
26th International Conference on Knowledge-Based and Intelligent Information & Engineering Systems (KES 2022)**Assistive health systems for home-dwelling elderly: connecting training and monitoring technologies to a data integration platform****Petra Friedrich^{a*}, Maksym Gaiduk^b, Ángel Serrano Alarcón^c, Daniel Scherz^b, Natividad Martínez Madrid^c, Ralf Seepold^b, Matthias Gaßner^a, Dominik Fuchs^a**^a*University of Applied Sciences Kempten, Bahnhofstr. 61, 87435 Kempten, Germany*^b*HTWG Konstanz, Alfred-Wachtel-Str. 8, 78462 Konstanz, Germany*^c*Reutlingen University, Alteburgstr. 150, 72762 Reutlingen, Germany*

Abstract

Home health applications have evolved over the last few decades. Assistive systems such as a data platform in connection with health devices can allow for health-related data to be automatically transmitted to a database. However, there remain significant challenges concerning intermodular communication. Central among them is the challenge of achieving interoperability, the ability of devices to communicate and share data with each other. A major goal of this project was to extend an existing data platform (COMES[®]) and establish working interoperability by connecting assistive devices with differing approaches. We describe this process for a sleep monitoring and a physical exercise device. Furthermore, we aimed to test this setup and the implementation with a data platform in both a laboratory and an in-home setting with 11 elderly participants. The platform modification was realized, and the relevant changes were made so that the incoming data could be processed by the data platform, as well as visually displayed in real-time. Data was recorded by the respective device and transmitted into the data server with minor disruptions. Our observations affirmed that difficulties and data loss are far more likely to occur with increasing technical complexity, in the event of instable internet connection, or when the device setup requires (elderly) subjects to take specific steps for proper functioning. We emphasize the importance for tests and evaluations of home health technologies in real-life circumstances.

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Peer-review under responsibility of the scientific committee of the 26th International Conference on Knowledge-Based and Intelligent Information & Engineering Systems (KES 2022)

Keywords: Home health; assistive systems; interoperability; exercise; sleep assessment

* Corresponding author. Tel.: +49-831-2523-9256

E-mail address: petra.friedrich@hs-kempten.de

1. Introduction

Globally, the population aged 65+ is growing faster than any other age group. According to an estimate by the World Health Organization (WHO), the number of individuals over 60 years will nearly double from 12% to 22% during the 2015-2050 period. Approximately 80% of older adults have at least one chronic disease and 77% have at least two [1].

Furthermore, it is difficult to maintain comprehensive medical care due to the increasing shortage of doctors (particularly in rural areas) and caregivers, and most recently, a worldwide pandemic. The socio-demographic situation in the healthcare system is therefore increasingly calling for technological systems that may help to fill this gap and serve the independence of the elderly population. Accordingly, treating individuals remotely with the support of technology is on the agenda of national and global health policymakers [1].

Home health applications have evolved over the last few decades, addressing many healthcare conditions. When it comes to home monitoring and home training methods, assistance systems, local autonomous systems or networked monitoring systems can improve the life and care of seniors living at home. These assistive technologies aim to empower individuals through disease prevention, health promotion and self-management [2].

Remote health monitoring gives clients assurance that their health-related conditions (e.g. heart rate, blood pressure, fall risk factors, or sleep quality) are monitored and alerts can be generated to inform healthcare professionals in real time [2]. Home based health monitoring improves consistent patient care and allows it to continue, for example, after a patient is discharged from a hospital or nursing home. Healthcare providers can reach their clients more easily, perform tele-monitoring of patient health conditions without the need to travel, and identify or oversee at-risk populations. It similarly helps clients to feel safer due to an ongoing connection or communication with their health providers, enable them to be more compliant with treatment plans and improve their health conditions and maintain independence and life satisfaction at home [2].

Telemedicine (i.e., remote medical service) systems such as a data platform for health devices allow vulnerable groups such as elderly to independently measure vital data such as heart rate, blood pressure, body weight, sleep quality, and exercise continuity and intensity, and have them automatically transmitted to a database via wireless/mobile communications. The values can then be verified, and feedback can be given to the patient or, if necessary, a doctor. The sensor devices required for this are commercially available and therefore inexpensive medical devices such as blood pressure monitors, pulse oximeters or pedometers, which can communicate with an app on the smartphone via Bluetooth [3,4].

