Aus dem Institut/der Klinik CC13 – Forschungsgruppe Geriatrie
der Medizinischen Fakultät Charité – Universitätsmedizin Berlin

DISSERTATION

Assistive and Robotic Health Technologies and Devices (ATD) for Vulnerable Patient Groups: Identification of User Requirements on the Basis of ATD Usage Barriers and Perceived ATD Strengths

zur Erlangung des akademischen Grades
Doctor rerum medicinalium (Dr. rer. medic.)

vorgelegt der Medizinischen Fakultät
Charité – Universitätsmedizin Berlin

von

Cornelia Simone Eva Eicher
aus München

Datum der Promotion: 18.12.2020

Table of Contents

List of Tables

1. Abstract

1.1. Abstract German

Einführung: Die Bedeutung von assistiven und robotischen Gesundheitstechnologien (AT) für Menschen mit Unterstützungsbedarf nimmt zu. Insbesondere vulnerable Patientengruppen mit chronischen Erkrankungen können von deren Nutzung profitieren. Eine hohe Benutzerfreundlichkeit (Usability) von assistiven Technologien ist für eine erfolgreiche Implementierung von entscheidender Bedeutung, ist jedoch oftmals nur unzureichend gegeben. Der Anspruch für eine bedarfsgerechte Technologieentwicklung besteht daher in der Identifikation von Nutzeranforderungen und der Bereitstellung von Empfehlungen. Diese werden jedoch meist für bestimmte Zielgruppen und Technologien ausgesprochen, daher ist die Übertragbarkeit eingeschränkt. Ziel der vorliegenden Arbeit ist es, allgemeingültige Bedarfe vulnerabler Patientengruppen an AT zu identifizieren.

Methodik: Es wurden Ergebnisse aus vier Studien herangezogen, in denen AT mit unterschiedlichen vulnerablen Patientengruppen getestet wurden. Zwei Studien untersuchten AT Prototypen im Laborsetting: ein Biofeedback-System mit Personen mit chronischen Rückenschmerzen und einen robotergestützten Gangtrainer mit geriatrischen und jüngeren neurologischen Patienten. Zwei weitere Studien untersuchten kommerziell erhältliche AT: AT mit Patienten mit ALS und eine Gesundheits-App mit Patienten mit Fettstoffwechselstörungen. Innerhalb der Studien wurden verschiedene Methoden wie leitfadengestützte Interviews und Fragebögen angewendet.

Ergebnisse: Es konnten allgemeingültige Bedarfe für vulnerable Patientengruppen identifiziert werden. Diese begründen sich in Zielgruppengerechtigkeit, geringem Nutzungsaufwand, technischer und sicherheitsrelevanter Stabilität, Attraktivität, Komfort sowie in einer für die Zielgruppe angemessenen Bedienbarkeit und Erlernbarkeit.

Fazit: Diese Arbeit schafft ein Bewusstsein für die Herausforderungen vulnerabler Patienten beim Gebrauch von AT und liefert wichtige Erkenntnisse zu ihren Anforderungen für einen reibungslosen Einsatz von AT. Abschließend ist zu bemerken, dass vulnerable Patientengruppen kontinuierlich in den Entwicklungsprozess von AT miteinbezogen werden müssen. Die wichtigsten Empfehlungen für die zukünftige Gestaltung bestehen dabei in der Beachtung des Nutzer- und Nutzungskontexts, sowie einer schnellen Bedien- und Funktionsweise, einer umfassenden Systemunterweisung mit der Zielgruppe und der Entwicklung modular aufgebauter AT.

1.2. Abstract English

Introduction: The importance of assistive and robotic health technologies (ATD) for persons in need of support has been increasing. Especially vulnerable patient groups facing chronic diseases benefit from ATD. A high usability of ATD is crucial for a successful implementation but is often insufficient. Therefore, the requirement for a needs-based technology development comprises the identification of user requirements and provision of recommendations and guidelines. Nevertheless, those are valid for specific user groups and technologies only and transferability is restricted. Thus, the aim of this work is to identify universal requirement for ATD for vulnerable patients.

Methodology: Results from four different studies evaluating various ATD with diverse vulnerable patient groups were included in this work. Two studies examined prototypes of ATD in a lab setting: a biofeedback system with persons with chronic back pain and an over-ground robot-supported gate trainer with both geriatric and younger neurologic patients. The other two studies examined commercially available ATD: different ATD for ALS patients and a health app for patients with lipid metabolism disorders. Different research designs such as semi-structured interviews and questionnaires were used within the studies.

Results: Several universal requirements areas of vulnerable patient groups could be identified. Those comprise target group adequacy, low usage effort, technical and safety related reliability, high level of stimulation and comfort, ease of use and ease of learning.

Conclusion: This work has created awareness about the challenges of vulnerable patient groups using ATD and has identified their requirements for a smooth ATD usage. In conclusion, it is most important to involve vulnerable patients at every stage of ATD development. In this context, the main recommendations for future ATD development are to carefully consider target group needs and ATD usage context, to provide a quick system operation and functioning, as well as to offer an adequate and comprehensive user training and create modular-based ATD.

2. Introduction and Background

The discussion about the lack of professional caregivers within the context of demographic change in Germany has proceeded towards a socio-political debate about the use and implementation of robotic and assistive technologies and devices (ATD) for support and caregiving purposes. Technology-driven support can enhance the autonomy and independence of persons with physical and/ or mental impairments and at the same time disburden formal and informal caregivers. The World Health Organization (WHO) defines **assistive technology and devices (ATD)** as those, whose "*primary purpose is to maintain or improve an individual's functioning and independence to facilitate participation and to enhance overall well-being*" (*WHO | Assistive Devices and Technologies*, n.d.). According to the American Assistive Technology Act of 2004 ATD is "*any item, piece of equipment, or product system, whether acquired commercially, modified, or customized, that is used to increase, maintain, or improve functional capabilities of individuals with disabilities*" (Bausch et al., 2005). ATD comprise, but are not limited to, mobility devices, information and communication systems, augmentative and alternative communicating systems and hearing aids, and orthoses and lifter systems (Larsson Ranada & Lidström, 2017). Furthermore, the significance of mHealth (mobile health) and robot-supported technologies for healthcare has increased during the past decade.

Research has shown, that ATD can enhance mobility, communication, perceived autonomy and social participation, and can contribute to an increased quality of life (Caligari et al., 2013; Nguyen et al., 2018; Pedrozo Campos Antunes et al., 2019; Requejo et al., 2015). Smartphones and tablets supporting mobile health apps can be used as intervention strategies to facilitate and enhance disease management. They show positive effects for example on medication adherence (Marcolino et al., 2018; Steinert et al., 2015). Robotic-supported technologies have gained significance for the health and caregiving sector. For example, social-assistive and companion robots such as Pepper (Pandey & Gelin, 2018) are used for persons with (mild) cognitive or physical impairments. Other robotic technologies are used to complement physiotherapy and rehabilitation, e.g. robotic treadmills, or exoskeletons. Thus, ATD can offer support for broad scenarios, ranging from disease management, to maintaining independence, regaining body functionalities, increasing quality of life and social participation (Lancioni & Singh, 2014).

Especially vulnerable patient groups, who often show terminal impairments and therefore an increased need for support, may benefit from ATD. Even though a uniform definition of **vulnerable patients** does not exist (Boldt, 2019), the European legislation (EU Regulation No. 536/2014 of the European Parliament and Council and ICH GCP E6 (R1)), provides the following categories of vulnerable patient groups:

Pregnant or breastfeeding women, minors, students and employees, people suffering from multiple chronic conditions or terminally ill, ethnic minorities, older people, military, people affected by mental health disorders.

