander, Å., 2003. Key principles for user-centred systems design. Behaviour & Information Technology, 22:6, 397-409. doi:10.1080/01449290310001624329

[11]   Nielsen, J. 1993. Usability engineering, Elsevier. ISBN-13: 978-0125184069, ISBN-10: 0125184069

[12]   Chan, J., Shojania, K. G., Easty, A. C., Etchells, E. E., 2011. Does user-centred design affect the efficiency, usability and safety of CPOE order sets? Journal of the American Medical Informatics Association, 18, 276e281. doi:10.1136/amiajnl-2010-000026

[13]   Goldberg, L., Lide, B., Lowry, S., Massett, H. A., O'Connell, T., Preece, J., Quesenbery, W., Shneiderman, B., 2011. Usability and accessibility in consumer health informatics current trends and future challenges. American Journal of Preventive Medicine Vol 40, Issue 5, Supplement 2, S187–S197. doi:10.1016/j.amepre.2011.01.009

[14]   Jaspers, M. W., 2009. A comparison of usability methods for testing interactive health technologies: methodological aspects and empirical evidence. International Journal of Medical Informatics, 78(5), 340-353.

[15]   Kushniruk, A. W., Patel, V. L., 2004. Cognitive and usability engineering methods for the evaluation of clinical information systems. Journal of Biomedical Informatics, 37(1), 56-76.

[16]   Lazar, J., Feng, J. H., Hochheiser, H., 2010. Research methods in human-computer interaction, Chichester, United Kingdom, John Wiley & Sons, ISBN 978-0-470-72337-1

[17]   NHN, 2015: Norwegian Health Network. [cited 2015 Dec 10]. Available from: https://www.nhn.no/english/Pages/default.aspx

[18]   Gerdes, M., Smaradottir, B., Fensli, R., 2014. End-to-end infrastructure for usability evaluation of ehealth applications and services. Proceedings of Scandinavian Conference on Health Informatics, Grimstad, Norway, August 21-22, 53-59. ISSN(print): 1650-3686, ISSN(online): 1650-3740, ISBN: 978-91-7519-241-3

[19]   Ericsson, K. A., Simon, H. A., 1980. Verbal reports as data. Psychological Review, 87(3), 215-251.

[20]   Brooke, J., 1996. SUS: a quick and dirty usability scale. Usability Evaluation in Industry. London: Taylor & Francis, p.189-194.

[21]   NSD, 2015: Norwegian Social Science Data Services. [cited 2015 Dec 10]. Available from: http://www.nsd.uib.no/personvern/en/index.html

[22]   MacLellan, S., Muddimer, A., Peres S., C. 2012. The Effect of Experience on System Usability Scale Ratings. Journal of Usability Studies, Vol. 7, Issue 2, 56-67.

[23]   Bangor, A., Kortum, P., Miller, J., 2009. Determining What Individual SUS Scores Mean: Adding an Adjective Rating Scale. Journal of Usability Studies, Vol. 4, Issue 3, 114-123.

[24]   Nielsen, J., 1994. Estimating the number of subjects needed for a thinking aloud test. International Journal of Human-Computer Studies, 41(3), 385-397. doi:10.1006/ijhc.1994.1065

[25]   Nielsen J, Landauer TK. A mathematical model of the finding of usability problems. Proceedings of ACM INTERCHI Conference; 1993 Apr 24-29; Amsterdam: Netherlands: 206-13.

[26]   Smaradottir, B., Gerdes, M., Martinez, S., Fensli, R., 2015a. The EU-project
         United4Health: user-centred design of an information system for a Norwegian
         telemedicine service. Journal of Telemedicine and Telecare Nov 2015.
         doi:10.1177/1357633X15615048

[27]   United4Health 2015, European Commission Competitiveness Innovation
         Programme, ICT Programme to Support Policy. [cited 2015 Dec 10]. Available
         from: http://www.united4health.eu

Appendix H

Paper VII

eHealth-extended Care Coordination: Development of a Collaborative System for Inter-municipal Dementia Teams

A research project with a user-centered design approach

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Abstract—In Norway, a health reform was recently adopted to improve continuity of care. Services that were carried out in hospitals were transferred to municipalities. Small and medium size municipalities have established inter-municipal cooperation to provide specialized services across borders. The research project *eHealth-extended Care Coordination* studied the inter-municipal cooperation for assessment of dementia, identifying a need for improved communication and coordination. This paper presents the development process of a collaborative information system for dementia assessment using a user-centered design approach. Mixed methods, such as observations, semi-structured interviews and questionnaire, were used for data collection. The results showed that end-user involvement usefully informed the development. The information system effectively supported collaborative work and shared access to information for the inter-municipal team.

Keywords—User-centered Design; Usability; Inter-municipal Cooperation; Dementia Assessment; Health Information System

I. Introduction

Health care services are provided by organisations where information systems play an important role for coordination and collaboration within and between their members. In Norway, the health authorities addressed the need for continuity of care for citizens across the established organisational borders of health care services. The Coordination Reform [1] was adopted with the aim of enhancing adequate treatment at the right time and right place. As a consequence, services that traditionally were carried out by specialized health care services (e.g., hospitals) were then transferred to primary health care provided by municipalities. Due to the large number of small (less than 5000 inhabitants) or medium (between 5000 and 20000 inhabitants) size of municipalities in Norway, the challenge of providing specialized health care services to citizens by local institutions required structural and organisational changes [2]. In order to improve capacity, competence and quality, many municipalities have established inter-municipal cooperation (IMC) with specialized health care teams carrying out specialized health care services, such as assessment of the cognitive disorder dementia [3][4][5] in neighbor municipalities.

However, a recent Delphi study [6] with experts in coordination and IMC in health care services, reached consensus about the challenges concerning electronic communication. Specifically, the lack of available tools impeded the coordination and collaboration in health care services. This brought to light the need for available information and communication technologies (ICT) tools that support effective coordination and collaboration across organisational borders.

In this context, the research project eHealth-extended Care Coordination (Samhandling uten grenser) 2011-2015, focused on the communication and information flow of an inter-municipal dementia team based on the organisation of IMC. The project was divided into four phases, already presented in [7][8][9].

This paper reports from the overall user involvement throughout the entire project, where representative end-users participated during all its phases.

The two research questions (RQ1, RQ2) of this study were:

RQ1: How can an information system be developed taking into account the needs and requirements of the end-users for collaborative access and information sharing in an inter-municipal team?

RQ2: What lessons and methodological procedures from this study are transferable and applicable to the development of technological solutions for other clinical assessment workflows?

II. RESEARCH BACKGROUND

Health care services are complex organisations by nature, integrated by multiple and diverse user groups interacting between them. ICT are present in the majority of processes carried out in clinical environments, such as communication between peers, storage and process of information, and support for decision-making procedures. Development of efficient information systems requires detailed analysis of end-user groups' needs, preferences and suggestions to inform system design. User-centered design (UCD) [10][11][12][13][14] involves end-users throughout the entire development cycle, describing the context of use and user requirements. These are all key elements for building and continuously using over time new information systems.

Through iterations in the development phases, users participate in usability evaluations and contribute to potential refinements. The aim of a usability evaluation [15][16][17] is to analyze user's interaction with the system and the user satisfaction. In addition, for adoption and user satisfaction purposes, the usability aspects of ICT are crucial for continuous and efficient use of technological solutions.

III. METHODS

Qualitative methods were used in the research project *eHealth-extended Care Coordination* for data collection and analysis. The data collection in the UCD process was executed from November 2011 until June 2015. The project had four phases, see Figure 34. The project phases comprised from the initial end-user requirement elicitation phase until final deployment of the collaborative information system. The new system was intended to provide a platform to facilitate the communication and information flow across municipal borders.
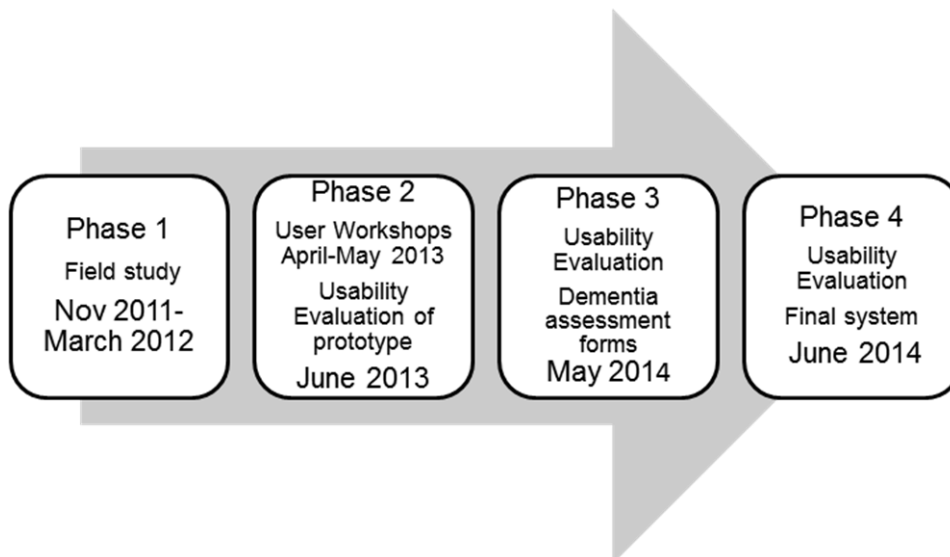
Figure 34 The four phases of the project eHealth-extended Care Coordination.

A. *Participant Selection*

In the participant selection, all participants had to work in inter-municipal dementia team based on IMC organisation. In total seven members of the inter-municipal dementia team participated in project phases two, three and four. They were five female and two male participants, aged 25-58, see Table 8 for the participant distribution. They reported an average of 12.7 years of experience using clinical systems and evaluated their computer skills as medium, except one with good skills.

Table 8 End-user Participation

| End-users n=7 | Project Phases | | | |
	Phase 2 User workshop n=2	*Phase 2 User test n=5*	*Phase 3 User test n=4*	*Phase 4 User test n=5*
Team Coordinator	x	x	x	x
Nurse 1	x	x	x	
Nurse 2		x	x	x
Nurse 3			x	x
Nurse 4				x
Physician		x		
Social Educator		x		x

B. The Research Team

The research team was composed of six people in total, see Table 9 for the participation in the different project phases. They had background on health informatics and human-computer interaction, all with working experience in health and technological environments.

