# 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

## 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 1. 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 telemedical 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.

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 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.

## State-of-the-art

eHealth applications and services have multiple user groups, and there is a need for systems supporting collaborative work across organizational 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].

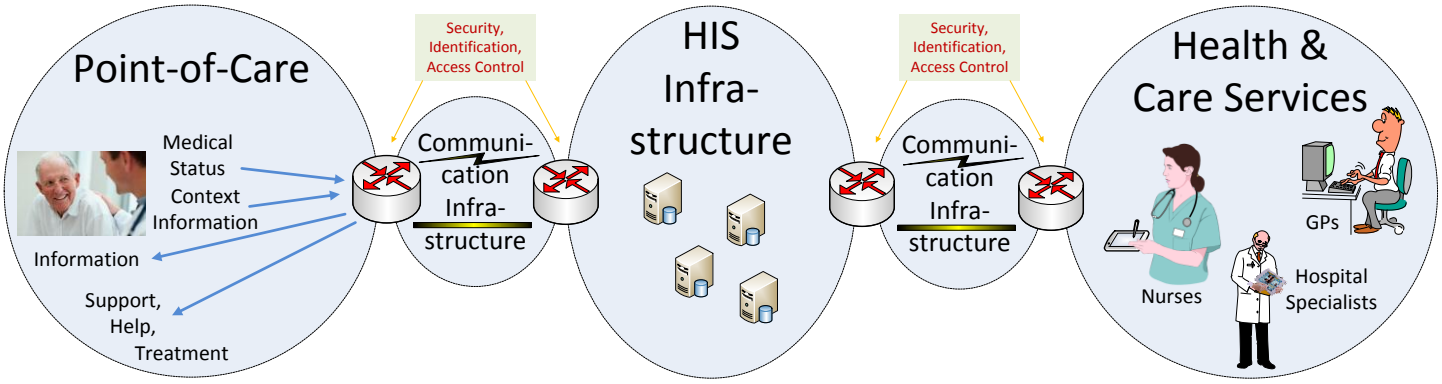


**Figure 1: Reference System for Tele-Health and Tele-Care Services**

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 multi-faceted 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.