The prevalence of vulnerable patient groups with reported disabilities is high with 26 % of persons aged 16 and above in the EU28 reporting health-related and above 6 months lasting limitations in usual activities, the share increasing among persons aged 65 and above (Scholz, 2015). Chronic illnesses are complex and multicausal, have long latency periods and, according to the current state of medical research, are largely incurable (Bernell & Howard, 2016). Vulnerable patients with (multiple) chronic conditions or who are terminally ill are often less capable of exercising their rights, are more often prone to infringements regarding social participation, dignity or well-being and are to a certain extent dependent from the support by third parties. Thus, the aim for vulnerable chronically ill patients exceeds the stabilization of the disease process and slowing down the course of the disease: the regain of control over their lives, a certain level of autonomy and quality of life are essential and need to be the center of the overall patientcare (Badura & Feuerstein, 1994, p. 11), which can be addressed by the usage of ATD.

However, to support persons in need, ATD must be developed in an appropriate way to be accepted, implemented, and adequately used by the target group. A variety of models and theories have been developed and applied to help understand the underlying motives of technology acceptance, and to consider them during technology development. Common models are for example the Theory of Reasoned Action (TRA) (Fishbein & Ajzen, 1977), the Technology Acceptance Model (TAM) (Davis, 1989), the Matching Person and Technology Model (MPT) (Scherer, 1998), or the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003). Some of these models were refined, adapted or are new constructs developed for specific study purposes. They generally describe in different ways factors which can affect technology acceptance, such as social and subjective norms, performance expectancy, perceived usefulness, perceived ease of use, and attitude toward use. Developers and researchers apply them to predict, influence and finally increase user acceptance of new technology.

Diverse instruments have been developed to ultimately assess innovative technologies on the other side of the development process. An extensive range of tools is available for the evaluation of usability, user experience (UX) or design. They comprise both quantitative and qualitative methods, such as questionnaires, semi-structured interviews, or think-aloud methods. Some technology evaluation approaches are developed for specific areas such as e-commerce or for specific target groups such as children, others may be used more generally (compare Kuniavsky et al., 2012; Sarodnick & Brau, 2006). Despite the above mentioned models and measure instruments, research has demonstrated unmet user requirements in ATD (Arthanat et al., 2009), which can lead to frustration, non-use or even the rejection of ATD - every third ATD prescribed to adult users is abandoned (Brown-Triolo, 2003; Scherer & Craddock, 2002). This gap between the user groups' requirements and their realization has to be closed, ATD must meet the user requirements in order to be accepted (Broadbent et al., 2009; van Ommeren et al., 2018). A prominent approach to close this gap is the User-Centered Design (UCD), which aims to achieve a high usability and the best possible UX by placing the user at the center of the technology development process (Rubin & Chisnell, 2008, pp. 12–13). The consideration of context-relevant user needs, including for example psychosocial and environmental factors, can facilitate a smooth, beneficial, and sustainable ATD use by the target groups (Alves & Matsukura, 2016). While a lot of research has been conducted to identify user needs and has provided recommendations and guidelines, those are usually valid for one specific user or patient group only, and focus on one specific ATD (compare *Connecticut Assistive Technology Guidelines*, n.d.; Encarnação, Azevedo, Gelderblom, Newell, & Mathiassen, 2013; Iancu & Iancu, 2017). As far as technology acceptance models are concerned, these provide information about general factors influencing technology acceptance and do not refer to vulnerable patients. Moreover, according to Sun et al. (2013), the greater focus of studies using these models for health technologies is on understanding the acceptance by professionals and thus the patients' health technology acceptance needs a closer examination. Overall, recommendations and guidelines are not universally valid for all patient groups and types of ATD. Nevertheless, a basic understanding of the requirements of vulnerable patients towards ATD is highly significant for a user-centered development and to close the gap between user requirements and their realization. Due to the value of ATD for vulnerable patients, the aim of this work is to identify requirements for future ATD development which are universally valid, and to discuss corresponding recommendations.

2.1. Research Questions

The following primary research questions is central for this work:

What are universally valid requirements of vulnerable patients on assistive and robotic health technologies?

In order to answer the research question, the following sub questions were processed:

1. What usage barriers do vulnerable patient groups face using ATD?
2. What are the perceived strengths of ATD?

3. Material and Methodology

To identify requirements which are universally valid for ATD use in vulnerable patient groups, a broad database is needed, including a broad range of patient groups and types of ATD, which will increase the transferability of the results. Therefore, four studies evaluating diverse ATD types with different vulnerable patient groups were included. All patient groups were characterized by chronic conditions affecting physical functionalities. Three of the studies were designed as prospective intervention studies assessing the following ATD types: a mobile health app for persons with lipid metabolism disorders (SMARTPATIENT), a Wii console with biofeedback for persons with chronic low back pain (ALFRED), and a robot-supported over-ground gait trainer for persons with neurologic diseases (MOPASS). The remaining of the included four studies was designed as a retrospective interview study, asking patients with amyotrophic lateral sclerosis (ALS) about current ATD in usage (ROBINA). The main objective of the included studies was to assess user acceptance and usability of the developed assistive technologies. For this purpose, different instruments were used, which are presented in the following paragraphs. They share the identification of strengths and weaknesses or usage barriers of innovative technologies. These can be used to define user requirements. The underlying assumption was that usage barriers are unmet needs which must be addressed for ATD to develop their full potential and be accepted by the users. Strengths, however, are considered as those qualities or attributes of ATD which have been approved by the users, and thus lead to a high usability and acceptance. Therefore, they must be sustained and are a component of user requirements. Consequently, ATD usage barriers and ATD strengths were extracted from all four studies as basis for the

determination of requirements. As a next step, the individual results were grouped according to their subject matter, and these groups of barriers and strengths were assigned to each other by subject and aggregated to one category each. The categories thus formed represent the universal requirements areas of vulnerable patient groups towards ATD. In ROBINA, ATD strengths were not directly addressed by the study participants. However, they phrased recommendations how ATD could be improved. Those recommendations will be integrated into the results as potential strengths. Finally, the results will be discussed using further literature and providing possible recommendations.

For each study, all participants received information material prior to the study about its aim, process of the study, data protection and had at least 24 hours to decide whether to take part or not. They gave their written consent prior to the start of the study. An Ethics Committee approved each study. Socio-demographic data was collected from all participants by questionnaires developed by the Geriatrics Research Group of the Charité, Universitätsmedizin Berlin. A pretest was conducted in each study to ensure comprehensibility and consistency of the assessments. Quantitative data was analyzed using Excel and SPSS Statistics 22 (IBM Corp, Armonk, New York). All data was analyzed for normal distribution using the Kolmogorov-Smirnov Test. Prerequisites for statistical tests were performed as needed. Qualitative results from interviews were analyzed using content analysis according to Mayring (2016).

The following paragraphs provide a general overview about the included studies.

3.1. STUDY SMARTPATIENT

"Effects of a long-term smartphone-based selfmonitoring intervention in patients with lipid metabolism disorders"

The study was conducted as part of the R&D project *SMARTPATIENT*. The aim of the study was to assess a health smartphone app, regarding usage, impact on health-related behavior, usability, and acceptability. Participants suffering from lipid metabolism disorders were asked to download and use the app over the course of one year. Relevant data was collected via questionnaires posted to the users and logging data of the app.