Table 9 Researchers' Participation

Researchers n=6	Project Phases				
	Phase 1 Field study	*Phase 2 User workshop n=2*	*Phase 2 User test n=4*	*Phase 3 User test n=4*	*Phase 4 User test n=5*
Project leader and Professor		x	x		
Associate Professor	x		x	x	
Assistant Professor					x
Postdoctoral Research Fellow				x	x
PhD Research Fellow	x		x	x	x
PhD Research Fellow		x	x	x	x

C. First Project Phase

In the first project phase, a field study was conducted in an IMC consisting of four municipalities, focusing on the information flow and collaborative processes. Observations and interviews were made by the research team with the inter-municipal dementia team that was responsible for carrying out dementia assessment. The observations were annotated by the involved researchers and the interviews were audio-recorded.

D. Second Project Phase

In the second project phase, members of the inter-municipal dementia team participated in two user workshops, in order to define end-users' needs, preferences and suggestions for the development of a functional prototype for a collaborative information system. The user workshops were held to understand the context of use and the workflow for dementia assessment in inter-municipal dementia team. In addition, these workshops allowed collecting user requirements for the development of the initial functional prototype. When the first version of the interactive web-based prototype had been developed, a usability evaluation took place with five members of

the inter-municipal dementia team. The evaluation was performed in the Usability Laboratory of the Centre for eHealth and Healthcare Technology at the University of Agder, Norway. The details of the technical infrastructure are further described in [18]. The usability evaluation followed a Think Aloud (TA) protocol [15][16][17][19] and entailed several tasks. To score user satisfaction, the questionnaire System Usability Scale (SUS) [20] was individually filled in by each participant. Group interviews were made after the evaluations in order to qualitatively complete the feedback. The user workshops and usability evaluation were audio-video recorded. The group interviews were annotated by the research team.

E. Third Project Phase

In the third project phase, electronic dementia assessment forms, (e.g., Mini-Mental State [21]) to be used in home visits by the inter-municipal dementia team, were developed based on user needs identified in the user workshops of previous phase. A usability evaluation of the electronic dementia assessment forms was made together with test of a videoconference solution for shared documents visualization in the Usability Laboratory. The videoconference solution was used to test collaborative dementia assessment report writing with participants located in different municipalities. The usability evaluation had four test participants and used a TA protocol. After the evaluations, group interviews were made to complete the feedback. The usability evaluations and group interviews were audio-video recorded.

F. Fourth Project Phase

In the fourth project phase, the final version of the collaborative information system was developed by a project partner (Devoteam AS in Grimstad, Norway) and deployed within the secured Norwegian Health Network (NHN) [22]. A usability evaluation with a TA protocol was carried out in the Usability Laboratory together with five members of the inter-municipal dementia team in order to validate whether the system accomplished acceptable levels of effectiveness, efficiency and satisfaction. After each task, participants were asked to score the task solving. After all the tasks were solved, the SUS questionnaire was individually filled in. Semi-structured post-test group interviews were made. The usability evaluations and group interviews were audio-video recorded.

G. Data Collection

All three usability evaluations and the group interviews in phases three and four were recorded from two independent cameras (one fixed, another portable). The audio-

visual data from the cameras and a screen capture tool (used in usability evaluations) were merged into one single video file using the software Wirecast v.4.3.1 [23]. The purpose was to ease the data analysis, having just one file including multiple video perspectives with a single audio channel. The recordings (.mov video file format) were imported into QSR NVIVO 10 [24]. The audio- and video recordings were transcribed verbatim by members of the research team and the transcripts were coded into categories for a qualitative content analysis [17].

H. Ethical Considerations

This study was approved by Norwegian Social Science Data Services [25] with the project numbers: 28027 and 37920. All participants received oral and written information about the project and confidential treatment of the collected data. All participants signed a consent form and the participation was voluntary. Participants were aware that they could withdraw at any time without reason. In this case, their data would be consequently destroyed.

IV.   RESULTS

The results are presented following the four phases of the UCD process.

A. First Project Phase

The field study identified that the inter-municipal dementia team faced challenges such as limited information flow across the borders of the municipalities and interoperability problems between different information systems. Due to legislation, the dementia team members did not have access to information systems outside their own municipality. One of the main conclusions of the field study was the need for a collaborative information system with shared access between the municipalities to improve the information flow and coordination within the inter-municipal dementia team.

B. Second Project Phase

In the workshop, the end-users described their current clinical workflow of dementia assessment and how the user interface (UI) of a collaborative information system would best fit into their work processes. The outcome of the workshops creatively informed the design of the working interactive prototype, which was qualitatively usability tested. The results of the usability test identified several graphical issues, but it showed that overall the UI effectively and efficiently supported the work processes of the inter-municipal dementia team. The SUS questionnaire

scores indicated a sufficient level of satisfaction among the end-users. In the group interviews, the users suggested to make individual usability evaluation, but also a group evaluation in order to analyze the system from a multi-personal perspective. They also suggested having in advance the opportunity to get familiar with the system through self-exploration before the usability test. This would save time to test participants and would allow them to provide more reflective comments during the post-test interviews.

C. Third Project Phase

The usability evaluation of the electronic dementia assessment forms showed that the digital version of the forms would help to reduce the paper load in the dementia assessment process. In addition, it would allow members of the team to have multiple accesses to the forms for retrospective amendments and reviews. The test of videoconference with shared document visualization between two municipalities was reported to be an effective and satisfactory tool to cooperatively work on the final report of the assessment between the members of the dementia team.

D. Fourth Project Phase

Based on the outcome of project previous phases, the final version of the collaborative information system was developed. The findings in the usability evaluation of the final system identified graphical issues that needed refinements. All participants successfully solved all the tasks during the tests. The scores of the SUS questionnaire showed sufficient level of user satisfaction. In the group interviews, participants positively evaluated the participation in the UCD process. They found the test situation interesting, but not easy to score the difficulty of task accomplishment. For further evaluations, they suggested user training in advance or some time for self-exploration, in order to get familiar with the system and be able to provide more reflective feedback. Even though some tasks were not straight forward to solve, they evaluated the system as easy to navigate within. Due to their experience with other clinical systems, they recommended to have as few actions (e.g., mouse clicks) as possible while interacting with the system.

V. DISCUSSION

This paper has presented the UCD process for the development of a collaborative information system for an inter-municipal dementia team. Health care information systems typically involve multiple users in number and type. The involvement of those

groups of end-users in the design of a new technical system is crucial to understand the clinical workflow where the solution will be deployed, its context of use and the interactions involved. The two research questions (RQs) formulated at the beginning of this paper are answered below based on the results from the study.

About the RQ1, which asked about how to take into account user needs and requirements in the development of a new collaborative information system, the involvement of end-users was the key in the development of the clinical system. The UCD approach divided the study into different phases. The first project phase consisted of a field trial, including observations and interviews to analyze the information flow and work processes in a dementia assessment. This gave the research team an in-depth understanding of the clinical workflow, allowing identifying the need for a collaborative information system that supported inter-municipal work. In the second phase of the project, the workshops with end-users provided an insight in the dementia assessment workflow. It drew a clear picture of how users would have liked to interact with the new system and integrate the new tool in their existing work processes. Users' suggestions about the UI practically informed the graphical UI design. The usability evaluation, questionnaire and interviews enabled the users to give useful feedback and first impressions about the graphical UI, functionality and interactions with the system. In the third project phase, the usability evaluation of electronic dementia assessment forms and videoconference enabled the users to test their own suggestions from earlier phases regarding an improved workflow. The fourth project phase that included usability evaluation, a questionnaire filling and interviews regarding the final version of the collaborative information system, enabled the users to provide feedback about the graphical UI, functionality and user interactions. Overall, the iterative mixed methods approach efficiently took into account and considered user needs in the development of the system, and in line with previous research findings, elaborating on the importance of involving end-users throughout the development process [26][27].

About the RQ2 that asked about lessons and methodological procedures learned during the UCD process that could be transferable for the development of systems other clinical assessment workflows. Firstly, the development of health care information systems requires active and continuous involvement of the end-users in the design and evaluation of the solution. The mixed methods research approach was a sufficient model for the data collection in all the phases of the UCD process. Secondly, a lesson learned, was that the circumstances for the context of use and key requirements for the system gathered in an early project phase may change as the

project evolves due to rapid development of other technologies and applications. A long time for system development should be avoided. Thirdly, new systems should support already existing work processes and integration of new systems with existing ones is vital in order not to increase the users' workload, which impacts on user acceptance.

The research study of the UCD process also had limitations such as a reduced number of end-users and user-scenarios tested in a simulated environment. However, the simulated test environment allowed creating highly realistic scenarios under controlled conditions and the test participants meaningfully represented the end-users of the system. In addition, in qualitative usability studies, a small number of participants can be sufficient for having valid results [28][29].

VI. CONCLUSION

This study was framed within the research project eHealth-extended Care Coordination, which aimed to study the communication and information flow in an inter-municipal dementia team. In order to provide a platform for communication and shared access to information, a collaborative information system was developed in order to improve the information flow between the members of an inter-municipal dementia team. This study focused on the user involvement in a UCD process, which included end-users' needs, suggestions and preferences in the design and evaluation of an information system. Positive results were reported after user evaluations regarding ease of use and user satisfaction of the collaborative information system. The user involvement in the development was the key to fully develop an information system suitable for collaborative work in inter-municipal teams.

In terms of future work, it is proposed to address research on integration of other clinical inter-municipal teams to the collaborative information system, with added decision support in the application.