However, there remain significant challenges concerning interface integration and intermodular communication. Central among them is the challenge of achieving interoperability, which can be defined as “the ability of two systems to communicate and share services with each other” [5]. It plays a major role in the development and evaluation of assistive health systems, particularly in the healthcare domain. Remote home health technology incorporates varied sensors, devices, applications, and services, with different amounts of data exchange and heterogeneous formats. Hence, developers and manufacturers should consider interoperability from early on.

Interoperability tasks get more difficult to handle with the increased complexity of interconnected systems in terms of technologies, integrated services, and cross-border governance frameworks. As the volume of integrated system increases, system integration can become complex. Thusly, the variety of different Application Programming Interface (API) styles and formats can appear nearly overwhelming for vendors, employees, and customers [2].

The importance of interoperability in home health technology has been emphasized by both academia and industry. The industry frequently attempts to address interoperability challenges through standardization. Several efforts have emerged to establish standards for providing interoperability between devices, networks, services, and data formats owned by different providers. However, it remains questionable if related standards are ever fully agreed upon and accepted. To resolve this issue, researchers have been developing innovative solutions for interoperability and heterogeneity in different systems with regard to the respective home health scenario and particular requirements.

Therefore, the aims of this explorative study were to extend an existing data platform and establish working interoperability by connecting two assistive devices with different approaches, one device for sleep monitoring and the second device for physical exercise (leg training). Furthermore, we aimed to test these assistive health systems and their implementation with a data platform in both a laboratory and a real-life setting.

We hope by identifying common pitfalls as well as describing our (exemplary) solutions, this work may assist future system integrators to avoid or quickly solve similar difficulties, and to consider critical aspects early in the process.

2. Data Integration Platform COMES®

2.1. Origins and development goals

Currently, there are many devices on the market that can be used to monitor various biomedical or health-related signals and values [6,7]. So far, these devices and their associated applications have been used only in limited ways for a variety of reasons. Evidence in practice shows that assistive technologies face a variety of obstacles [8]. In most cases, they only offer isolated solutions: Often, each device has its own app and data collection technology. The potential for these technologies is great if they opt for the use of incorporated data, which is rarely the practice yet.

In principle, intelligent assistance systems can be operated fully or partially autonomously. In fully autonomous systems, data processing and storage takes place in the system. Semi-autonomous systems, on the other hand, transmit the data determined by sensors to a control center or server, either after authorization by the user or automatically. An example of a semi-autonomous assistance system is a home emergency call system that uses fall sensors to detect a dangerous situation and, in the event of an alarm, can transmit the data to an emergency service [9].

2.2. Architecture and functions

The central component of the assistive health data platform *COMES*® is a database system that can be networked with a variety of sensory devices. With these sensors, it can easily register physiological data and use it for risk prevention and general health monitoring, among others. With the help of risk prevention, for example, a large part of the medical emergencies and their consequential costs could be avoided. If these assistive devices are linked via a control center, individual help can be offered via mobile devices, making everyday life easier for people in need of care and their environment [9,10].

The *COMES*® platform allows patients, caregivers, or researchers to review the measured health parameters, like blood pressure, weight or activity. These data are recorded by the respective device and transmitted by a device or a smart phone into the *COMES*® database. Online, a caregiver, therapist or doctor has the possibility of remotely reviewing these parameters and derive new insights and goals for the clients from the given data. The user itself is likewise able to review her or his vital data on the platform [3,11]. In our study, we focused on interoperability challenges, and merely the research staff was able to track the gathered data.

The health system integration platform *COMES*® is designed to enable:

- Automated documentation
- Flexible displays and evaluations
- Statistical analysis
- Scientific support
- Systemic approach
- Feedback and interaction
- Therapy management and control
- Multi-user system
- Adjustable Rights and roles
- Scalability

COMES® stands for Cognitive Medical Systems (Comes = Latin for “companion”) and is a registered trademark of Prof. Dr. Bernhard Wolf and the “Steinbeis-Transferzentrum Medizinische Elektronik und Lab on Chip-Systeme”.

3. Research Methodology

3.1. The 'Home Health Living Lab' project

The overall objective of the international project “IBH living lab ‘active and assisted living’”, a research and innovation network made up of a number of universities and practice partners from the Lake Constance region, was to develop assistance systems for self-determined living and to implement and test them under real-life conditions.