3.1.1. Description of study population

One hundred patients (19 female, 81 male) were recruited from the outpatient lipid department of the Charité, who were diagnosed with lipid metabolism disorders, aged 18 or older and in possession of a smartphone. They were excluded when having a legal representative or showing severe cognitive deficits. The participants were between 25 and 81 years old (m = 52.6 years, SD ± 10.6); 61 % were 50 years and older.

3.1.2. Description of study conduct and analysis procedure

The 100 participants received written instructions about the health app and were asked to download and use it for one year after they had given written informed consent to take part in the study. After the duration of 12 months, all participants received a questionnaire by mail or email about usage of the app (frequency of use, reasons for non-usage), usability, and changes in medication adherence. Usability was measured by the validated System Usability Scale (SUS) (Bangor et al., 2008) which consists of 10 questions to evaluate the perceived usability of a complete system and provides an overall score, ranging from 0 (worst imaginable device) to 100 (best imaginable device). The response rate was 63.0 % (n = 63). Logging data from the app, e.g. time of app registration and monthly activity, was automatically collected during the study period. All collected data was analyzed with univariate and descriptive methods, using arithmetic mean and frequency distribution. To investigate the differences between app users and non-users (non-paired samples) the t-test was used for normally distributed data and the Mann-Whitney-U test for non-normally distributed data.

3.2. STUDY ALFRED

“Evaluation of biofeedback based bridging exercises on older adults with low back pain: A randomized controlled trial (RCT)”

This randomized controlled trial was conducted as part of the R&D project *ALFRED*. The aim of the study was to evaluate a biofeedback system for bridging exercises in adults with chronic low back pain (LBP) regarding effectiveness of intervention, perceived disability, usability, and user acceptability. Participants were randomly assigned to three arms (biofeedback, standard care, and control). Relevant data was collected by questionnaires and several physical tests.

3.2.1. Description of study population

Sixty-two participants (44 female, 18 male) aged 65 or older (m = 74.0 years, SD ± 5.7) with chronic low back pain (LBP) were included to the RCT study through leaflets placed in local pharmacies, senior activity centers and GP´s offices. They were randomized to the three arms biofeedback exercises (BF) (n = 22), standard exercises (SC) (n = 20) and control group (C) (n = 20). Two participants withdraw their participation from the biofeedback group and one from the control group straight after assignment, and sixteen participants were lost to follow-up. Persons with either subacute or chronic low back pain were included. Persons with any self-reported or apparent present affective or cognitive diseases, participation in another intervention study, legal care, immobility, recent surgical intervention, acute herniated disc or spinal tumor, and no written consent were excluded.

3.2.2. Description of study conduct and analysis procedure

The two intervention groups performed identical bridging exercises of 16 variations twice a week over the course of 12 weeks. Each session lasted 30 minutes. The study researchers developed a standardized protocol providing instructions for the bridging exercises. The biofeedback exercises in the BF group were performed on Wii Balance Boards (one for each participant's feet, one for the shoulders). The participants received feedback on their performance on a Samsung Galaxy Tab 2 tablet attached to a tripod in front of the foot Balance Board. The standard group performed the exercises on a regular sports mat, and the control group received no intervention. Thus, only the results from the BF group assessing the biofeedback system are relevant for this work. The User Experience Questionnaire (UEQ) (Laugwitz et al., 2008) was used to evaluate the usability. It consists of 26 opposite pairs of items within 6 sub-scales measuring the overall impression of and human-machine-interaction with a system. Additionally, a questionnaire developed by the Geriatrics Research group was used to assess the participants' perceived enjoyment and motivation during the exercises. Participants were excluded when they missed more than six sessions.

3.3. STUDY MOPASS

"Usability and acceptability by a younger and older user group regarding a mobile robot-supported gait rehabilitation system"

The study was conducted within the R&D project *MOPASS.* The aim of the study was to assess a mobile over-ground robot-supported gait system, regarding usability, acceptability, and barriers of usage. Two patient groups were included in the study, a group of geriatric patients aged 60 and above, and a group of younger patients aged 59 and below. The system was tested in a clinical setting during five therapy sessions. Relevant data was collected via semi-structured interviews and questionnaires.

3.3.1. Description of study population

Sixteen participants were included in the study and tested the MOPASS system. Ten of them were geriatric patients from the Charité and assigned to group G (geriatric); six of them were younger patients from a neurological rehabilitation center (Neurologisches Rehabilitationszentrum Friedehorst) and assigned to group Y (young). Three participants dropped out of group G during the tests due to an increasing feeling of insecurity, all the other participants completed the test sessions. They were between 69 and 84 years old (m = 75.7 years, SD ± 5.5) in group G, and between 20 and 55 years old (m = 36.2 years, SD ± 14.1) in group Y. Patients aged 18 or older with the risk/ fear of falling and insecure gait were included; patients with fresh fractures, recent implantation of endoprosthetics, orientation disorders, as well as cardiovascular diseases and no written consent were excluded. The study sample received the standard gait rehabilitation therapy Bobath (neuro-developmental treatment) (Gillen, 2015). Stroke/ brain hemorrhage was the main reason for gait rehabilitation in group G (5/7), followed by accidents and falls (2/7). Stroke/brain hemorrhage, hemiplegia and other reasons were equally represented in group Y (each 2/6).

3.3.2. Description of study conduct and analysis procedure

Two different patient groups evaluated the MOPASS system in a clinical setting over the course of five regular therapy sessions conducted by trained therapists. Each session lasted 20 minutes. The system was pretested together with the therapists who were trained in operating the system correctly. The system was adapted to each participant's individual therapy needs and physical properties. The participants were asked to rate the

system after each therapy session. To measure system usability, the SUS was used. Additionally, the AttrakDiff assessment was used (Hassenzahl et al., 2003) to assess the systems usability and appearance. By using a list of 23 opposite adjectives (e.g., “simple-complicated”), users can assess interactive products regarding their functionality. To assess the acceptability of MOPASS, two questionnaires were developed by the Geriatrics Research Group of the Charité, containing questions about the handling, user comfort, appearance, perceived safety, gait support, senior-friendliness, and ease of learning. To collect qualitative data about the system’s usability, structured interviews developed by the Geriatrics Research Group were used. The aim was to gather further information about the overall therapy process and to assess the quality of the therapy using the MOPASS system.

3.4. STUDY ROBINA

“Experiences with Assistive Technologies and Devices (ATD) in patients with Amyotrophic Lateral Sclerosis (ALS) and their Caregivers”

The study was conducted within the R&D project *ROBINA*. The aim of the study was to assess usage, usability, and acceptability of different ATD used by patients with amyotrophic lateral sclerosis (ALS). Three groups were interviewed: patients with ALS, informal caregivers, and professional caregivers. Relevant data was collected via semi-structured interviews that were conducted individually with patients and formal caregivers, and additionally with professional caregivers in a focus group interview.

3.4.1. Description of study population

Five ALS patients from the Charité were included who were between 55 and 79 years old (m = 66.2 years, SD ± 11.3), had a clinical diagnosis of ALS (according to the revised Al-Escorial criteria) and the ability to speak without major effort. Four of them were male. They showed severe functional limitations for mobility, arm and hand movement and were characterized by a high level of need in the activities of daily living and personal hygiene. Five relatives were included who were between 50 and 83 years old (m = 63.6 years, SD ± 13.6), two of them were male, and all were partners and involved in the caregiving processes of ALS patients. Five professional caregivers from the Pflegewerk Berlin GmbH (a caregiving network) were included who were certified nurses and had experience with nursing ALS patients for at least one year. They were between 38 and

48 years old (m = 44.8 years, SD ± 4.1), all of them were female. The results of the formal and informal caregivers were included to obtain subjective data for analysis. Participants were excluded when showing cognitive impairments, psychological issues such as depression and when given no written consent.