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REFERENCES

[1]   Norwegian Ministry of Health and Care Services, "The Coordination Reform, Proper treatment – at the right place and right time," Report No. 47 (2008-2009) to the Storting. [retrieved: November, 2015]. Available from: https://www.regjeringen.no/contentassets/d4f0e16ad32e4bbd8d8ab5c21445a5dc/no/pdfs/stm200820090047000dddpdfs.pdf

[2]   The Norwegian Association of Local and Regional Authorities (KS). The organisation of muncipalities (Kommunesektorens organisasjon, ARTE-Arbeidskraft og teknologi i KS 2009). 2009 Feb . [retrieved: November, 2015]. Available from: http://www.ks.no/PageFiles/43061/ARTErapport.pdf

[3]   Dementiaplan, 2015: Norwegian Ministry of Health and Care Services. 2007. Demensplan 2015 "den gode dagen" Delplan til omsorgsplan 2015. [retrieved: November, 2015]. Available from: http://www.regjeringen.no/upload/HOD/Vedlegg/Omsorgsplan_2015/Demensplan2015.pdf

[4]   Directorate of Health and National Expertise Service for Ageing and Health 2011. Etablering og drift av Demensteam, Demensutredning i primærhelsetjenesten. [retrieved: November, 2015]. Available from: http://www.aldringoghelse.no/ViewFile.aspx?ItemID=2824

[5]   Gustafson, L, "What is dementia?," Acta Neurologica Scandinavica, Vol 94, Issue Supplement s168, 22–24, 1996, doi:10.1111/j.1600-0404.1996.tb00367.x

[6]   E. Holen-Rabbersvik, T.R. Eikebrokk., R.W. Fensli, E. Thygesen, and Å. Slettebø, "Important challenges for coordination and inter-municipal cooperation in health care services: a Delphi study," BMC Health Serv Res, 13(1), 451. doi:10.1186/1472-6963-13-451

[7]   B. Smaradottir, E. Holen-Rabbersvik, E. Thygesen, R. Fensli, and S. Martinez,. "User-centred design and usability evaluation of the user interface of a collaborative information system for inter-municipal dementia team," Proceedings of The 8th International Conference on Health Informatics (HealthInf 2015), Jan 2015, pp. 446-453, ISBN 978-989-758-068-0, doi:10.5220/0005222704460453

[8]   B. Smaradottir, E. Holen-Rabbersvik, E. Thygesen, R. Fensli, and S. Martinez, "Usability evaluation of electronic forms and collaborative assessment report in an inter-municipality health care team for dementia diagnose,". Proceedings of Scandinavian Conference on Health Informatics (SHI 2014), Aug 2014, pp, 45-

54, ISSN(print): 1650-3686, ISSN(online): 1650-3740, ISBN: 978-91-7519-241-3

[9]   B. Smaradottir, S. Martinez, E. Holen-Rabbersvik, T. Vatnøy, and R. Fensli, "Usability evaluation of a collaborative health information system- lessons from a user-centred design process," in press.

[10]   K. Vredenburg, J. Mao, P.W. Smith, and T.Carey, "A Survey of User-Centered Design Practice," Proceedings of Conference on Human Factors in Computing Systems (SIGCHI 2002), p. 471-478, doi:10.1145/503376.503460

[11]   J. Gulliksen, B. Göransson, I. Boivie, S. Blomkvist, J. Persson, and Å. Cajander, "Key principles for user-centred systems design," Behav Inf Technol, 22:6, pp. 397-409, 2003, doi:10.1080/01449290310001624329

[12]   C.I. Martínez-Alcalá, M. Muñoz, and J. Monguet-Fierro, "Design and Customization of Telemedicine Systems," Comput Math Methods Med vol. 2013; Article ID 618025, doi:10.1155/2013/618025

[13]   L. Goldberg, B. Lide, S. Lowry, H.A. Massett, T. O'Connell, J. Preece, W. Quesenbery, and B. Shneiderman, "Usability and Accessibility in Consumer Health Informatics Current Trends and Future Challenges," Am J Prev Med Vol 40, Issue 5, Supplement 2, pp. S187–S197, May 2011, doi:10.1016/j.amepre.2011.01.009

[14]   J. Lazar, Web Usability- a User-centered Design Approach. Pearson Education. 2006, ISBN-10: 0321321359, ISBN-13: 9780321321350

[15]   M.W Jaspers, "A comparison of usability methods for testing interactive health technologies: methodological aspects and empirical evidence," Int J Med Inform, vol. 78(5), pp. 340-353, 2009, doi:10.1016/j.ijmedinf.2008.10.002

[16]   A.W. Kushniruk and W.L. Patel, "Cognitive and usability engineering methods for the evaluation of clinical information systems," J Biomed Inform, vol. 37, pp. 56-76, Feb 2004, doi:10.1016/j.jbi.2004.01.003

[17]   J. Lazar, J.H. Feng, and H. Hochheiser. Research Methods in Human-computer Interaction. Chichester, United Kingdom, John Wiley & Sons, 2010, ISBN 978-0-470-72337-1

[18]   M. Gerdes, B. Smaradottir, and R. Fensli, "End-to-end infrastructure for usability evaluation of eHealth applications and services," Proceedings of Scandinavian Conference on Health Informatics (SHI 2014), Aug 2014, pp. 53-59, ISSN(print): 1650-3686, ISSN(online): 1650-3740, ISBN: 978-91-7519-241-3

[19]   K.A. Ericsson and H.A. Simon. "Verbal reports as data," Psychol Rev 87, pp. 215-251, 1980.

[20]   J. Brooke, "SUS: a quick and dirty usability scale," In P. W. Jordan, B. Thomas, B. A. Weerdmeester & I. L. McLelland, Eds. Usability Evaluation in Industry, pp. 189-194. London: Taylor & Francis, 1996.

[21]   M.F Folstein,. S.E Folstein, and P.R. McHugh, "Mini-mental state: A practical method for grading the cognitive state of patients for the clinician," J Psychiatr Res, Vol 12, Issue 3, 189-198, 1975, doi:10.1016/0022-3956(75)90026-6

[22]   Norwegian Health Network. [retrieved: November, 2015]. Available from: https://www.nhn.no/english/Pages/default.aspx

[23]   Wirecast, [retrieved: November, 2015]. Available from: http://www.telestream.net/wirecast/overview.htm

[24]   QSR NVIVO v10. [retrieved: September, 2015]. Available from: http://www.qsrinternational.com/products_nvivo.aspx

[25]   Norwegian Social Science Data Services, [retrieved: November, 2015]. Available from: http://www.nsd.uib.no/personvern/en/index.html

[26]   M. Kyng and J. Grennbaum, Design at work: Cooperative design of computer systems. Lawrence Erlbaum Associated, 1991, ISBN 0-8058-611-3

[27]   E.L. Drazen, J.B. Metzger, J.L. Ritter, and M.K. Schneider, Patient Care Information Systems, Computers in Health Care Series, Springer-Verlag, New York, 1995, ISBN 978-1-4612-6914-4, doi:10.1007/978-1-4612-0829-7

[28]   J. Nielsen and T.K. Landauer, "A mathematical model of the finding of usability problems", Proceedings of Conference on Human factors in computing systems (ACM INTERCHI'93), May 1993, pp. 206-213, doi: 10.1145/169059.169166

[29]   J. Nielsen. "Estimating the number of subjects needed for a thinking aloud test", Int J Hum-Comput St, 41(3), 385-397, 1994, doi:10.1006/ijhc.1994.1065

[30]   Regional Research Fund Agder, [retrieved: November, 2015]. Available from: http://www.regionaleforskningsfond.no/prognett-rff-hovedside/RFF_in_English/1253976860326

Appendix I

Paper VIII

Title:	End-to-End Infrastructure for Usability Evaluation of eHealth Applications and Services
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End-to-End Infrastructure for Usability Evaluation of eHealth Applications and Services

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Abstract—**eHealth technologies are widely used in collaborative health care services involving multiple different user groups. A very important aspect of the design and development of such applications is the ease-of-use and user-friendliness of the user interface for the end-users. Usability testing is performed in a simulation or real environment to ensure that the system is adapted to the specific needs of the different end-users and to evaluate the interaction between users and system.**

The aim of this paper is to present an infrastructure for end-to-end usability testing of eHealth technologies in a controlled environment simulating both the Point-of-Care and the Health and Care Service Provider. The primary focus is on the requirements and technical aspects of the test infrastructure itself, but on top of that also a trial project is presented where the proposed usability testing infrastructure has been used and validated.

Keywords—eHealth; health informatics; usability evaluation; end-to-end test infrastructure; point-of-care; user centered design

I. INTRODUCTION

eHealth applications and services are designed for the exchange of information between different collaborating user groups of the same system, utilizing certain information and communication technologies (ICT) [1].

The reference system that sets the framework for the usability evaluation system discussed in this paper is illustrated in Figure 35. One of the major aspects is the collaboration between a patient in his point-of-care environment (e.g. his private home) and certain health and care service providers (as e.g. a specialized nurse in a telemedicine central, a general practitioner, or a medical specialist in a hospital).

Collaboration means in this context, that certain information about the medical and health status of the patient as well as about his current living context is made available to the health and care service providers via dedicated eHealth installations, applications and services. For that the information has to be transmitted through communication and health information system (HIS) infrastructures by means of information and communication technology (ICT). In turn this information shall enable the health and care service providers to provide optimal health and care support to the patient in an efficient and cost effective manner. For that the same eHealth infrastructure is utilized to get in contact with the patient, and to assist him with information, general support, and with dedicated treatment recommendations as e.g. medication changes.
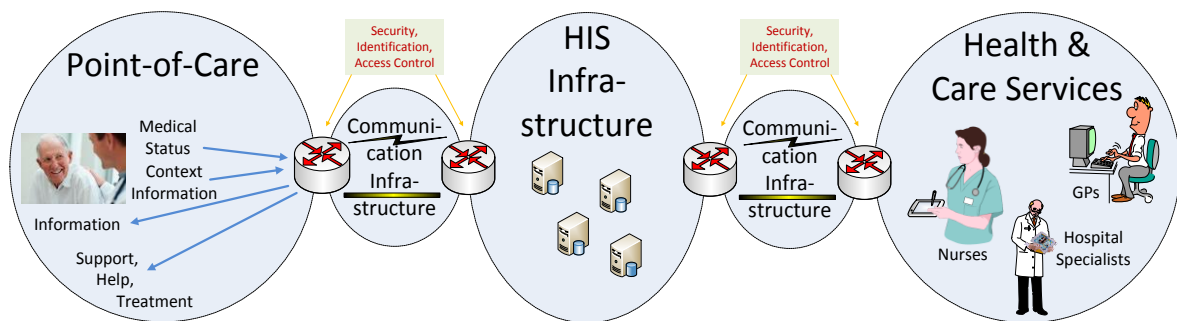
Figure 35: Reference System for Tele-Health and Tele-Care Services.