In the IBH-Living lab, home-dwelling people in need of support were using various home health products. Afterwards, they were typically asked to report on their experience with the products. These experiences were then included, for example, in the further development of products and services in the field of home health and Ambient Assisted Living (AAL) or the building of strategies, in order to find out how assistive devices can best be made accessible to a wider public. In this context, the “Home Health Living Lab” sub-project, on which this research project was based, has set itself the objective of testing and developing sustainable home-health systems and services.

The “Home Health Living Lab” project lasted from 01.03.2018 to 31.12.2021 and was funded by the EU Interreg V-Program "Alpenrhein-Bodensee-Hochrhein": Project "IBH Living Lab Active and Assisted Living". The project worked out the core question about the challenges in the area of “Home Health” in the Lake Constance region. It was concerned with the integration of in-home health devices to record vital functions (e.g. pulse, heart signals, muscular movement, fall risk and sleep behavior) and activity of elderly residents in apartments of the IBH Living Lab AAL association. Older people were thus facilitated to use assistive technologies to monitor their sleep quality, their individual stress levels and improving their adherence to fall prevention and exercise.

A central goal of the project was to realize a prototype technical implementation of several home health technologies and to evaluate their functionality and the user's experience in the test apartments. We conducted two studies with caregivers and elderly living at home, the first of which was done without a data platform and aimed to identify the feasibility and acceptance of several home health devices, most notably a leg training device for home exercise [12] and a sleep monitoring device [13] in a mixed-methods evaluation. The experiences from the first series of tests revealed several weaknesses without an integrating data platform, for example:

- Parameters were recorded and documented only individually
- Evaluations had to be done manually and per modality
- No holistic view of data parameters
- Correlations recognizable only after manual data analysis
- No immediate feedback to users possible
- Troubleshooting was only possible with delay

Thus, in preparing for a second evaluation, we first aimed to connect the assistive devices to the data platform *COMES*[®], which was used before by our team, and then analyze the functionality and interoperability both in laboratory pre-testing as well as in-home testing with another group of 11 elderly participants in their living environment (Fig. 1).

3.2. Platform extension

Prior to the software modification of the data platform and enabling device implementation, a software requirements specification (SRS) was written. The specification aimed to facilitate the integration of the two assistive health devices as well as a front end, that is, the web-based presentation layer of *COMES*[®]. The SRS was created as a document that collected information specifically on the external interface requirements and the requirements for efficiently displaying the collected data to the user (in this study: the researchers). The SRS described how the platform would be expected to perform and included in-depth descriptions of the changes that had to be made. We engaged an external software company (SHZ Softwarehaus Zuleger GmbH, Ottobrunn, Germany), to make the requested changes for the data platform. Concerning the interoperability with the devices, several key requirements were formulated:

- Enable connectivity of the devices with the respective APIs/interfaces

- Enable data storage and transmission
- Enable data visualization (graphs, statistics, etc.)
- Enable user input (an option for user feedback)
- Enable data export in several formats (e.g., Excel, PDF)

3.3. Device implementation

We initially used three devices for the device implementation: A sleep monitoring and a home exercise product as well as a smartwatch. Regarding the smartwatch (aidwatch 2, NESTOR Intl. Corp. AG), throughout the in-home testing, data was not received at the platform server. This was mainly due to the problem that with an unstable internet connection in the user's home, the system was presumably in an undefined state and no longer sent data, which led to a near total data loss. Hence, in this paper, we want to focus on the interoperability of the remaining two devices, which successfully established connection from device to platform.

The technology used for sleep monitoring was the *EmFit QS+* system [14]. This device has already been described and evaluated in several scientific publications [15]. It can measure several physiological and sleep-related parameters (such as heart rate, respiratory rate, sleep quality and identification of sleep stages). One of the most important points considered in the selection of this technology was the possibility of automatic functioning without user intervention which is supposed to increase user acceptance. In addition, the *Emfit* system offers an internet-based interface that allows for the connection to the data integration platform.

The second home health device was a modified version of the *TheraTrainer tigo®* (medica Medizintechnik GmbH, Hochdorf, Germany), with which individuals can carry out cyclical movements of the lower extremities from a chair or a wheelchair. Device-supported pedaling is an effective form of home-based exercise, since cycling and walking have similar modular features and similar neuromuscular mechanisms [16]. Walking, however, may expose older adults to larger fall-risks compared to other training activities [17]. The influence of cyclical movement training on improving walking ability, endurance and speed is well established [18]. By means of an integrated Bluetooth interface, the training device was able to communicate with the single-board computer Raspberry Pi 3, from which users received (acoustic) feedback and which was also used to establish the connection to the platform server.