3.4.2. Description of study conduct and analysis procedure

An interview guideline was developed for this study by a group of researchers trained in qualitative research and a medical doctor with expertise in the treatment and ATD provision of ALS patients. The guideline consisted of questions about living and caregiver/ support situation, expectations to and experiences with assistive technology, and usage barriers and related problems. Patients, informal and formal caregivers were likewise interviewed using this guideline. The same two researchers trained in conducting interviews were present during all interviews. All interviews were audio recorded. Relevant information was additionally filled in a standardized protocol form.

4. Results

From each study, ATD usage barriers and ATD strengths were extracted and are presented in the following. They will be categorized and merged according to their subject matter in 4.5 following to the approach described in 3.

4.1. STUDY SMARTPATIENT

4.1.1. Usage barriers

The participants did not or rarely use the app as they perceived it as not being useful (34.4 %, n = 21, 2 missing) and/ or as it was too much effort using it (23.0 %, n = 14, missing). This was underpinned by the finding that users took on average 5.1 drugs compared to nonusers who took 3.3 drugs, indicating that nonusers were less severely affected and thus probably perceived the app as less useful. Further reasons they reported were lack of time (13.1 %), technical problems (18.0 %), disruptive in daily life (13.1 %), forgot usage (14.8 %), and health issues (4.9 %). In the category “other reasons”, participants named loss of smartphone, lack of data security, and usage of other apps.

4.1.2. Strengths

45.9 % (n = 17) of the users perceived the app as useful in lipid metabolism disorder management. In this context, users rated disease-relevant functions of the app. The provided daily to-do-list and the therapy plan for medication intake and physical activity received the best ratings (79.3 % (n = 23, 8 missing) / 76.0 % (n = 19, 12 missing) “good” or “very good”). Furthermore, the structure and the health report were rated positively by 55.6 % (n = 25) and 50.0 % (n = 6), respectively. Generally, the app was rated as user-friendly by 62.2 % (n = 23) of the participants. The study also demonstrated an increase in the number of users with high medication adherence, from 16.2 % (n = 6) to 29.7 % (n = 11), and an increase of physical activity in the user group indicating the effectiveness of the health app.

4.2. STUDY ALFRED

4.2.1. Usage barriers

Based on the results of the UEQ, participants in the BF group rated the “attractiveness” (overall impression), “efficiency” (fast reaction, tasks without unnecessary effort), “dependability” (user feels in control, system is secure and predictable) and “stimulation” (exciting and motivating, fun to use) “below average” to “bad”. Usage issues were mainly raised regarding the biofeedback trainer. Mostly, they were related to connectivity problems between the boards and tablets. This resulted in reconnecting tasks by the instructor, and in 34 documented instances in shifting from the biofeedback to standard intervention for the participant as no connection could be established anymore. Furthermore, the boards were occasionally sliding on the floor and had to be repositioned. Related but not limited to that, participants negatively assessed the comfort of the system, especially the hard surface of the shoulder board.

4.2.2. Strengths

Participants rated the “novelty” (creative design, catches interest of users) and “perspicuity” (easy to get familiar with, ease of learning) of the biofeedback system as “above average” to “good”.

4.3. STUDY MOPASS

4.3.1. Usage barriers

Usability rating with the AttrakDiff assessment showed that the geriatric participants (group G) evaluated the system as rather cumbersome and complicated compared to the younger neurologic group (group Y). The system was additionally rated regarding several features and functions with a questionnaire (1 = very good, 7 = very bad). The attachment and detachment of the system received scores in the lowermost third by all participants (mean = 4.6), so did the overall appearance (mean G = 4.0, Y = 4.7). The fit and weight received moderate scores by the two groups (mean = 3.0 and 2.9, respectively), so did the wearing comfort (mean G = 3.4, Y = 3.0) and the manufacturing quality (mean G = 2.7, Y = 3.8). The system was rather not perceived as being easy to use (mean G = 2.7, Y = 1.5). Furthermore, the study participants criticized the attachment and detachment procedure of the system as time-consuming and exhausting, so was the solving of technical issues raised during the tests. At the same time, geriatric users reported the need for technical support, whereas this was not the case in the younger group. The leg shells of the system left pressure marks on a few patients. Related to that, they were criticized as not being individually adjustable and uncomfortable during the training. Furthermore, the system received negative quotes about its appearance as being bulky and looking technical.

4.3.2. Strengths

Overall, participants from the younger group perceived the robot-supported gait trainer as more suitable for severely affected persons. This was also reflected by higher usability ratings by the geriatric group compared to the younger neurologic group (scores ranging between 40 and 88 compared to 43 and 73), and statements demonstrating a perceived benefit for the geriatric group. In this context, the geriatric group rated the general acceptance of the system better than the younger group, with 57 % and 33 % as rather good, respectively, and 33 % of the younger group as “rather bad”. At the same time, the system was perceived as “senior-friendly” by 57 % of the geriatric participants.

The AttrakDiff ratings showed that both groups perceived the system as rather manageable, clearly structured, and practical as well as functional and predictable. Both groups regarded the ease of learning as “rather good” or “very good”. The younger

participants regarded it as rather straightforward and simple. Overall, the possibility to partly adapt the system to individual physical properties was perceived as an advantage.

4.4. STUDY ROBINA

4.4.1. Usage barriers

The study sample described technical malfunctioning as drastic experiences, especially in life sustaining ATD such as ventilating machines or mobility devices such as electric wheelchairs. In this context, safety features were regarded as crucial. However, some participants expressed their mistrust regarding the overall safety level of certain ATD mentioning negative experiences. Furthermore, the lack of crucial technical features, such as voice output or long-lasting batteries was criticized in some of the evaluated assistive technologies. Likewise, many study participants criticized the lack of certain ATD control units and functionalities to adapt to individual needs and to the progressive nature of ALS, which led to limited or non-usage by the patients. On the other hand, many technologies were reported to offer a vast number of features, settings, and hardware adaptation options as well as parameter settings, which was perceived as complex and time-consuming, especially by professional caregivers.

Apart from functionality and operability, the exterior shape and appearance of assistive technologies were described as influencing factor for its appropriateness and usage. Oversized, overweight, and bulky ATD was inoperable and exhausting for many caregiving persons, especially women, and needed the support from a third person. This was also identified as an issue of lacking adaptability to certain living circumstances, e.g. to smaller or fully furnished flats, the patients' need for mobility and social participation. Furthermore, stigmatization was another issue raised within the study. Stigmatization did derive from both internal factors, such as the perception of being disabled due to ATD usage, and from external factors, such as social attitudes and perceptions of persons with impairments and visible technical aids. In this context, a few participants criticized the appearance of some ATD.

4.4.2. Strengths

The study provided important insights into what ALS patients would consider to be a strength in assistive technologies and devices. The adequate functionality and usability were of fundamental importance for the participants. According to them, assistive

technologies should consider the living circumstances and social needs of ALS patients and be adaptable to them, e.g. by offering mobile solutions. They should also offer modular-based operation systems and features, in order to be adaptable to the progressive nature of the ALS disease and related altering needs of patients and caregivers. Furthermore, ATD should offer a quick and easy operation as well as launch of features in order to avoid operating errors, counteract frustration and to foster social participation. In this context, training workshops provided by the supplier companies should consistently involve both professional and informal caregivers and should be conducted at the time of the implementation and iterative after that. The interviewees also reported requirements regarding an appealing appearance to avoid stigmatization and increase quality of life.