The most important requirement on such a collaborative eHealth system should be the *usability* of the system for all involved user groups. In order to support the patient to derive the health and care related information required by the staff in the telemedical central, the design of all involved eHealth devices and user interfaces of applications have for example to consider physical and mental limitations of the

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patient. On the other side it has to be taken into account that health and care personnel have to take care for many individual patients. Consequently, the design of the user interfaces of the eHealth services used by the health and care service providers have to consider for example an intuitive and optimal presentation of relevant and important information.

In this paper we present a usability test infrastructure addressing this utmost important requirement. It consists of an environment simulating both a point-of-care and a typical health and care service provider, and it allows performing end-to-end usability tests of applications and services for all involved user groups through a controlled health and care information system. The primary scope is on the technical aspects of the usability test infrastructure, from a health informatics and ICT perspective.

Following this introduction, a rough overview of the *state-of-the-art* of related usability testing infrastructures will be given. The section on *end-to-end infrastructure for usability evaluation* discusses first the identified requirements on the targeted usability testing infrastructure, and presents then the details of the different parts of the proposed infrastructure. Subsequently a trial system for the realization and verification of the proposed usability testing infrastructure is presented. That system was developed under the umbrella of the 3-year European funded project United4Health [2] for the usability evaluation of eHealth technologies.

II. STATE-OF-THE-ART

eHealth applications and services have multiple user groups, and there is a need for systems supporting collaborative work across organisational borders of health care services. However, the development of such systems is a complex process.
The overall objective of usability evaluation is to improve both the interaction design between all involved users as well as the user interfaces of eHealth applications and services [3-5].

User-centered design methods, where real end-users are involved in all steps of the development of eHealth applications and services, are used to collect users' needs and to understand the context of use, in particular the clinical workflows and their impact of on the requirements on support applications and service. Applying user-centered design methods is the basis for the adaption of the eHealth applications and services to the users' needs [3, 6, 7].

The main benefits of systems with a high level of usability are increased productivity, reduced errors, less needs for user training and support, and an overall improved acceptance by the users [5].

With the focus on bringing a human-centered perspective to the formulation of system requirements and the configuration of effective user interfaces, Samaras presents a systems engineering method providing a framework for incorporating human factors (ergonomics) knowledge and integrating ergonomists in the interdisciplinary development of health information systems [8]. Validation and verification testing is an essential part of the presented iterative systems engineering lifecycle model.

User-based evaluation means that users participate in the evaluation. They are asked to do typical tasks or to explore a system, while being observed and recorded. The goal is to identify flaws that cause errors or difficulties in the use of the system. Measurements are performed on time for solving a task, on numbers of completed tasks, and on numbers and types of errors. The aim is to provide a better understanding of the interaction between the user groups and the graphical user interfaces provided by the collaborative eHealth services [3].

Usability evaluation can be performed in laboratory settings or natural environments such as the home of the patient or the work place of a health or care service provider. The strength of a laboratory setting is the controlled environment for the test, but it can also influence the behavior of the test participants. The unfamiliar environment and the knowledge of being observed and recorded can impact on the problem solving, which is also known as the Hawthorne Effect [7]. Natural settings are often easiest for test participants, but can be a challenge for the research team.

Usability evaluation can usually not be performed in real clinical environments because of the legal, ethical and privacy regulations to protect patients. Therefore simulation of the health care services environment is important to create a realistic test scenario for the user groups [9, 10].

In their paper on *Televaluation* Kushniruk et al [11] describe an integrated approach for distance evaluation for assessing Web-based clinical information systems. The development of methods for assessing the effectiveness and usability of such systems is identified as a critical issue.

Kaufman et al [12] present an approach to usability evaluation of computer-based health care systems designed for patients use in their homes. Their approach incorporates a cognitive walkthrough usability evaluation and methods for usability testing that can be conducted in the patient's homes. Based on the usability evaluation,

they stress the importance of a multifaceted usability approach. However, an integrated usability testing framework is not presented.

The ALFA toolkit [13] offers support for the observation of computer mediated consultations of patients at a doctor. The Activity Log File Aggregation (ALFA) serves as basis to provide an analysable overview of the Clinician-Computer-Patient interactions.

III. END-TO-END USABILITY EVALUATION INFRASTRUCTURE

In this section we describe an end-to-end infrastructure for the usability testing of tele-health and tele-care services corresponding to the reference system introduced above. In the following the underlying requirements towards the usability testing infrastructure are discussed.

A. Requirements on the Usability Testing Infrastructure

The requirements on the infrastructure for the usability testing (including hardware components and software solutions) are determined by the main service scenarios that shall be tested.

B. Guiding Service Scenarios for Usability Tests

The usability test infrastructure shall support the evaluation of the following basic scenarios, which correspond to the reference architecture in Figure 35 for collaborative services.

1) Measurements of Medical Values

Patients at the point-of-care shall measure certain data about their medical status, using corresponding measurement devices (as Personal Medical Devices, PMD). The measurement process shall be supported by dedicated patient services and applications that provide a user interface with information and instructions showing the progress of the measurement scenario. This shall for example include information regarding the transmission of the measured data to the health and care service providers via the Health Information Services (HIS) infrastructure, and shall provide instructions in certain possible error cases.

The measurements shall in turn be made available to the health care professionals in their health and care services environment. Dedicated health care services and applications shall process and present the data in dedicated user interfaces that support an optimal and efficient support for the corresponding patient.

2) Questionnaires

The patient shall provide subjective information about his health status by answering specific questionnaires, which shall be made available to the health care specialists. Corresponding user interfaces of the patient services and applications shall support the patient through the process of answering the questions and with the delivery of the data through the HIS infrastructure to the health care professionals.

Dedicated computer services and applications for the health and care service providers shall then process the answers and present the (processed) questionnaire results to the health and care staff. The corresponding user interfaces shall support the utilization of the results for an optimal and most efficient patient support.

3) Video Consultation

The services and applications of both the patient and the health and care specialists shall include means to establish an audio-video communication session between each other. The user interface for the patient shall make it easy to establish an on-demand-video-call with their dedicated health and care service provider, and to accept an incoming audio-video-call. The user interface for the health and care service provider shall give optimal support to establish a video call with a selected patient (out of all patients the service provider has to take care for) following e.g. a timetable of appointments, or to initiate an immediate on-demand session as reaction on a critical situation determined by certain measurements or questionnaire outcomes.

C. Joint Testing of Collaborating User Groups

One of the main requirements of the usability testing and evaluation of interactive and collaborative services is the study of interactions and dependencies between different user groups of the same system. For that it must be possible to monitor and study different user groups independently from each other, while they use interactive and collaborative applications and services (via certain equipment and user interfaces). The main aspect of interaction and collaboration is that each user group has to react on actions that the respectively other user group is carrying out.

D. User-group Specific Tasks for Usability Tests

The usability test infrastructure shall allow studying arbitrary test cases of each user group involved in a collaborative service. For that it is required that specific usability test tasks can be specified independently for each involved user group.

E. Full Control over Specific Actions and Events

   The usability evaluation of certain specific test tasks for one individual user group might require full control of specific actions and reactions of the system they interact with. That means that the system should allow that the counter-part of the tested user group is either fully simulated (i.e. it carries out specific actions and re-actions according to a defined test process), or that the actions and re-actions are carried out by the usability test staff according to a defined test plan.

F. Further General Requirements

   A few further aspects have to be considered regarding the usability test configuration and the infrastructure and technologies for the observation of the test persons.

   1) The users of all user groups (i.e. both "test-patients" and "test-health-service-providers") shall be able to focus on the user interfaces of the applications and service components they typically interact with in order to utilize a certain function or service of the tested system. Hence, the distraction by any test-specific device or functionality (e.g. for observation purposes) should be minimized.

   2) The interaction of the user with the tested applications and services should be recorded during the tests in terms of video and audio, covering as many aspects as required for future evaluation.

IV. END-TO-END USABILITY TEST INFRASTRUCTURE

   Considering the requirements presented above, an end-to-end infrastructure for usability tests is proposed as illustrated in Figure 36.

   . The infrastructure is distributed over three interconnected rooms: a Point-of-Care Test Room, a Health- and Care Service Provider Test Room, and an Observation and Control Room.