3.4. Tests and Experiments

Before the in-home testing, additional tests were conducted in the laboratory, however, in a way that was similar to the scenario of end-users engaging with the platform, i.e., clients and caregivers. These tests sought to verify that the *COMES®* platform met the initial requirements included in the SRS. Several test cases were written to test the usability and functionality of the *COMES®* platform and website, together with the integration of the devices. Various aspects were considered in terms of usability testing, such as execution time, possible errors, and delays. Functional tests aimed to ensure the interoperability between the platform and the devices. Therefore, the functional tests focused on verifying that the data received, and the statistics derived from such data were correct. A document with test cases was completed. It included the pre-test requirements to be fulfilled by the user, the expected results after the test, the results obtained after the test, and relevant comments by the tester.

The in-home explorative study was conducted over two weeks with eleven subjects (nine women and two men). The following inclusion criteria were determined: age 65 years old or older, able to perform the majority of household tasks independently. To the best of our knowledge, the study participants had no serious acute illnesses. Each participant was in her or his private household to conduct the experiment in the everyday environment. Participant signed informed consent prior to partaking and were able to terminate participation at any point. On the first day, the necessary equipment was installed and explained. On the last day, the devices were collected, and the final survey (not included in this article) was filled out with the participant.

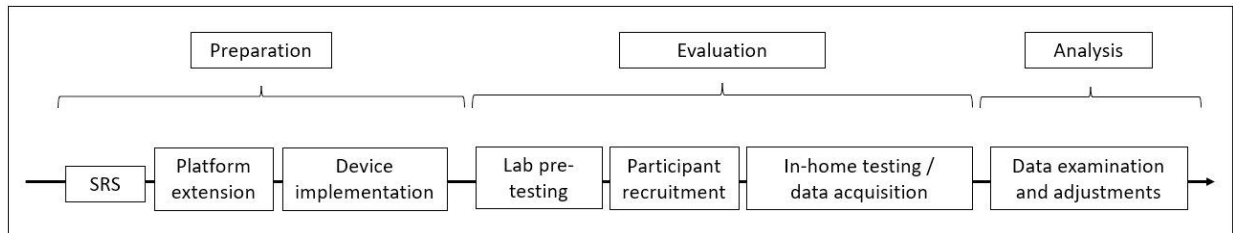


Fig. 1. Project phases and procedure (SRS: software requirements specification).

4. Results and Discussion

The SRS was realized by the external software company and the relevant changes were made so that the incoming data could be processed by the data platform, as well as visually displayed in real-time, with separate options of graphical representation for the sleep monitoring and the home exercise data. The visual platform was web-based and, in our exploratory study, merely monitored by the research staff. However, future studies will evaluate its functionality for caretakers and primary device-users themselves. Detailed and continuous communications between the external software developers and the project team throughout the software development process proved to be crucial.

Regarding the interoperability of the *Emfit* device and the *COMES*[®] platform, the data after a night's sleep was stored on the company's (*Emfit*) server. The data could then be accessed through the *Emfit* API. From the API information, it was specified to push the data to a specified web hookup. From the Specification of the device API, only the sleep summary was relevant to our study. The interface for transferring data from the *Emfit* system to the integrative platform was implemented through the application of JavaScript Object Notation (JSON) messages and worked without any problems. An API provided by *Emfit* was used for this purpose (Fig. 2). The transmission and visualization of the data onto the platform proved to be successful. Initially, there was a problem with the visualization of the sleep data when a test person had a longer (more than 20 minutes) absence from bed during the night. However, this has been quickly resolved.

A document was drafted with errors found in the *COMES*[®] platform that had arisen in the course of the pre-testing. Since the data transfer was almost entirely successful, the main inaccuracies we found were concerning the visual representation of the data, for example a time representation error in various graphs and the appearance of random warning messages. These errors were recorded and immediately reported to the software company. The errors were resolved during the pre-test phase.