## 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.

### 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.

#### *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 1 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.

***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.

***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.

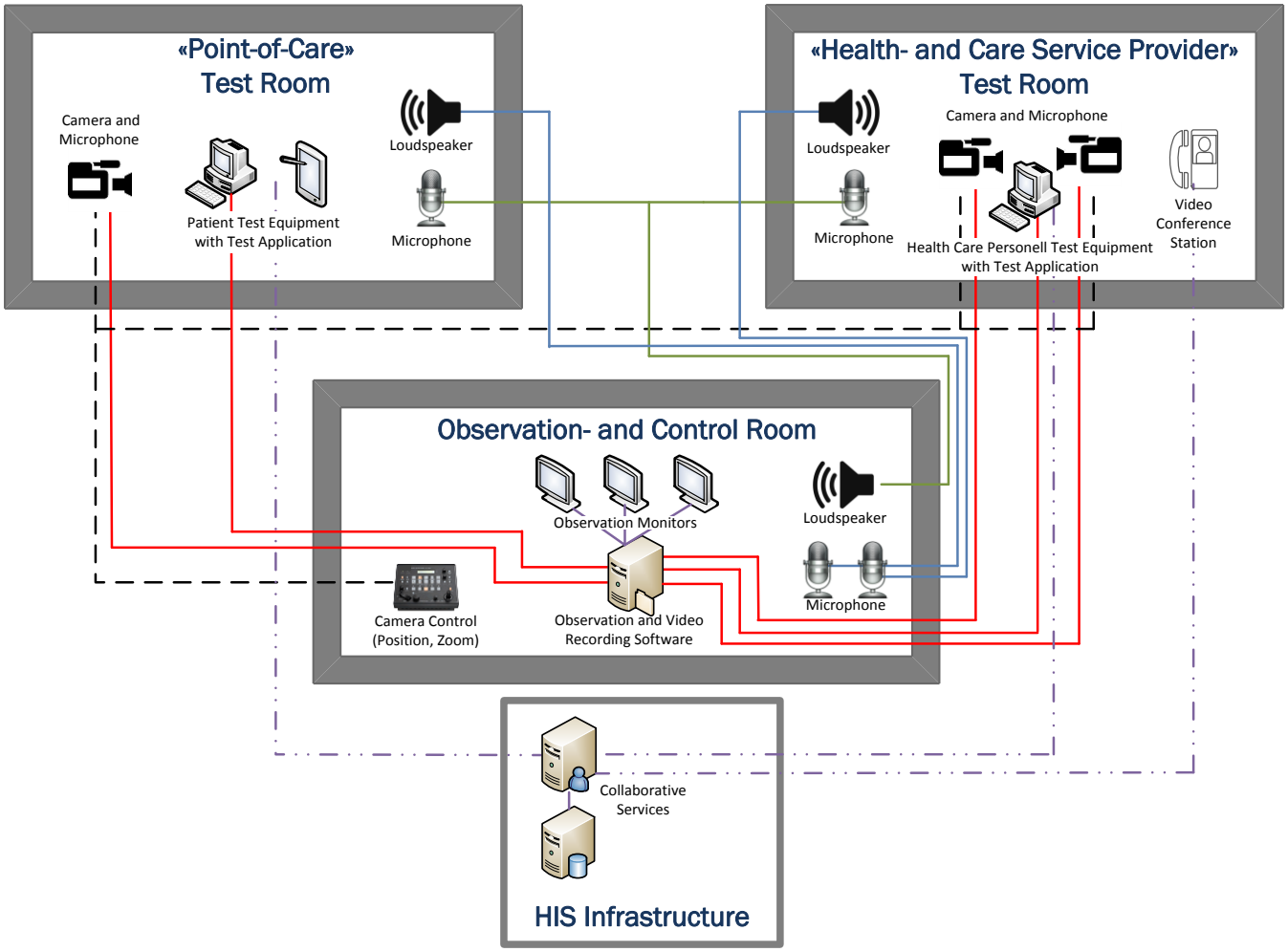


**Figure 2: E2E Usability Test Infrastructure**

***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.

***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.

- 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.
- 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.

**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 2. 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.

***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 3.

**Figure 3: Video Observation of Point-of-Care**

***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.

**Figure 4: Health- and Care Service Provider Test Setup**

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 4 the Health- and Care Service Provider Test Room at the University of Agder can be seen as an example setup.

***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 5), 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 5: 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.

## 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].

**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 organizational 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 telemedical 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.

**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.

**Figure 6: Introduction to eHealth technology**

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 6).

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 7).

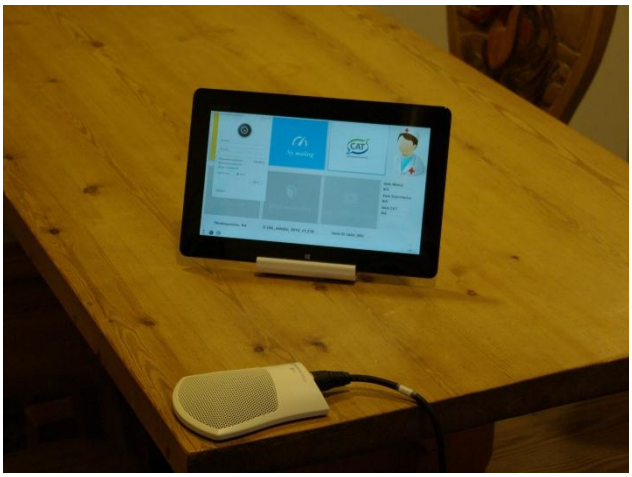

**Figure 7: eHealth Technology at the Point-of-Care**

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 8). 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 8: 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 5) 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.

## 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.

## 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.

## Acknowledgments

We thank all test participants for their contributions in the trial project. Furthermore, we thank all project partners for their support and collaboration.

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