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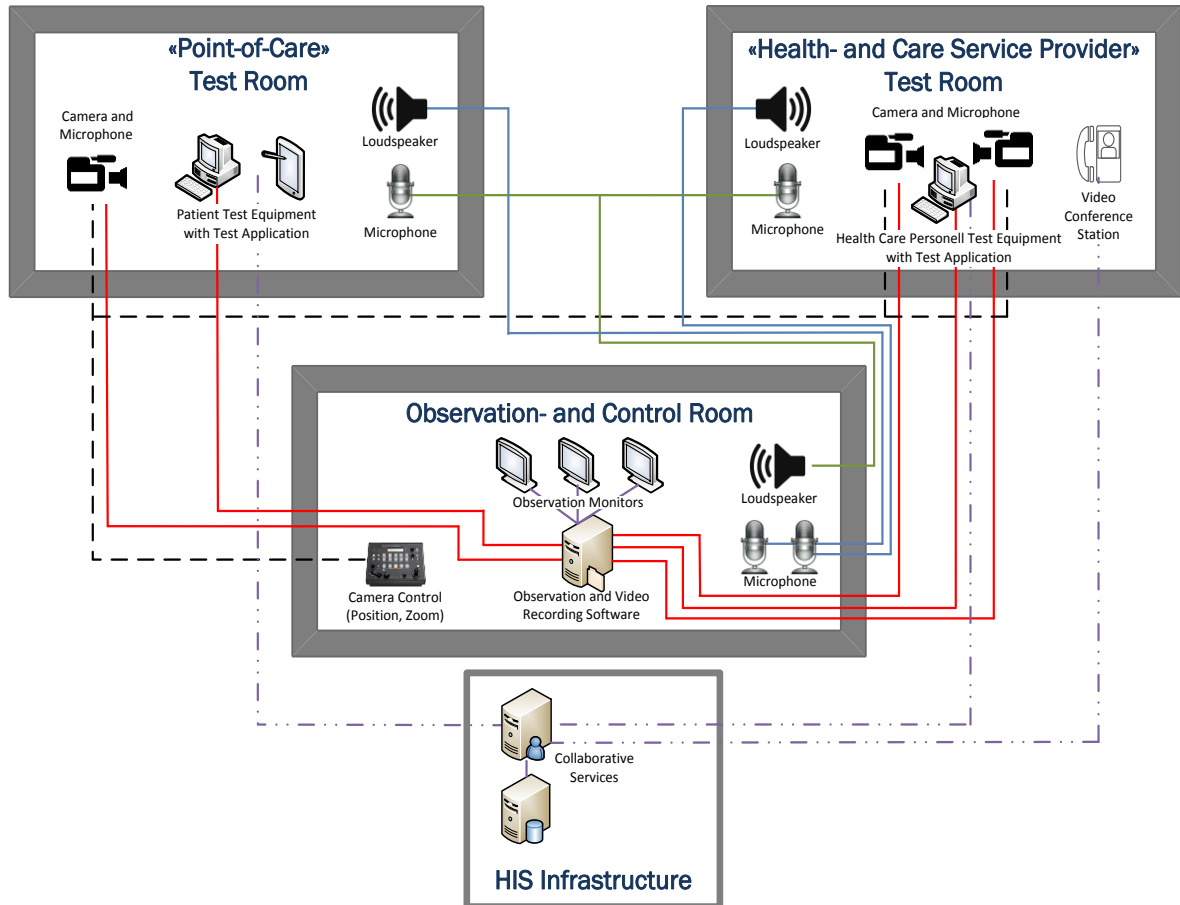
Figure 36: E2E Usability Test Infrastructure.

A. *Point-of-Care Test Room*

The Point-of-Care Test Room contains all equipment needed to carry out the usability tests of the user group representing the "patient".

The patient test equipment should be similar or optimally the same equipment a patient would use in a real point-of-care to carry out the activities that are subject of the usability tests. That equipment runs the corresponding point-of-care services and applications, which are connected to the collaborative services in the Health Information Services (HIS) infrastructure, and provide the user interfaces to be tested. Besides the services and applications that are subject to the usability tests, the test equipment might also contain certain software to support the observation during a test session (refer to description of the Health- and Care Service Provider Test Room below).

For the observation of the test person during the test session a video camera with microphone is installed. Both the video and audio signals are digitized using an embedded capture device, and transmitted to the Observation- and Control Room via

the LAN. The camera can be remotely controlled from the Observation- and Control Room in terms of observation direction and zoom.

Besides the test and observation equipment, there's also a simple microphone and loudspeaker installed in the Point-of-Care Test Room. This allows communicating between the test persons and the test staff in the Observation- and Control Room independently from an ongoing observation and recording session.

An example Point-of-Care Test Room setup as deployed at the University of Agder is shown in Figure 37.

Figure 37 Video Observation of Point-of-Care.

B. Health- and Care Service Provider Test Room

The Health and Care Service Provider Test Room is equipped for the usability tests with the user group representing the "health care specialists".

The health care personnel test equipment runs the test applications which are subject to the usability tests with health care professionals. The test applications communicate with the collaborative services in the HIS infrastructure via LAN, and provide the user interfaces that shall be assessed regarding usability. In order to support the observation and evaluation of the operation and usage of the test application by the test persons, the user interfaces are captured and streamed to the Observation- and Control Room via LAN, using a screen capturing and streaming software.

Besides the test equipment, the Health- and Care Service Provider Test Room also contains a dedicated video conference station, which is also subject to the usability tests of collaborative services with the point-of-care user group.

Similar to the Point-of-Care Test Room setup, a set of video cameras with microphones allow observing the whole test session. The video cameras can also be remotely controlled, and their audio and video signals are digitized and streamed over the LAN to the Observation- and Control Room.

Furthermore, a separate microphone and loudspeaker allow communication of the test persons with the test staff in the Control- and Observation Room independently from a test session.

In Figure 38 the Health- and Care Service Provider Test Room at the University of Agder can be seen as an example setup.

Figure 38: Health- and Care Service Provider Test Setup.

C. Observation and Control Room

The Observation- and Control Room contains the installations for the observation, control and recording of the usability test sessions.

Separate loudspeaker(s) and microphones allow communicating with the user groups in both the Point-of-Care Test Room and in the Health- and Care Service Provider Test Room. The devices are connected to embedded digitizing devices, which transmit and receive the digitized audio data over IP protocol. All data is sent through the common LAN infrastructure interconnecting all rooms of the test infrastructure.

The central component of the Observation- and Control Room is a dedicated PC running the observation- and video recording software. The PC receives the IP data from all digitized audio-video sources in the two test rooms, i.e. from the video

cameras with microphones, as well as from the streamed screen output from both the patient test equipment and the health care personnel test equipment. The observation and video recording software allows to observe selected sources (see left screen in Figure 39), and to record all sources simultaneously and synchronized in time on a data storage. Independently from that, selected (or even all) sources can be observed on separate screens. For that, embedded rendering devices, corresponding to the embedded digitizing devices in the test rooms, are connected to the screens, and are configured to receive a specific IP stream from the LAN.

Figure 39: Observation and Control Setup.

During the whole usability test session, the video cameras in the test rooms can be remotely controlled by the test staff regarding camera direction and zoom. Also the control signals are transmitted from the control device to the cameras via the LAN infrastructure.

V. REALIZATION OF END-TO-END TEST INFRASTRUCTURE

The end-to-end infrastructure as presented above has been realized in the usability test laboratory at the University of Agder, and has been used for user tests in the Norwegian part of the United4Health project [2].

A. The United4Health Project

The European project United4Health involves more than 20 countries and includes 20.000 patients with chronic diseases. The idea of using eHealth technology in United4Health is to support the collaboration across organisational borders, and to support the management of the health care information related to home-monitoring.

The Norwegian project focusses on collaborative eHealth technologies to support COPD-patients after hospital discharge. In the South-Norwegian region of Agder 200 patients are planned to be involved in a field trial.

The University of Agder was responsible for the development of the eHealth technology for home-monitoring of the COPD-patients. The development included the design of a tablet application to be used by the patients for home measurements of blood oxygen saturation (SpO2), pulse and a questionnaire to be filled out daily. Already early in the design and development process, the user groups were invited to participate in workshops about the interface design and functionality.

The hospital partner is responsible for the selection of patients for the field trial, and introduces home-monitoring to the included COPD-patients. The municipality partner has established a pilot telemedicine central run by specially trained nurses that use a dedicated health care information system for management of home measurements and daily follow-up of the COPD-patients. Video conversation with the patient is supported by a video conferencing system.

*B. Usability Evaluation in United4Health Project*

User-centered methods were applied in the development of the eHealth technology. The user groups participated in two usability evaluation sessions within two weeks. The tested eHealth applications were iteratively developed between the test sessions. The infrastructure for the point-of-care and the health- and care service provider was used and tested in the usability evaluation.

In the first test scenario, the health and care service provider test room represented the hospital, where the nurse and the COPD-patient prepared for home measurements (see Figure 40).

Figure 40: Introduction to eHealth technology.

In the next test scenario, the point-of-care test room represented the home of a COPD-patient. The test participant took the role of a recently discharged patient (from hospital) and interacted with the eHealth tablet technology to make home measurements and fill in a questionnaire (see Figure 41).
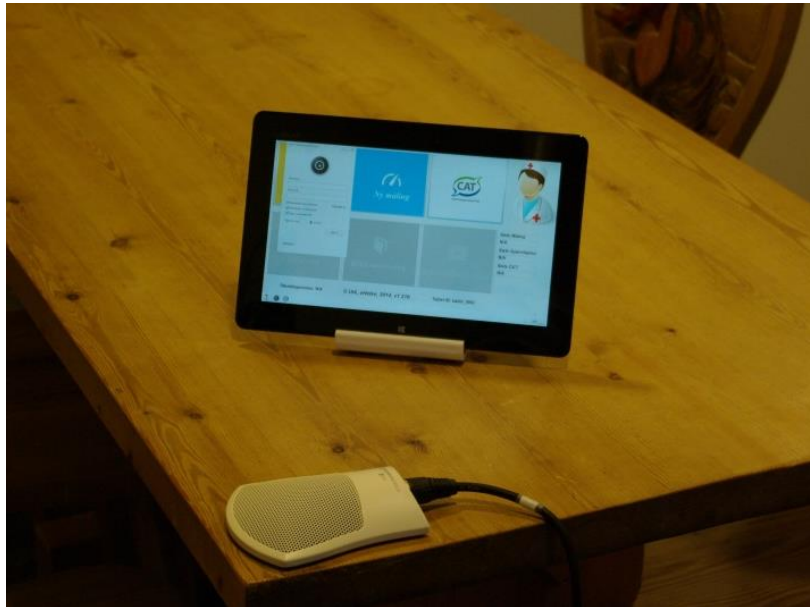
Figure 41: eHealth Technology at the Point-of-Care.

In the third test scenario, the nurse from the telemedical central interacted with the dedicated health information system to evaluate the home measurements and questionnaires from the COPD-patient (see Figure 42). A videoconference system was used for face-to-face communication between the COPD-patient in the point-of-care and the nurse in the health and care service provider test room.

Figure 42: Health- and Care Service Provider Test Setup.

During the three presented scenarios, all sources of the test infrastructure were shown simultaneously on one master screen (see Figure 39) in the observation and control room. Each source could also be followed on a separate big screen.

In parallel the audio- and video sources were recorded for later evaluation of various usability aspects.

In this usability evaluation of eHealth technology, the end to end test infrastructure simulated a scenario which was difficult to test in a real health care environment, and the outcome was relevant feed-back on functionality and usability for further system refinements.

VI. DISCUSSION

In this paper we have presented an end-to-end test infrastructure to carry out usability evaluations of eHealth technology.