4.5. Requirements of vulnerable patients on ATD

The following table presents the identified ATD usage barriers and strengths from the included studies, which were matched and merged to the ATD requirements categories valid for vulnerable patients, as described in paragraph 3: ensure target group appropriateness, decrease usage effort, increase technical sufficiency, increase user stimulation, increase comfort, increase ease of use and ease of learning. For a better allocation of the results to the study of origin, references were provided for each barrier and strength.

*Table 1: Summary of the results**

Usage barriers	Strengths	Requirement
- not perceived as useful by target group[1,3] - lack of essential features[1,4] - forgot usage[1] - use of an alternative[1,4] - health issues[1,4] - disruptive in daily life[1,4]	- usefulness for purpose[3] - disease-relevant functions[1] - adaptability of system[4] - consideration of individual needs and user context[3] - approved effectiveness[1,4]	Ensure target group appropriateness
- too much effort using it[1,4] - time expenditure[1,3,4] - low efficiency (slow reaction, unnecessary effort needed)[2,4] - loss of technological medium[1]	- straightforward and predictable[3] - quick reaction, operation and launch of features[4] - clear structure[1,3]	Decrease usage effort
- technical problems[1,2,3], failure and fear of failure [3,4] - technical support needed[3,4] - safety concerns[3,4] and lack of data security[1] - low dependability (user does not feel in control, system is not secure and predictable)[2,3]	- high functionality[1,4] - safety features[3,4] - technical support and adequate user training[3,4]	Increase technical sufficiency
- low stimulation (exciting and motivating, fun to use)[2] - low attractiveness[2,3,4] - low manufacturing quality[3] - stigmatization[4]	- high novelty (creative design, catches interest of users)[2] - appealing appearance[4]	Increase user stimulation
- discomfort[2,3] - physical pain and exhaustion[3,4] - technology not individually adjustable[3,4]	- adjustable to physical properties[3]	Increase comfort
- cumbersome and complicated[3,4] - overload of features and settings[3,4] - improper weight and size[3,4] - technology not adjustable to usage environment[4] - external support needed[3,4] - low ease of use and ease of learning[3]	- high perspicuity (easy to get familiar with, ease of learning)[2,3] - manageable[3,4] - adaptability of system[3,4] - modular-based[3,4]	Increase ease of use and learning

* Extracted from study SMARTPATIENT ([1]), ALFRED ([2]), MOPASS ([3]), ROBINA ([4]).

5. Discussion

Research has shown that every third ATD prescribed to adult users is abandoned (Brown-Triolo, 2003; Scherer & Craddock, 2002) and that ATD often do not meet the users' requirements (Arthanat et al., 2009). This gap between requirements and realization must be closed to avoid frustration and ATD abandonment. Therefore, this work sought to determine universally valid requirements for vulnerable patient groups by identifying ATD usage barriers and perceived ATD strengths from four different ATD evaluation studies. The identified six requirements areas will be discussed in the following paragraphs.

The results showed that a (perceived) usefulness and usage purpose of ATD for the target group is essential. This is one of the core principles of user-centered design, as it ensures to consider preferences and needs according to the target group and as low usability can demotivate to use ATD (Morsi et al., 2016, p. 146). Thus, a user-centered design can help to provide products and services with the highest possible degree of target group appropriateness. The provision of crucial disease-relevant features and functions as well as waiving unnecessary features can help to improve the adequacy for the target group and increase user engagement.

User integration, however, goes beyond integration within technology development. A study from 2006 showed that persons in need of ATD who are not carefully involved in the ATD acquirement and delivery process and whose requirements are neglected, use those ATD concerned less often than actual necessary (Hedberg-Kristensson et al., 2006; Larsson Ranada & Lidström, 2017). The determinants perceived usefulness and ease of use, user participation in design, and attitude toward use are also described in the TAM by Davis (1989), highlighting their impact on system use and relevance for technology acceptance. Consequently, guidelines and policies should tackle both ATD development and provision processes to provide comprehensive recommendations.

Another identified requirement is the adaptability of ATD to individual needs, which can contribute to both an increased usefulness and expansion of the target group due to a new flexibility in usage and implementation. ATD which is adaptable to individual characteristics such as bodily properties, and which considers individual capacities such as technology commitment will also reduce discomfort, physical pain, and exhaustion in usage. However, it is also a requirement to establish assessments to evaluate ATD regarding comfort, as no clear concept for its measurement has been established yet

(Pearson, 2009). This would include the consideration of the user and usage context, such as living circumstances, the location of use as well as further user groups, e.g. caregivers who may have diverging needs in comparison to patients. Often, requirements analyses cannot sufficiently consider user and usage context, thus results may be biased and significant information for the adequate results interpretation and transferability may be missing. This does not diminish the significance but impedes the realization.

Especially patients with altering needs require adaptable ATD. In a study, assistive technology that was not adaptable to the changing needs of patients was proved to most likely effect its abandonment (Phillips & Zhao, 1993). Generally, an adaptability of ATD to meet the patients' individual needs is requested. At the same time, high adaptation levels are often not realizable from the economic perspective. Furthermore, many adjustment possibilities and functions are often regarded as complicated by users, including patients and caregivers, and require an increased time expenditure in turn. In this context, the results demonstrated the need to increase ease of use and ease of learning.

ATD is supposed to support persons with impairments and must therefore be easy to get familiar with instead of over-complicating the handling and effecting frustration and abandonment. The UTAUT model discusses a similar factor which is central in affecting technology acceptance. It is referred to as "effort expectancy", and is defined as "the degree of ease associated with the use of the system" (Venkatesh et al., 2003). Results from a qualitative study examining the requirements of persons with hearing and vision impairments and Autism Spectrum Disorders showed the most important requirement being ease of use, followed by flexibility and adaptability (Nierling et al., 2018). This can be achieved by omitting unnecessary features or functions, focusing on the appropriateness of ATD regarding the target group and by providing clear structures. In general, the control of ATD as well as its launch and the launch of features and functions should happen fast. This can enhance participation (e.g. quick communication), reduce invested time and frustration and increase the willingness to use ATD. Efficiency can be increased, and time expenditure and unnecessary effort reduced. However, in a study from 2013 which examined a robotic wheelchair, study participants preferred the by the wheelchair autonomously chosen most comfortable path compared to the shortest path (Morales et al., 2013). The comfort space was however linked to the safest space regarding collision with walls, therefore the term comfort must be regarded with caution, and participants were non-impaired persons. However, it shows there exist more important categories than speed and saving of time.

A position paper from 2013 about assistive technology service delivery in Europe reinforces the awareness from 1995 about the significance of training workshops for patients and professionals stating that *"training and education should be provided at various levels (from "AT for dummies" to postgraduate qualification). AT skills should also include the awareness of one's own knowledge limitation, the ability to ask for advice when needed, the understanding that AT does not solve all problems, the need to prevent damages (e.g. frustration) caused by improper use of AT"* (Andrich et al., 2013). In this context, Brandt et al. found that training with ATD use can have benefits regarding the reduction of non-use, increase of ATD satisfaction and quality of life (Brandt et al., 2015; Larsson Ranada & Lidström, 2017). Therefore, effective training workshops should consider the specific needs and circumstances of the user groups and be adopted to their characteristics, skills, and deficits. Caregivers and relatives must be included as they play a crucial role in the disease management process and they are valuable counselors for vulnerable patients. Those workshops should be held on a regular basis, to refresh the knowledge and reduce operating errors and the need of technical support.