With regard to the integration of data from the *TheraTrainer tigo*[®], the data transferred from the device to the added *Raspberry Pi* was communicated to the *COMES*[®] server via the network protocol SOAP, which originally stands for Simple Object Access Protocol. SOAP is a messaging/communication protocol specification for exchanging structured information. Via SOAP, the transmissions only work from sender to receiver. These requests can be combined in applications, allowing for more complicated requests and responses, which can extend to a communication between two systems. Via SOAP, we defined the rules for constructing and interpreting the transferred messages. It was also used so that the external systems do not have access to servers. The interface allowed only certain functions to be made available to users, which was established to ensure the security of the data, since SOAP has advantages particularly for highly confidential files like personal health information. However, SOAP has the disadvantage of being somewhat restrictive. Thus, for a more flexible (but less secure) architectural style with loose guidelines and recommendations, one might prefer Representational State Transfer (REST). The training data was transmitted to the *COMES*[®] database with JSON, an open standard file and data interchange format (Fig. 2). Despite what its name suggests, JSON has the advantage of being language-independent (like SOAP) and can be accessed/used with any programming language, not only JavaScript.

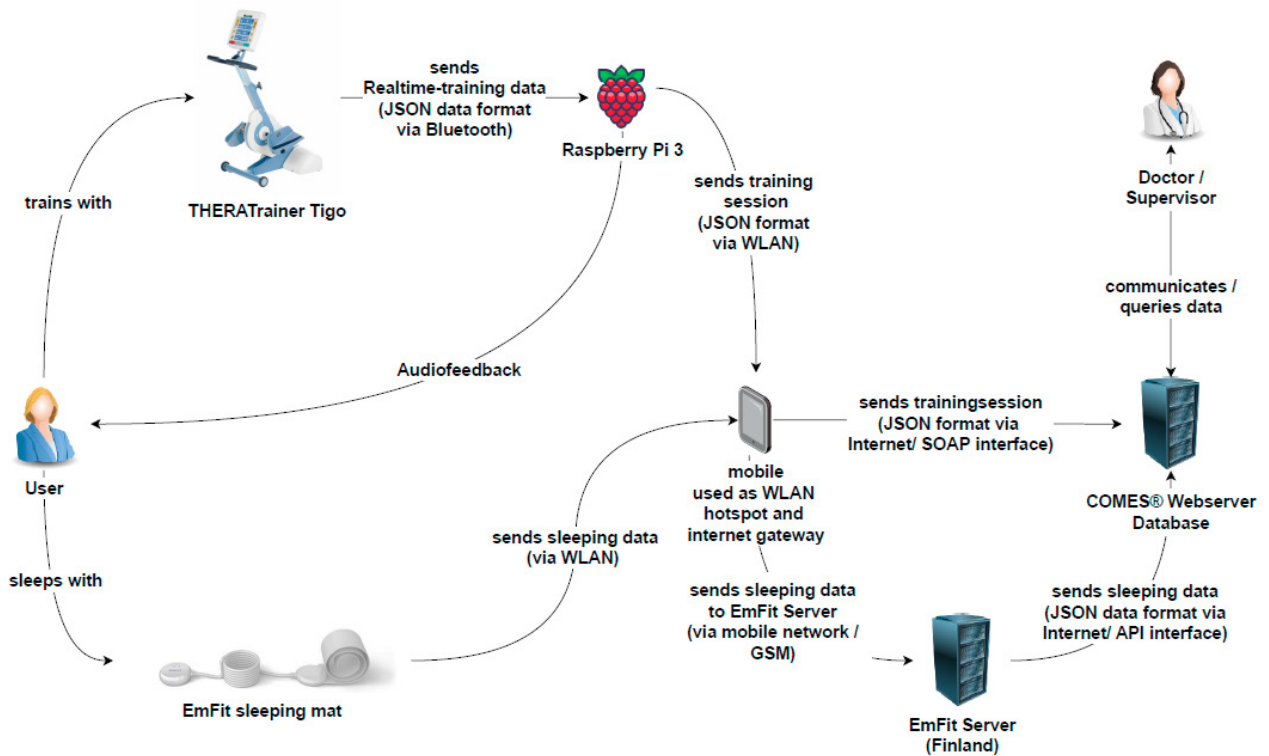


Fig. 2. System architecture of *COMES*[®] in connection with two assistive health devices.