Collaborative eHealth services involving multiple user-groups have to be tested and validated before being released and taken into regular operation. Due to ethical reasons, usability testing can usually not be done in real clinical environments [9, 10]. Therefore a simulated test environment with an end-to-end infrastructure contributes to a realistic scenario for the test users.

In user-centered design projects, there is a need to perform usability evaluation iteratively in each step of the development process. The iterative evaluation is enabled by a controlled environment, where the test team has full control over all steps of the test scenario, including tasks and actions of the test participants.

The trial project for the verification of the test infrastructure has limitations such as a limited number of tests and user groups. However, the test scenarios and the end-to-end test infrastructure provided a highly realistic simulation of real point-of-care (i.e. patient at home and patient in hospital) and health and care service provider (i.e. nurses at telemedical central) environments.

VII. CONCLUSION

eHealth technology is widely used by multiple user groups both at the point-of-care and at health and care service providers. Usability evaluation is essential in order to improve not only the interface design of the eHealth technology, but also the interactions between the devices and applications and the different user groups.

Our proposed end-to-end test infrastructure was validated through user tests within the trial project United4Health to carry out usability evaluations of collaborative

eHealth technologies involving multiple user groups. We found that the end-to-end test infrastructure provided the flexibility to simulate highly realistic environments.

As further research of the utilization of the end-to-end test infrastructure we suggest usability evaluation of mHealth solutions, and of security management technologies in eHealth services and applications. In those areas, there's a particular need to balance technical design and functionality against the usability.

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REFERENCES

[1]   Das A, Svanæs D. Human-centred methods in the design of an e-health solution for patients undergoing weight loss treatment. Int J Med Inform. 2013 11//;82(11):1075-91.

[2]   United4Health. European-funded project United4Health 2014. Available from: Web-site of umbrella project: http://www.united4health.eu/ (English); Web-site of Norwegian project: http://www.united4health.no/ (Norwegian)

[3]   Kushniruk AW, Patel VL. Cognitive and usability engineering methods for the evaluation of clinical information systems. J Biomed Inform. 2004;37(1):56-76.

[4]   Bastien JC. Usability testing: a review of some methodological and technical aspects of the method. Int J Med Inform. 2010;79(4):e18-e23.

[5]   Jaspers M. A comparison of usability methods for testing interactive health technologies: methodological aspects and empirical evidence. Int J Med Inform. 2009;78(5):340-53.

[6]   Rogers Y, Sharp H, Preece J. Interaction Design: Beyond Human-Computer Interaction: John Wiley & Sons; 2011.

[7]   Lazar J, Feng JH, Hochheiser H. Research Methods in Human-Computer Interaction: Wiley; 2010.

[8]   Samaras GM, Horst RL. A systems engineering perspective on the human-centered design of health information systems. J Biomed Inform. 2005 2//;38(1):61-74.

[9]   Svanæs D, Alsos OA, Dahl Y. Usability testing of mobile ICT for clinical settings: Methodological and practical challenges. Int J Med Inform. 2010;79(4):e24-e34.

[10]   Policy: World Medical Association Declaration of Helsinki. Ethical Principles for Medical Research Involving Human Subjects, (2009).

[11]   Kushniruk AW, Patel C, Patel VL, Cimino JJ. Televaluation of clinical information systems: an integrative approach to assessing Web-based systems. Int J Med Inform. 2001;61:45-70.

[12]   Kaufman DR, Patel VL, Hilliman C, Morin PC, Pevzner J, Weinstock RS, et al. Usability in the real world: assessing medical information technologies in patients' homes. J Biomed Inform. 2003 2//;36(1–2):45-60.

[13]   University of Surrey CIRG. ALFA Toolkit 2014. Available from: http://www.clininf.eu/alfa.html

Appendix J

Paper IX

Title:	Recommendations on a Test Infrastructure for Evaluation of Touchscreen Assistive Technology for Visually Impaired Users
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Recommendations on a Test Infrastructure for Evaluation of Touchscreen Assistive Technology for Visually Impaired Users

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Abstract—**Mobile technologies' touchscreen allows the use of choreography of gestures to interact with the user interface. Relevant aspects in mobile technology design become crucial when targeting users with disabilities. For instance, when assistive technology is designed to support speech interaction between visually impaired users and a system, accessibility and ease-of-use of such technology should be included in the usability and technical evaluation of their effectiveness. This paper presents the analysis of the technical and physical infrastructure of a controlled laboratory environment for user evaluations made in the research project "Visually impaired users touching the screen - A user evaluation of assistive technology" where VoiceOver, a screen reader in Apple Inc. products was tested. The paper reports on challenges related to the use of the test infrastructure, such as how to obtain valuable data when interactive high-speed gestures are performed and how to optimise the recording and synchronisation between audio and video data. The lessons learned by the research group showed that there are effective alternatives for each challenge, and these should be customised for each particular test, type of participants and device.**

I. INTRODUCTION

Mobile technology is used today in people's life [1][2][3] for information and communication purposes. Mobile technologies usually incorporate touchscreen for the interaction between the user and device's interface. Touchscreen technologies [4][5] allow users to interact with a system through touch gestures made with their fingers. However, this type of interaction becomes a challenge for visually impaired users who cannot see the screen with sufficient detail to distinguish interface dimensions, elements inside the interface and buttons without tactile feedback [6]. Globally, the number of people with visual impairment is estimated to be 285 million. The main impairment causes are uncorrected refractive errors, such as myopia, hyperopia or astigmatism, and cataracts. 39 million people are estimated to be blind because of cataracts [7][8]. The International Statistical Classification of Diseases and Related Health Problems 10th Revision (ICD-10) provides a categorisation for visual impairments: normal vision, moderate visual impairment, severe visual impairment and blindness [9]. WHO estimates that about 65 % of visually impaired people are older than 50 years and 90% live in developing countries [7].

In order to improve the accessibility and the interaction with the user interface, several solutions of assistive technology are available in the market for visually impaired users [10][11]. In this context, the research project "Visually impaired users touching the screen - A user evaluation of assistive technology", aimed to evaluate the interaction of visually impaired users using VoiceOver, a built-in screen reader in Apple Inc. products (provided by default since April 2005, Mac OS X 10.4) that allows users to interact with the user interface (UI) through gesture-based (since June 2009, iPhone 3GS OS 3.0) speech-assisted navigation. One of the major aspects of the evaluation of touchscreen assistive technology is how accessible the UI is for users with and without visual impairments. For an optimal gathering of test data, a physical and technical infrastructure is essential to support a multiple visual and audio perspective for data collection of such interaction. The collected data will form the basis of a retrospective analysis where touch interaction details observed in the recordings can be coupled with comments and observations obtained during the test. It is relevant to note that because users are visually impaired, the touch gestures will be only seen by the researchers, and therefore a slow pace observation of them is necessary after the test to build up a meaningful analysis of the interaction. Another key requirement of a mobile device with assistive technology is the usability of the

system. Considering the sensory limitations of the target user group, the assistive technology should be intuitive, with an optimal presentation of the information facilitating a general understanding of the functionality and distribution of the UI.

This paper presents the challenges related to the testing of touchscreen assistive technology from the perspective of how the technical aspects of a laboratory infrastructure can be used in an Information and Communication Technologies (ICT) and Health Informatics research environment. It reports on the lessons learned by the research group exploring how to effectively carry out accessibility and usability evaluations of the mobile applications and technologies used in the research project. The research questions (RQs) of this study were:

RQ1: What technical infrastructure is suitable for evaluation of touchscreen assistive technology with disabled users?

RQ2: What are the learned lessons transferable for testing other mobile technologies?

Following this introduction, an overview of related research is presented. Analysis of the use of the technical and physical test infrastructure for user evaluations of touchscreen assistive technology and reflections on lessons learned during the project are presented in the next sections. Later, the discussion section highlights the benefits of having an optimal infrastructure for the type of the evaluation carried out. Finally, the conclusions regarding the characteristics of a technical infrastructure for accessibility and usability evaluations of touchscreen assistive technology are drawn.

II. RESEARCH BACKGROUND

Assistive technology [12][13][14] includes devices or technological solutions that assist people with disabilities. Assistive technology is used as an alternative way of performing actions or interactions with technology. The accessibility [15][16] of a technology refers to how accessible a technology is regardless of user's ability.

Leporini et al. [17] investigated the interaction between Apple touchscreen devices with pre-installed VoiceOver screen reader through a usability inspection of the UI and an online survey with feedback from 55 blind users. They found that VoiceOver made the devices more accessible, but operations such as writing long text took too long or were uncomfortable for users.

McGookin et al. [6] presented a study with 12 visually impaired participants operating two different touchscreen-based MP3players. They found that participants could generally use the devices but they encountered problems in doing short time operations. They evaluated the touchscreen accessibility and provided guidelines for touchscreen technology design for visually impaired users.

Phillips and Zao [18] did a study on user acceptance of assistive technology. They found that almost 30% of assistive devices were rejected by the users. Factors such as device performance, procurement and user need played an important role because they were related to the acceptance of technology. They concluded that involving users and focusing on their long-term needs would enhance user satisfaction.

Demers et al. [19][20] described the development of a clinical instrument for evaluation of user satisfaction with assistive technology devices. They described several variables used to help user assess and rate the degree of satisfaction with assistive technology in a structured way.