Another requirement was to prevent the development of oversized, overweight, and bulky ATD regarding again the user and usage context. The dimensions of ATD play a crucial role, especially when implemented in private homes or for mobile use. However, it is also a matter of appearance, which plays an important role in stigmatization. Assistive technology may make impairments visible. Therefore, to avoid stigmatization and non-use due to fear of stigmatization, it is inevitable to decrease the potential for stigmatization and instead to include motivating elements that enhance a regular and sustainable use of ATD. It also includes to create attractive ATD, with high novelty levels that catches the interest of the user and increases the enjoyment and motivation to use the technology. In addition, a good manufacturing quality should be strived for and can contribute to an appealing appearance.

One major requirement is to reduce technical failure and increase technical reliability. Especially vulnerable patients who are dependent from assistive technologies or who rely on them for disease management purposes, cannot dispense with faulty ATD and additionally might lack of alternatives, and thus need to deal with it. Apart from fear of failure and frustration, issues with ATD may also effect an increased time expenditure and users may experience a loss of control and demand technical support. As a result, patients may lose both the motivation for and their trust in the ATD. In this context, the safety feeling in ATD is also of high importance. In a study surveying recent work in

assistive technologies to improve mobility in persons with impairments, Cowan et al. identified three areas, which should be addressed to improve the integration of ATD. Those were improvements to the assistive technology mechanics (including hardware and software), improvements to the user-technology physical interface, and improved shared control between the user and the technology (Cowan et al., 2012). As vulnerable patients often suffer from impairments which concern body functionalities, they are often incapable to react to technical issues or malfunctioning, or they might even experience a medical emergency, therefore safety and the potential to immediately stop ATD in the case of an emergency plays a major role and must not be underestimated.
Associated to safety, data security is of a certain importance. As health-related data may be generated, collected, and saved, it must be a priority to prevent unauthorized access and provide a high level of data security especially in times of (sensitive) data theft and data publication. Furthermore, it is extremely important to inform the users about data collection and control and their own role within data protection to empower them.

The identified requirements are deeply connected with each other. The effort using assistive technology for example influences the invested time. The invested effort is in turn influenced by technology reliability, usability aspects, and ease of use. Both the adaptation to individual needs and usage and user context can have a sustainable impact on the perceived comfort and target group appropriateness of ATD, and so can its appearance and attractiveness, especially regarding stigmatization and discrimination. This interconnection is of high significance. Experts working on assistive technologies must therefore know that tackling one field has far reaching consequences and vice versa.

5.1. Limitations

There are several limitations to this work. The identified results are based on merely four studies with rather small sample sizes, few heterogeneous patient groups and partly short intervention times. More and larger patient groups from a broader evidence base should be included and longer ATD intervention times should be provided to verify the results and generate a larger data basis for recommendations. A mixed approach of qualitative and quantitative methods is usually considered a strength. However, in this context, quantitative methods may constitute a limitation. In contrast to qualitative methods, the

applied usability and acceptability assessments within the studies imply default categories. Therefore, derived requirements are to a certain extent predetermined and thus some of them do not origin from the user groups. Nevertheless, different assessments were used in the studies, resulting in a greater variety of the results and thus greater data basis. Furthermore, only persons with physical impairments were included. The results are therefore not transferable to persons with mental impairments.

6. Conclusion

This work provided important insights in usage barriers vulnerable patient groups face while using assistive and robotic health technology and pointed out perceived strengths of ATD. Using the identified barriers and strengths, the following universal requirements of vulnerable patients on ATD could be provided: target group adequacy, low usage effort, technical and safety related reliability, level of stimulation and comfort, ease of use and ease of learning. Moreover, the work gave recommendations for future ATD development: to carefully consider target group needs and ATD usage context, to provide a quick system operation and functioning, and to offer adequate user training and create modular-based ATD. The presented results are plausible and confirm recommendations from specific ATD guidelines. Nevertheless, we have learned from research that even though the development of ATD has been subject to user-centered design aiming at considering user requirements, there exists a gap between user needs and needs realization, often resulting in frustrated users and ATD abandonment. Therefore, it is of great importance to point out the significance of the topic and to contextualize and condense the relevant findings for future ATD construction.

7. Reference List

Alves, A. C. de J., & Matsukura, T. S. (2016). Theoretic models for recommendation and implementation of assistive technology. *Cadernos de Terapia Ocupacional Da UFSCar*, *24*(3), 591–599. https://doi.org/10.4322/0104-4931.ctoAO1078

Andrich, R., Mathiassen, N.-E., Hoogerwerf, E.-J., & Gelderblom, G. J. (2013). Service delivery systems for assistive technology in Europe: An AAATE/EASTIN position paper. *Technology and Disability*, *25*(3), 127–146. https://doi.org/10.3233/TAD-130381

Arthanat, S., Nochajski, S. M., Lenker, J. A., Bauer, S. M., & Wu, Y. W. B. (2009). Measuring Usability of Assistive Technology From a Multicontextual Perspective: The Case of Power Wheelchairs. *American Journal of Occupational Therapy*, *63*(6), 751–764. https://doi.org/10.5014/ajot.63.6.751

Badura, B., & Feuerstein, G. (1994). *Systemgestaltung im Gesundheitswesen: Zur Versorgungskrise der hochtechnisierten Medizin und den Möglichkeiten ihrer Bewältigung*. Juventa-Verlag.

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. https://doi.org/10.1080/10447310802205776

Bausch, M. E., Mittler, J. E., Hasselbring, T. S., & Cross, D. P. (2005). The Assistive Technology Act of 2004: What Does It Say and What Does It Mean? *Physical Disabilities: Education and Related Services*, *23*(2), 59–67.

Bernell, S., & Howard, S. W. (2016). Use Your Words Carefully: What Is a Chronic Disease? *Frontiers in Public Health*, *4*. https://doi.org/10.3389/fpubh.2016.00159

Boldt, J. (2019). The concept of vulnerability in medical ethics and philosophy. *Philosophy, Ethics, and Humanities in Medicine*, *14*(1), 6. https://doi.org/10.1186/s13010-019-0075-6

Brandt, As., Christensen, A., & Grünberger, P. (2015). How to Accomplish the Assistive Technology Service Delivery Process for Adults in Order to Obtain the Best Outcomes; A Literature Review. *Studies in Health Technology and Informatics*, 469–477. https://doi.org/10.3233/978-1-61499-566-1-469

Broadbent, E., Stafford, R., & MacDonald, B. (2009). Acceptance of Healthcare Robots for the Older Population: Review and Future Directions. *International Journal of Social Robotics*, *1*(4), 319–330. https://doi.org/10.1007/s12369-009-0030-6

Caligari, M., Godi, M., Guglielmetti, S., Franchignoni, F., & Nardone, A. (2013). Eye tracking communication devices in amyotrophic lateral sclerosis: Impact on disability and quality of life. *Amyotrophic Lateral Sclerosis and Frontotemporal Degeneration*, *14*(7–8), 546–552. https://doi.org/10.3109/21678421.2013.803576

Connecticut Assistive Technology Guidelines. (n.d.). 243.

Cowan, R. E., Fregly, B. J., Boninger, M. L., Chan, L., Rodgers, M. M., & Reinkensmeyer, D. J. (2012). Recent trends in assistive technology for mobility. *Journal of NeuroEngineering and Rehabilitation*, *9*(1), 20. https://doi.org/10.1186/1743-0003-9-20

Davis, F. D. (1989). Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. *MIS Quarterly*, *13*(3), 319. https://doi.org/10.2307/249008

Encarnação, P., Azevedo, L., Gelderblom, G. J., Newell, A. F., & Mathiassen, N.-E. (Eds.). (2013). *Assistive technology: From research to practice, AAATE 2013*. IOS Press.