In the evaluation under real-life conditions with elderly participants, the complex data transfer of the exercise data via Raspberry Pi was less effective. However, this was mostly due to communication difficulties between the assistive device (*TheraTrainer tigo*[®]) and the Raspberry, which in turn was caused mainly by problems regarding the sequence of booting and connection establishment between the devices and not because of issues with the Bluetooth connection. Once the connection was established and the training was finished, the data transfer to the *COMES*[®] server was mostly satisfactory. In rare cases, data transfer was not possible, and we were not able to find the root cause for the connection and/or data transfer malfunction. In retrospect, the main cause of these problems was arguably the extensive structure of the exercise system, which was – in contrast to the *EmFit* setup – more complex with more data stations/devices and therefore more susceptibility to error. In addition, users had to follow certain steps upon system activation, which was another possible source of error, again, in contrast to the *EmFit* device that did not require attending to. We therefore highlight that any modification and extension of an existing single device with subsequently more data transfer points – especially if it requires users to follow several steps for product activation – may cause additional issues regarding connectivity and data communication.

Also, a stable WLAN-enabled Internet gateway must be available for the patient, which is not always the case with older people and has to be considered when planning to implement wireless technology in older people's homes. Similar to the reflections of the graphical *EmFit* data representation, retrospectively, we found some graphical or logical inconsistencies in the visual representation.

5. Conclusions and future perspectives

In this article, we aimed to describe the process of connecting two distinct assistive home health technologies to an integrating data platform. After defining the specifications and preparing the software architecture for intermodular

communication (interoperability), we evaluated the established interconnections and data networks first in a laboratory setting and subsequently in a home setting with 11 elderly participants.

Importantly, our observations underline the need for tests and evaluations in real-life circumstances. If technical assistance systems are to be used more extensively in home care, their effectiveness and performance must be evident in this very setting. It is therefore vital for the success of assistive health applications that the technology is tested and refined in a way that generates broad acceptance, promotes adherence to exercises, and ensures intuitive handling by the facilitators and the users themselves [19]. Ideally, older adults should be involved as “co-designers” in the process to enable naturalistic and realistic insights on everyday life aspects and interactions with digital technologies in the home environment [20].

A telemedicine/telecare system such as *COMES*[®] may be used as a supplementary measure for therapeutic, medical and nursing services or for extended care [9]. The utilization of assistive health technologies and applications, like sleep analysis and home exercise devices, may attenuate the caregiver’s stress and workload [10].

The telemedical system *COMES*[®] was designed in a way that it can cooperate and communicate with other assistance systems, and therefore be networked with a variety of different sensor devices. This is to say that it can be used for a wide variety of indications, for example cardiovascular diseases, obesity, sleep disturbances, fall prevention or telematic rehabilitation, opening up future options of utilizing the data, e.g., for pattern recognition, early warning, and personalized recommendations [3,9,10]. If needed, the data collected by the sensors may be forwarded to a professional health care worker, or service center. The necessary measures can then be initiated: For example, the doctor calls the patient into consultation, the patient receives a reminder from the system not to forget his or her rehabilitation units or medication, or the service center alerts the health professionals in an emergency [9,11,21].

In general, our results underline some of the recommendations of prior research [2]. Among the most important prerequisites for successful intermodular integration of home health devices that should be considered at early stages of research and development are adaptability, interoperability, user experience, and security [22].

Interoperability and adaptability specifically imply that platforms should be extensible to support heterogeneous protocols and sensor devices and be interoperable with heterogeneous devices and a cloud. The architecture should be modular and extensible to also handle different sensor configurations. When choosing the assistive devices that are to be connected to an integrating platform/server, besides reliable functionality of the device itself, considering the options and complexity for data transmission and communication of the device at an early stage is recommended.

Regarding the user experience, accessibility, usability, reliability, and timeliness are among the most important requirements of the patient/user-side of remote health monitoring technologies. In terms of usability, direct and timely feedback from the devices to the user via an integrating data platform will likely reinforce the certainty that the device is working correctly. Consequently, this would also help to avoid certain operating errors without unnecessary delay. The experiences made during our study are in line with the usability heuristic known from [23].

Also, keep in mind that developing technology for older and vulnerable clients requires an interdisciplinary approach to supervision and maintenance, both from the viewpoint of healthcare and technology. This entails a steadfast concept of service, support, and maintenance, which might benefit from an extended period of familiarization and instruction for caregivers and those in need of care in the early stages of technology implementation.

To comply with the rising requests of data policies worldwide and to increase the acceptance of both caregivers and elderly technology users, sound security and privacy concepts are vital to strengthen confidentiality, reliability, and accessibility of assistive home health technology.