Svanæs et al. [21] presented a study on mobile ICT in clinical settings. They showed that the design of the graphical user interface (GUI) affects usability, ergonomic and social aspects. They concluded that usability tests of mobile ICT should be performed in a simulation environment with a high level of realism. Further, they stated that usability testing of mobile ICT for healthcare requires new ways of designing, recording and analysing the data collected.
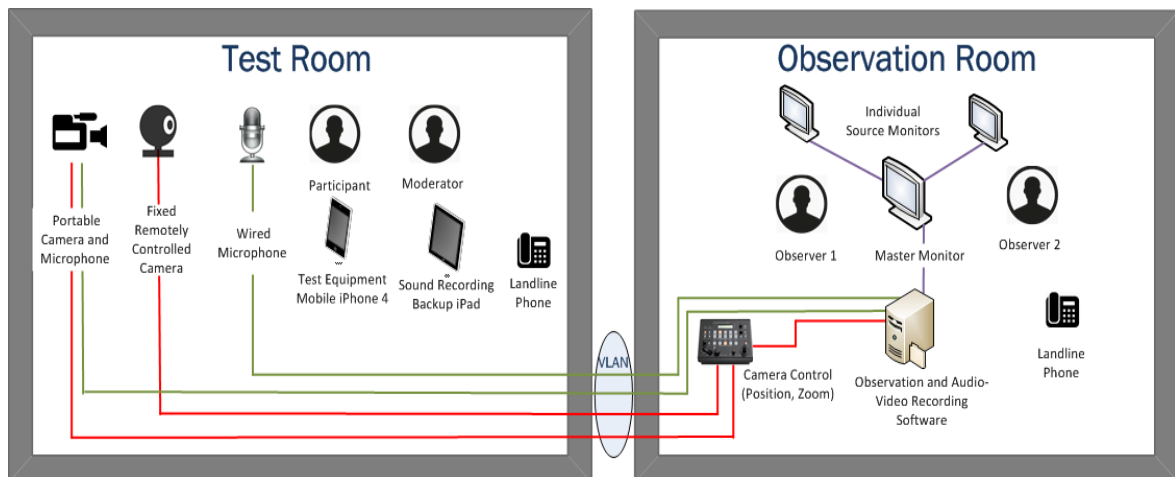
III. TEST INFRASTRUCTURE

In order to test the infrastructure for evaluation of touchscreen accessibility, 6 visually impaired users participated in a study where they individually performed representative tasks related to gesture's performance and task solving using the screen reader VoiceOver.

A. The Research Group

The evaluation research team consisted of three members with multidisciplinary background: one member with experience from teaching and supporting visually impaired students with assistive technology; the other two members with professional experience in health, ICT and human-computer interaction (HCI). All had professional experience in working with visually impaired people. One team member was the moderator in all the tests. In addition, an external senior researcher advised regarding planning and execution of the research study. A technician provided technical expertise and was available in case of need for assistance during the tests.

B. Test Environment Infrastructure

The evaluation of mobile assistive technology was held in the Usability Laboratory at the Centre for eHealth and Healthcare Technology of the University of Agder, Norway. The Usability Laboratory had two rooms: the Test room and the Observation room, connected through one-way mirror (visualisation from the Observation room towards the Test room). The complete infrastructure is described in details in [22]. The technical infrastructure for the usability evaluation is illustrated in Figure 43.

Figure 43: Scheme of the technical infrastructure for evaluation of mobile assistive technology.

The moderator and participant were in the Test room, while the other two members of the research team were in the Observation room. The moderator sat down on a table in the middle of the Test room with the participant besides. The elements used in the room were a smartphone, a task list, a table microphone and a tablet for additional sound-recording. The participant had the smartphone in their hands. The room had 2 IP cameras, 1 fixed and 1 portable with an external microphone. The Observation room had a desktop PC connected to three monitors. The observers followed the evaluation, remotely controlled the zooming of the fixed camera and made recordings and annotations of the test sessions.

The Observation room and the Test room were connected with a dedicated segment of the LAN infrastructure of the Centre for eHealth and Healthcare Technology, making use of VLAN technology. This connection was used for the IP-based streaming of video and audio signals from the Test room to the Observation room, using Wirecast 0 as capture and encoding software.

C. Materials

The material used during the study is presented below grouped by rooms for reproducibility and information purposes.

Test room:

- •Apple Inc. iPhone 4 MD128B/A iOS 7.1.2 with VoiceOver activated.
- •Fixed Camera: SONY BRCZ330 HD 1/3 1CMOS P/T/Z 18x Optical Zoom (72x with Digital Zoom) Colour Video Camera.
- •Portable Camera: SONY HXR-NX30 Series.
- •Apple Inc. iPad MD543KN/A iOS 8.1 for additional sound-recording.
- •Sennheiser e912 Condenser Boundary Microphone.
- •Landline phone communication

Observation room:

- •Stationary PC: HP Z220 CMT Workstation, Intel Core i7-3770. CPU@3.4 GHZ, 24GB RAM, Win-dows 7 Professional SP1 64 bit.
- Monitor: 3x HP Compaq LA2405x
- •Remote controller: SONY IP Remote Controller RM-IP10.
- •Streaming: 2x Teradek RX Cube-455 TCP/IP 1080p H.264.
- •Software Wirecast 4.3.1.
- •Landline phone communication.

D. Data Collection

The test sessions were audio-visually recorded in the F4v video file format, exported to the Windows Media Video (WMV) format and then imported from QSR NVIVO 10 [24]. The recordings from two independent audio-visual sources were merged into one video file using the software Wirecast v.4.3.1, with multiple video perspectives and a single audio channel. In addition, annotations were made by the evaluation team during the test. After the evaluation, all recordings were transcribed verbatim and divided into categories for a qualitative content analysis [25]. The data collection of the study was approved by the Norwegian Social Science Data Services (NSD) [26] with the project number 40636.

IV. LESSONS LEARNED FROM THE TEST

This section presents the challenges and lessons learned about the technical infrastructure in the laboratory through the evaluation of touchscreen mobile assistive technology.

A. Optimisation of the Test Environment

Before the start of each test session, participants were asked to sit in a natural and relaxed position with the mobile phone in their hands. The cameras were then adjusted for optimal recording of the screen and hand gestures. The remote controlled camera zoomed on the mobile interface, visualised in full screen on one of the PC monitors in the Observation room. The portable camera was placed near the participant's side. In general, both cameras were slightly angled from above to record the interaction and provide the best possible shot of mobile user interface and participant's hands.

B. Moderator's View

The moderator was sitting beside the test participant to guide them through the tasks on the smartphone. Two factors negatively influenced the accurate observation of the interaction between participant and the device: the mobile device's small-size screen and the high speed of gestures.

In order to improve the moderator's view and allow the possibility of following the actions of the participant and screen response on-live, a screen capture tool (e.g., software Mirroring 360 [27], Apple Airplay [28]) could be used to show the screen interface on a larger external screen in the Test room. The screen interface could be simultaneously recorded by a screen recording program (e.g., software Snagit [29]). In order to observe and record the finger interaction and the system's response a screen capture tool (e.g., UX Recorder [30]) would also allow detecting, in time, when the hand interaction touches the interface. To closely observe gesture choreography, one common alternative in mobile usability testing is to place a macro-focused camera on the mobile phone to record user's hand gestures. Its signal could also be displayed on an external screen in the Test room if necessary. However, its suitability for testing visually impaired users has not been yet tested by the researchers.

C. Clarity of Screen Reader Sound for Moderator

In the Test room, the moderator had in some cases difficulty to adequately listen the feedback from the VoiceOver, even when the settings were at maximum volume for the screen reader.

In order to improve the sound quality, Bluetooth or dedicated software such as Mirroring 360 could be used for transmission of sound to an external loudspeaker in the room. The use of external loudspeaker could increase the perception of sound for the moderator. However, this would create a new different setting for a test participant that would not directly hear the sound as usual from the mobile device, but instead from an external loudspeaker.

Effective communication between research team members was essential to perform on time any readjustment of equipment or task necessary during the test. The landline phone communication was available between the two rooms and used when the test was being recorded and none of the researchers could leave the Observation room. In order to improve the communication, an ear plug to connect moderator to observers watching the recordings would allow instant 1-way communication to do the adjustments without interrupting the test session.

D. Quality Optimisation of the Recordings

A high level of quality of the recordings is generally recommended for an optimal retrospective analysis of data in usability studies. The audio-visual recordings in the usability evaluation had a F4v video file format and were converted to the WMV format to be imported into the qualitative analysis program QSR NVIVO 10, used for watching and transcription purposes. Several factors associated with the quality of video and sound were identified that influenced the analysis in detail of the actions performed by participants during task execution. They are next described in 4 subcategories: visual improvements, sound improvements, video and sound synchronisation and storage.

E. Visual Improvements

In the Test room, the light source was directed down to the floor. Some footage showed glares that impeded the correct view of the mobile interface during the analysis. An alternative would be to have a light source directed to the walls of the Test room instead of directly down to the floor. In addition, a *dimmer* device could be used to reduce the brightness of the light sources that produced the glare. The Test room had one remotely controlled camera and another that was controlled manually.

An advantage would be to also have the second camera remotely controlled for adjusting the angle and the zooming in case of glare or unexpected movement by a participant. Participant's gestures were usually performed at high speed. This impeded the ability to accurately distinguish the finger gesture several times when retrospectively analysing the video at normal speed. In those cases, instead of using

QSR NVIVO 10 that only allowed reducing up to 50% of the speed, the software Cyberlink [31] was chosen to show the footage even at lower speed, down to 20%.

F. Sound Improvements

In the recordings, in spite of the fact of having one wired microphone placed on the table and another on the external camera, the quality of sound reception was not sufficient at times. When testing mobile assistive technology, it should be taken into consideration that the VoiceOver of the smartphone gives a speech feedback that may interfere with other sounds listened during the test, e.g., participant's answers or comments. For instance, there were up to three sound sources (i.e., moderator's voice, participant's voice, smartphone's VoiceOver speech) recorded simultaneously in several occasions. Recording overlapped sound sources obstaculised the accurate perception of the sound during the analysis phase. It would be then advised to try to implement the policy of speaking one at time during the test, even though the VoiceOver could interfere at any point. A wireless microphone worn by participant and moderator would increase sound reception quality in addition to a stable sound source place nearby. This would remove the constraint of placing the participant beside the table microphone and allow them to freely move around.

In the case of insufficient quality of sound recordings, an additional sound recording during the session is recommended as a backup. In the usability evaluation, a tablet device was used as backup for sound recording; very useful when sound recordings from the main sources were not optimal. To improve the sound during the analysis, the VLC media player [32] was used to adjust frequencies of sound.

G. Video and Sound Synchronisation

When analysing the recordings, video and sound signals were not perfectly synchronized, with a delay of the video signal of approximately 0.5 s. regarding the audio one. This was probably due to the network latency added to the video signal streaming. This issue that may seem generally unimportant, is however especially relevant when the study includes rapid movements and actions of high order of magnitude. A potential solution could be to record all sources separately with digital audio workstation software (e.g., ProTools by Avid [33]) and transfer them to an editing program (e.g., Cyberlink [31], Final Cut Pro X [34] or Adobe Premiere Pro CC [35]). In such programs, the synchronisation can be adjusted frame by frame. This software also allows discretionary switching between the different video and sound recordings and zooming.