Fishbein, M., & Ajzen, I. (1977). *Belief, attitude, intention, and behavior: An introduction to theory and research*.

Gillen, G. (2015). *Stroke Rehabilitation: A Function-based Approach*. Elsevier Health Sciences.

Hassenzahl, M., Burmester, D. M., & Koller, F. (2003). AttrakDiff: Ein Fragebogen zur Messung wahrgenommener hedonischer und pragmatischer Qualität. In G. Szwillus & J. Ziegler (Eds.), *Mensch & Computer 2003* (pp. 187–196). Vieweg+Teubner Verlag. https://doi.org/10.1007/978-3-322-80058-9_19

Hedberg-Kristensson, E., Ivanoff, S. D., & Iwarsson, S. (2006). Participation in the Prescription Process of Mobility Devices: Experiences among Older Patients. *British Journal of Occupational Therapy*, *69*(4), 169–176. https://doi.org/10.1177/030802260606900404

Iancu, I., & Iancu, B. (2017). Elderly in the Digital Era. Theoretical Perspectives on Assistive Technologies. *Technologies*, *5*(3), 60. https://doi.org/10.3390/technologies5030060

Kuniavsky, M., Goodman, E., & Moed, A. (2012). *Observing the user experience: A practitioner's guide to user research* (2nd ed). Morgan Kaufmann.

Lancioni, G. E., & Singh, N. N. (2014). Assistive Technologies for Improving Quality of Life. In G. E. Lancioni & N. N. Singh (Eds.), *Assistive Technologies for People with Diverse Abilities* (pp. 1–20). Springer New York. https://doi.org/10.1007/978-1-4899-8029-8_1

Larsson Ranada, Å., & Lidström, H. (2017). Satisfaction with assistive technology device in relation to the service delivery process—A systematic review. *Assistive Technology*, *31*(2), 82–97. https://doi.org/10.1080/10400435.2017.1367737

Laugwitz, B., Held, T., & Schrepp, M. (2008). Construction and Evaluation of a User Experience Questionnaire. In A. Holzinger (Ed.), *HCI and Usability for Education and Work* (Vol. 5298, pp. 63–76). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-540-89350-9_6

Marcolino, M. S., Oliveira, J. A. Q., D'Agostino, M., Ribeiro, A. L., Alkmim, M. B. M., & Novillo-Ortiz, D. (2018). The Impact of mHealth Interventions: Systematic Review of Systematic Reviews. *JMIR MHealth and UHealth*, *6*(1), e23. https://doi.org/10.2196/mhealth.8873

Mayring, P. (2016). *Einführung in die qualitative Sozialforschung: Eine Anleitung zu qualitativem Denken* (6., überarbeitete Auflage). Beltz.

Morales, Y., Kallakuri, N., Shinozawa, K., Miyashita, T., & Hagita, N. (2013). Human-comfortable navigation for an autonomous robotic wheelchair. *2013 IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2737–2743. https://doi.org/10.1109/IROS.2013.6696743

Morsi, Y. S., Shukla, A., & Rathore, C. P. (Eds.). (2016). *Optimizing assistive technologies for aging populations*. Medical Information Science Reference.

Nguyen, B. J., Kim, Y., Park, K., Chen, A. J., Chen, S., Van Fossan, D., & Chao, D. L. (2018). Improvement in Patient-Reported Quality of Life Outcomes in Severely Visually Impaired Individuals Using the Aira Assistive Technology System. *Translational Vision Science & Technology*, *7*(5), 30. https://doi.org/10.1167/tvst.7.5.30

Nierling, L., Maia, M. J., Hennen, L., Wolbring, G., Bratan, T., Kukk, P., Čas, J., Capari, L., Krieger-Lamina, J., Mordini, E., European Parliament, European Parliamentary Research Service, & Scientific Foresight Unit. (2018). *Assistive technologies for people with disabilities. Study Part III, Part III,*. http://www.europarl.europa.eu/RegData/etudes/IDAN/2018/603218/EPRS_IDA(2018)603218(ANN3)_EN.pdf

Pandey, A. K., & Gelin, R. (2018). A Mass-Produced Sociable Humanoid Robot: Pepper: The First Machine of Its Kind. *IEEE Robotics & Automation Magazine*, *25*(3), 40–48. https://doi.org/10.1109/MRA.2018.2833157

Pearson, E. J. M. (2009). Comfort and its measurement – A literature review. *Disability and Rehabilitation: Assistive Technology*, *4*(5), 301–310. https://doi.org/10.1080/17483100902980950

Pedrozo Campos Antunes, T., Souza Bulle de Oliveira, A., Hudec, R., Brusque Crocetta, T., Ferreira de Lima Antão, J. Y., de Almeida Barbosa, R. T., Guarnieri, R., Massetti, T., Garner, D. M., & de Abreu, L. C. (2019). Assistive technology for communication of older adults: A systematic review. *Aging & Mental Health*, *23*(4), 417–427. https://doi.org/10.1080/13607863.2018.1426718

Phillips, B., & Zhao, H. (1993). Predictors of Assistive Technology Abandonment. *Assistive Technology*, *5*(1), 36–45. https://doi.org/10.1080/10400435.1993.10132205

Requejo, P. S., Furumasu, J., & Mulroy, S. J. (2015). Evidence-Based Strategies for Preserving Mobility for Elderly and Aging Manual Wheelchair Users: *Topics in Geriatric Rehabilitation*, *31*(1), 26–41. https://doi.org/10.1097/TGR.0000000000000042

Rubin, J., & Chisnell, D. (2008). *Handbook of usability testing: How to plan, design, and conduct effective tests* (2nd ed). Wiley Pub.

Sarodnick, F., & Brau, H. (2006). *Methoden der Usability Evaluation: Wissenschaftliche Grundlagen und praktische Anwendung* (1. Aufl). Huber.

Scherer, M. J. (1998). *Matching person & technology: A series of assessments for evaluating predispositions to and outcomes of technology use in rehabilitation, education, the workplace & other settings*. Institute for Matching Person & Technology.

Scholz, N. (2015). *Assistive technologies to support people with disabilities*. EPRS | European Parliamentary Research Service. http://www.europarl.europa.eu/EPRS/EPRS-Briefing-559513-Assistive-technologies-support-people-with-disabilities-FINAL.pdf

Steinert, A., Haesner, M., Tetley, A., & Steinhagen-Thiessen, E. (2015). Nutzungsverhalten einer Gesundheitsapplikation zum Selbstmonitoring von Senioren. *Prävention und Gesundheitsförderung*. https://doi.org/10.1007/s11553-015-0510-5

Sun, Y., Wang, N., Guo, X., & Peng, Z. (2013). Understanding the acceptance of mobile health services: A comparison and integration of alternative models. *Journal of Electronic Commerce Research : JECR*, *14*(2).

van Ommeren, A. L., Smulders, L. C., Prange-Lasonder, G. B., Buurke, J. H., Veltink, P. H., & Rietman, J. S. (2018). Assistive Technology for the Upper Extremities After Stroke: Systematic Review of Users' Needs. *JMIR Rehabilitation and Assistive Technologies*, *5*(2), e10510. https://doi.org/10.2196/10510

Venkatesh, Morris, Davis, & Davis. (2003). User Acceptance of Information Technology: Toward a Unified View. *MIS Quarterly*, *27*(3), 425. https://doi.org/10.2307/30036540

WHO | Assistive devices and technologies. (n.d.). Retrieved June 20, 2018, from http://www.who.int/disabilities/technology/en/

Alle im vorliegenden Manuskript beschriebenen Untersuchungen am Menschen wurden mit Zustimmung der zuständigen Ethikkommission, im Einklang mit nationalem Recht sowie gemäß der Deklaration von Helsinki von 1975 (in der aktuellen, überarbeiteten Fassung) durchgeführt. Von allen beteiligten Patienten liegt eine Einverständniserklärung vor.