Acknowledgements

This research was funded by the EU Interreg V-Program “Alpenrhein-Bodensee-Hochrhein”, Project “IBH Living Lab Active and Assisted Living”, grant ABH066. The manuscript creation was supported by the Bavarian State Ministry of Health and Care (project “CARE REGIO”).

We would like to thank the participants and caregivers of the Workers’ Welfare Association (AWO) Schwarzwald-Baar e.V. We also want to express our appreciation to the medica Medizintechnik GmbH and EmFit Ltd for the technical support. For the use of *COMES* we thank Prof. Dr. Bernhard Wolf from Steinbeis-Transferzentrum Medizinische Elektronik und Lab on Chip-Systeme and the Heinz Nixdorf Foundation.

References

- [1] World Health Organization, "WHO guideline: Recommendations on digital interventions for health system strengthening, World Health Organization, Geneva, 2019.
- [2] Philip, Nada Y., Joel J. P. C. Rodrigues, Honggang Wang, Simon James Fong, and Jia Chen (2021), "Internet of Things for In-Home Health Monitoring Systems: Current Advances, Challenges and Future Directions", *IEEE J. Select. Areas Commun.* 39 300–310. <https://doi.org/10.1109/JSAC.2020.3042421>.
- [3] Friedrich, Petra, Thomas Spittler, and Bernhard Wolf, "COMES® - a concept for personalized Telemedical Assistance, in: 2011 IEEE International Conference on Consumer Electronics -Berlin (ICCE-Berlin), Berlin, Germany, IEEE, 2011, pp. 140–144.
- [4] Abdi, Jordan, Ahmed Al-Hindawi, Tiffany Ng, and Marcela P. Vizcaychipi (2018), "Scoping review on the use of socially assistive robot technology in elderly care", *BMJ Open* 8 e018815. <https://doi.org/10.1136/bmjopen-2017-018815>.
- [5] Kiljander, Jussi, Alfredo D'elia, Francesco Morandi, Pasi Hyttinen, Janne Takalo-Mattila, Arto Ylisaukko-Oja, Juha-Pekka Soininen, and Tullio Salmon Cinotti (2014), "Semantic Interoperability Architecture for Pervasive Computing and Internet of Things", *IEEE Access* 2 856–873. <https://doi.org/10.1109/ACCESS.2014.2347992>.
- [6] Malwade, Shwetambara, Shabbir Syed Abdul, Mohy Uddin, Aldilas Achmad Nursetyo, Luis Fernandez-Luque, Xinxin Katie Zhu, Liezel Cilliers, Chun-Por Wong, Panagiotis Bamidis, and Yu-Chuan Jack Li (2018), "Mobile and wearable technologies in healthcare for the ageing population", *Comput. Methods Programs Biomed.* 161 233–237. <https://doi.org/10.1016/j.cmpb.2018.04.026>.
- [7] Conti, Massimo, Simone Orcioni, Natividad Martínez Madrid, Maksym Gaiduk, and Ralf Seepold, "A Review of Health Monitoring Systems Using Sensors on Bed or Cushion, in: I. Rojas, F. Ortuño (Eds.), Bioinformatics and Biomedical Engineering, Springer International Publishing, Cham, 2018, pp. 347–358.
- [8] Sovacool, Benjamin K., and Dylan D. Del Furszyfer Rio (2020), "Smart home technologies in Europe: A critical review of concepts, benefits, risks and policies", *Renewable and Sustainable Energy Reviews* 120 109663. <https://doi.org/10.1016/j.rser.2019.109663>.
- [9] Wolf, Bernhard, Christian Scholze, and Petra Friedrich, "Digitalisierung in der Pflege – Assistenzsysteme für Gesundheit und Generationen, in: M.A. Pfannstiel, S. Krammer, W. Swoboda (Eds.), Digitale Transformation von Dienstleistungen im Gesundheitswesen III, Springer Fachmedien Wiesbaden, Wiesbaden, 2017, pp. 113–135.
- [10] Wolf, Bernhard, Petra Friedrich, and Christian Scholze (in press), "Electronic assistance systems in times of demographic change", *Social Innovation in Long-Term Care Through Digitalization - Proceedings of the German-Italian Workshop LTC-2021*.