However, substantial technical knowledge is required for the correct use of these digital audio edition programs. Due to the network latency, data transmission through direct wire is usually better than streaming. A FireWire cable [36] could be used for high-speed and synchronous real-time data transfer; this also would separate the storage into different files.

H. Storage

In order to reduce the risk of data loss, a redundancy in the data collection system is advisable. During the test sessions, one incident resulted in 10 minutes of footage loss due to a recording software error. In that case, the portable camera provided an additional recording that made the analysis possible without repeating the task. Test repetitions should be avoided when possible, because of the risk of biasing the data collection when repeating the same task and the inherent difficulty of recruiting visually impaired participants. An additional solution would be to record the data gathered in two independent hard disk drives from two different computers. This alternative solution has been implemented into the technical infrastructure of the laboratory after the incident. A high level of quality of the recordings is generally recommended when a sufficient storage space is available. In other case, a trade-off between space and video quality should be made in advance.

V. DISCUSSION

This paper has presented a technical and physical infrastructure to carry out evaluations of mobile assistive technology with visually impaired users. The preparation and the execution of the laboratory test led to a series of reflections and lessons learned by the research team that are considered useful for future usability and accessibility research with visually impaired users. In addition, several lessons can be inclusively applied when testing touch interaction with able-bodied users.

An infrastructure suitable for the evaluation of touchscreen assistive technology with disabled users (RQ1) would be one that firstly optimises data collection; secondly, allows the research team to do an effective retrospective analysis under different and more demanding conditions than when testing able-bodied users; and thirdly does not interfere or trouble the comfortability, safety and trust of the users.

Having in mind that sensory-limited users do not have the same level of access to information, leaving aside that not all information channels are designed with this type of users in mind, their comfort and tranquillity are crucial to avoid interference and distortion of the test and results.

The proposed infrastructure contributes to a controlled scenario for evaluation; however, it is not exempted of potential improvements that can qualitatively benefit future tests and be applied to other mobile technologies and able-bodied users (RQ2). For instance, to evaluate the accessibility of touchscreens and the choreography of gestures associated, the video recordings require a sufficient quality that allows zooming in with great detail and professional software video visualisation to substantially reduce the speed for optimal viewing. In addition, the data should be collected through multimodal channels (e.g., video and audio), having the necessary tools to synchronise audio and video signals, which, if streamed over a network, usually incorporate latency. This synchronisation is the key to detect and understand the correlation between the sounds of the interface related to participant's touch on the screen.

Finally, due to the inherent difficulties of recruiting disabled users and the discomfort of having to unnecessarily repeat tasks and test sessions, redundancy in data collection is strongly advise through the use of two or more independent sources of data storage, i.e., two different computers.

VI. Conclusion

Mobile assistive technology for touchscreens is widely used by multiple user groups. When designing, testing and evaluating technology with sensory-limited users, there is a specific need to balance the interface design and functionality on the one hand and the usability and accessibility of mobile assistive technology on the other.

Accessibility and usability evaluations are essential in order to improve not only the interface design of the mobile assistive technology, but also the interactions between devices and users. These evaluations are enabled by a laboratory environment, where the research team has full control over all steps of the test scenario, including tasks and interactions between the test participants and the technology used.

In particular, for mobile assistive technology that involves visually impaired users, accessibility and usability evaluation aids to identify interaction issues that lead to uncover design flaws, obstacles to successfully use the device and potential adjustments of the system to accommodate user sensory limitations.

This paper has analysed the physical and technical infrastructure used for evaluating a mobile user interface using a gesture-based speech-assisted interface navigation system, Apple Inc. VoiceOver., within the research project *"Visually impaired users touching the screen - A user evaluation"*. The test infrastructure provided sufficient

control over the factors involved in the test at the same time that brought the flexibility to dynamically adjust the environment for adequate data collection.

Empirical research data obtained from the usability and accessibility evaluation using the infrastructure described in this paper will be published and available for the research community. Future research in the agenda of the authors includes the test of the infrastructure including the technical improvements proposed in this paper with other user groups, including other vendors and solutions of assistive technology for operating mobile user interfaces.

REFERENCES

[1]   Goggin G. Cell Phone Culture: Mobile Technology in Everyday Life. Routhledge, 2006.

[2]   Ling R. The Mobile Connection: The Cell Phone's Impact on Society. Elsevier Inc, 2004.

[3]   Jarvenpaa SL, and Lang KR. Managing the Paradoxes of Mobile Technology. Information Systems Management, 2005: 22:4: 7-23. DOI: 10.1201/1078.10580530/45520.22.4.20050901/90026.2

[4]   Albinsson A, and Zhai S. High precision touch screen interaction. Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems, 2003; 105-112. DOI: 10.1145/642611.642631

[5]   Butler A, Izadi S, and Hodges S. SideSight: multi-"touch" interaction around small devices. Proceedings of the 21st annual ACM symposium on User interface software and technology, 2008; 201-204.

[6]   McGookin D, Brewster S, and Jiang W. Investigating Touchscreen Accessibility for People with Visual Impairments. Proceedings of NordiCHI Using Bridges, 18-22 October, Lund, Sweden, 2008; 298- 307.

[7]   World Health Organization (WHO): http://www.who.int/mediacentre/factsheets/fs282/en/. [Accessed 2015 May 20].

[8]   Pascolini D, and Mariotti SP. Global issues:Global estimates of visual impairment: 2010 . British Journal of Ophthalmology, 2011. DOI: 10.1136/bjophthalmol-2011-300539

[9]   ICD-10 version 2015: chttp://apps.who.int/classifications/icd10/browse/2015/en#/H53-H54] [Accessed 2015 May 20].

[10]   Voiceover: http://www.apple.com/accessibility/osx/voiceover/ [Accessed 2015 May 20].

[11]   Window-Eyes: http://www.windoweyesforoffice.com/ [Accessed 2015 May 20].

[12]   Edyburn D. Rethinking Assistive Technology. Special Education Technology Practice, 5(4): 16-23.

[13]   Scherer M. The change in emphasis from people to person. Introduction to the special issue on Assistive Technology, Disability and Rehabilitation, 2002: VOL. 24: NO. 1/2/3, 1 ± 4.

[14]   LaPlante MP, Hendershot G, and Moss AJ. Assistive Technology Devices and Home Accessibility Features: Prevalence, Payment, Need, and Trends. Advance Data from Vital and Health Statistics, 1992: n217 Sep. National Center for Health Statistics (DHHS/PHS), Hyattsville, MD.

[15]   Iwarsson S, and Ståhl A. Accessibility, usability and universal design—positioning and definition of concepts describing person-environment relationships. Disability and Rehabilitation, 2003: 25:2: 57-66. DOI: 10.1080/0963828021000007969

[16]   Petrie H, and Kheir O. The relationship between accessibility and usability of websites. Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems, 2007; p 397-406.

[17]   Leporini B, Buzzi MC, and Buzzi M. Interacting with mobile devices via VoiceOver: Usability and Accessibility Issues. Proceedings of the ACM OzCHI '12, 24th Australian Computer-Human Interaction Conference, 2012; 339-348.

[18]   Phillips B, and Zhao H. Predictors of Assistive Technology Abandonment. Assistive Technology: The Official Journal of Resna, 1993: Volume 5: Issue 1: 36-45. DOI:10.1080/10400435.1993.10132205

[19]   Demers L, Weiss-Lambrou R, and Ska B. Development of the Quebec User Evaluation of Satisfaction with assistive Technology (QUEST). Assistive

Technology: The Official Journal of Resna, 1996: Volume 12: (Issue 1): 3-13. DOI:10.1080/10400435.1996.10132268

[20]   Demers L, Weiss-Lambrou R, and Ska B. Item Analysis of the Quebec User Evaluation of Satisfaction with Assistive Technology (QUEST). Assistive Technology: The Official Journal of Resna, 2000: Volume 1: (Issue 2): 96-105. DOI:10.1080/10400435.2000.10132015

[21]   Svanæs D, Alsos OA, and Dahl Y. Usability testing of mobile ICT for clinical settings: Methodological and practical challenges. International journal of medical informatics 2010: 79(4): e24-e34.

[22]   Gerdes M, Smaradottir B, and Fensli R. End-to-end infrastructure for usability evaluation of eHealth applications and services. Proceedings of the Scandinavian Conference on Health Informatics, Grimstad, Norway, 21-22 Aug 2014; 53-59. ISSN(print): 1650-3686, ISSN(online): 1650-3740.

[23]   Wirecast: http://www.telestream.net/wirecast/overview.htm. [Accessed 2015 May 20].

[24]   QSR NVIVO 10: http://www.qsrinternational.com/products_nvivo.aspx. [Accessed 2015 May 20].

[25]   Lazar J, Feng JH, and Hochheiser H. Research methods in human-computer interaction. John Wiley & Sons, 2010.

[26]   Norwegian Social Science Data Services: http://www.nsd.uib.no/personvern. [Accessed 2015 May 20].

[27]   Mirroring 360. http://www.mirroring360.com/. [Accessed 2015 May 20].

[28]   Apple Airplay: https://www.apple.com/airplay/. [Accessed 2015 May 20].

[29]   Snagit: http://snagit.en.softonic.com/. [Accessed 2015 May 20].

[30]   UX recorder: http://www.uxrecorder.com/. [Accessed 2015 May 20].

[31]   Cyberlink: www.cyberlink.com/. [Accessed 2015 May 20].

[32]   VLC media player: http://www.videolan.org/vlc/. [Accessed 2015 May 20].

[33]   ProTools: http://www.avid.com/US/products/family/pro-tools. [Accessed 2015 May 20].

[34]   Final Cut Pro X: https://www.apple.com/final-cut-pro/. [Accessed 2015 May 20].

[35]   Adobe Premiere Pro CC: www.adobe.com/PremierePro. [Accessed 2015 May 20].

[36]   FireWire: http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=4659233. [Accessed 2015 May 20].