- [11] Hinderer, Kai-Uwe, Philipp Eberle, Petra Friedrich, and Bernhard Wolf, "A concept for integration of rehabilitation in smart homes, in: 2014 IEEE Fourth International Conference on Consumer Electronics Berlin (ICCE-Berlin), Berlin, Germany, IEEE, 2014, pp. 7–8.
- [12] Fuchs, Dominik, Jakob Tiebel, and Petra Friedrich (2020), "Device-supported training and assessment for fall prevention of community-dwelling elderly: a pre-post mixed methods study", *Procedia Computer Science* 176 2322–2331. <https://doi.org/10.1016/j.procs.2020.09.293>.
- [13] Gaiduk, Maksym, Ralf Seepold, Juan A. Ortega, and Natividad Martínez Madrid (2020), "Comparison of sleep characteristics measurements: a case study with a population aged 65 and above", *Procedia Computer Science* 176 2341–2349. <https://doi.org/10.1016/j.procs.2020.09.297>.
- [14] Merilahti, Juho, Ari Saarinen, Juha Parkka, Kari Antila, Elina Mattila, and Ilkka Korhonen (2007), "Long-term subjective and objective sleep analysis of total sleep time and sleep quality in real life settings", *Annu. Int. Conf. IEEE Eng. Med. Biol. Soc.* 2007 5202–5205. <https://doi.org/10.1109/iembs.2007.4353514>.
- [15] Huysmans, Dorien, Pascal Borzé, Dries Testelmans, Bertien Buyse, Tim Willemen, Sabine van Huffel, and Carolina Varon (2019), "Evaluation of a Commercial Ballistocardiography Sensor for Sleep Apnea Screening and Sleep Monitoring", *Sensors (Basel)* 19. <https://doi.org/10.3390/s19092133>.
- [16] Simonsen, Erik Bruun (2014), "Contributions to the understanding of gait control", *Dan. Med. J.* 61 B4823.
- [17] Power, Valerie, and Amanda M. Clifford (2013), "Characteristics of optimum falls prevention exercise programmes for community-dwelling older adults using the FITT principle", *Eur Rev Aging Phys Act* 10 95–106. <https://doi.org/10.1007/s11556-012-0108-2>.
- [18] Shen, Cuiling, Fang Liu, Liqun Yao, Zhongyuan Li, Li Qiu, and Suzhu Fang (2018), "Effects of MOTomed movement therapy on the mobility and activities of daily living of stroke patients with hemiplegia: a systematic review and meta-analysis", *Clin. Rehabil.* 32 1569–1580. <https://doi.org/10.1177/0269215518790782>.
- [19] Schulz, Richard, Hans-Werner Wahl, Judith T. Matthews, Annette de Vito Dabbs, Scott R. Beach, and Sara J. Czaja (2015), "Advancing the Aging and Technology Agenda in Gerontology", *Gerontologist* 55 724–734. <https://doi.org/10.1093/geront/gnu071>.
- [20] Vaziri, Daryoush D., Konstantin Aal, Corinna Ogonowski, Thomas von Rekowski, Michael Kroll, Hannah R. Marston, Rakel Poveda, Yves J. Gschwind, Kim Delbaere, Rainer Wieching, and Volker Wulf (2016), "Exploring user experience and technology acceptance for a

fall prevention system: results from a randomized clinical trial and a living lab", *Eur Rev Aging Phys Act* 13 6.
<https://doi.org/10.1186/s11556-016-0165-z>.

- [21] Hinderer, Kai-Uwe, Petra Friedrich, Otto Hobel, and Bernhard Wolf, "Telematic rehabilitation 2.0, in: 2013 IEEE Third International Conference on Consumer Electronics ı Berlin (ICCE-Berlin), IFA Fairground, Berlin, Germany, IEEE, 2013, pp. 8–12.
- [22] Shkilniuk, Yurii, Ángel Serrano Alarcón, Maksym Gaiduk, Ralf Seepold, and Natividad Martínez Madrid (2020), "Analysis of Survey Tools for Recommender Systems in the Selection of Ambient Assisted Living Technologies", *Procedia Computer Science* 176 2332–2340. <https://doi.org/10.1016/j.procs.2020.09.294>.
- [23] Nielsen, Jakob, "Enhancing the explanatory power of usability heuristics, in: Proceedings of the SIGCHI conference on Human factors in computing systems celebrating interdependence - CHI '94, Boston, Massachusetts, United States, ACM Press, New York, New York, USA, 1994, pp. 152–158.