8. Eidesstattliche Versicherung

„Ich, Cornelia Eicher, versichere an Eides statt durch meine eigenhändige Unterschrift, dass ich die vorgelegte Dissertation mit dem Thema: Assistive and Robotic Health Technologies and Devices (ATD) for Vulnerable Patient Groups: Identification of User Requirements on the Basis of ATD Usage Barriers and Perceived ATD Strengths selbstständig und ohne nicht offengelegte Hilfe Dritter verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel genutzt habe.
Alle Stellen, die wörtlich oder dem Sinne nach auf Publikationen oder Vorträgen anderer Autoren beruhen, sind als solche in korrekter Zitierung kenntlich gemacht. Die Abschnitte zu Methodik (insbesondere praktische Arbeiten, Laborbestimmungen, statistische Aufarbeitung) und Resultaten (insbesondere Abbildungen, Graphiken und Tabellen) werden von mir verantwortet.

Meine Anteile an etwaigen Publikationen zu dieser Dissertation entsprechen denen, die in der untenstehenden gemeinsamen Erklärung mit dem/der Betreuer/in, angegeben sind. Für sämtliche im Rahmen der Dissertation entstandenen Publikationen wurden die Richtlinien des ICMJE (International Committee of Medical Journal Editors; www.icmje.og) zur Autorenschaft eingehalten. Ich erkläre ferner, dass mir die Satzung der Charité – Universitätsmedizin Berlin zur Sicherung Guter Wissenschaftlicher Praxis bekannt ist und ich mich zur Einhaltung dieser Satzung verpflichte.

Die Bedeutung dieser eidesstattlichen Versicherung und die strafrechtlichen Folgen einer unwahren eidesstattlichen Versicherung (§§156, 161 des Strafgesetzbuches) sind mir bekannt und bewusst.“

_____ _____

Datum Unterschrift

9. Anteilserklärung an den erfolgten Publikationen

Frau Cornelia Eicher hatte folgenden Anteil an den folgenden Publikationen:

Publikation 1: [Anika Steinert, **Cornelia Eicher**, Marten Haesner und Elisabeth Steinhagen-Thiessen], [Effects of a long-term smartphone-based selfmonitoring intervention in patients with lipid metabolism disorders], [Assistive Technology], [2018]

Beitrag der Promovendin:	
Studienplanung:	Mitbestimmung der verwendeten Messmethoden und Assessments, maßgebliche Beteiligung an der Erstellung der Antragsunterlagen (Ethikvotum, Datenschutzvotum)
Studiendurchführung:	Rekrutierung und Aufklärung der Studienteilnehmer, Einholung der Einwilligungserklärung, Versenden der Fragebögen
Auswertung:	Unterstützung bei der Dateneingabe, -kontrolle, -modifikation, deskriptive statistische Auswertung
Publikation:	Literaturrecherche, maßgebliche Erstellung und Bearbeitung des gesamten Manuskripts infolgedessen der komplette Hintergrund und die komplette Diskussion entstanden sind, maßgebliche Beteiligung am Ergebnisteil, Erstellung von Tabelle 1 und Figur 4, sowie Überarbeitung des Manuskripts im Rahmen des Reviewprozesses

Publikation 2: [Florian Feldwieser, Jörn Kiselev, Sandro Hardy, Augusto Garcia-Agundez, **Cornelia Eicher**, Elisabeth Steinhagen-Thiessen und Stefan Göbel], [Evaluation of biofeedback based bridging exercises on older adults with low back pain: A randomized controlled trial], [Physiotherapy Practice and Research], [2018]

Beitrag der Promovendin:	
Studienplanung:	Festlegung und Planung des Studiendesigns im Studienteam, Mitbestimmung der verwendeten Messmethoden und Assessments, maßgebliche Beteiligung an der Erstellung der Antragsunterlagen (Ethikvotum, Datenschutzvotum)
Studiendurchführung:	Rekrutierung der Studienteilnehmer, Einholung der Einwilligungserklärung, Beteiligung an der Intervention und Durchführung der Parametermessungen
Auswertung:	Unterstützung bei der Dateneingabe, -kontrolle, -modifikation, qualitative und statistische Auswertung
Publikation:	Literaturrecherche, maßgebliche Beteiligung am gesamten Manuskript infolgedessen die komplette Methodik entstanden ist, sowie Figur 1, Tabelle 1 und 2, maßgebliche Beteiligung an der Diskussion sowie maßgebliche Überarbeitung im Rahmen des Reviewprozesses

Publikation 3: [**Cornelia Eicher**, Marten Haesner, Matthias Spranger, Olena Kuzmicheva, Axel Gräser & Elisabeth Steinhagen-Thiessen], [Usability and acceptability by a younger and older user group regarding a mobile robot-supported gait rehabilitation system], [Assistive Technology], [2017]

Beitrag der Promovendin:	
Studiendurchführung:	Rekrutierung der Studienteilnehmer, Einholung der Einwilligungserklärung, Begleitung der Intervention
Auswertung:	Datenextraktion und -synthese, Dateneingabe, -kontrolle, -modifikation, qualitative und statistische Auswertung

Publikation:	Literaturrecherche, Erstellen des gesamten Manuskripts als Erstautorin, Erstellen aller Abbildungen und Tabellen, Einreichung des Manuskripts beim Journal, sowie Überarbeitung im Rahmen des Reviewprozesses

Publikation 4: [**Cornelia Eicher**, Jörn Kiselev, Kirsten Brukamp, Diana Kiemel, Susanne Spittel, André Maier, Thomas Meyer, Ursula Oleimeulen und Marius Greuèl], [Experiences with assistive technologies and devices (ATD) in patients with amyotrophic lateral sclerosis (ALS) and their caregivers], [Technology and Disability], [2020]

Beitrag der Promovendin:	
Studienplanung:	Festlegung und Planung des Studiendesigns im Studienteam, Mitbestimmung der verwendeten Messmethoden und Assessments, Erstellen der Antragsunterlagen (Ethikvotum, Datenschutzvotum) Aufstellen der Forschungsziele
Studiendurchführung:	Rekrutierung der Studienteilnehmer, Aufklärung und Einholen der Einwilligungserklärung, Durchführung der Interviews
Auswertung:	Datenaufbereitung, qualitative Auswertung
Publikation:	Literaturrecherche, Erstellen des gesamten Manuskripts als Erstautorin, Erstellen aller Abbildungen und Tabellen, Einreichung des Manuskripts beim Journal, sowie Überarbeitung im Rahmen des Reviewprozesses

_____

Unterschrift, Datum und Stempel des betreuenden Hochschullehrers/der betreuenden Hochschullehrerin

_____

Unterschrift des Doktoranden/ der Doktorandin

10. Druckexemplare der ausgewählten Publikationen

Publikation 1: [Anika Steinert, **Cornelia Eicher**, Marten Haesner und Elisabeth Steinhagen-Thiessen], [Effects of a long-term smartphone-based selfmonitoring intervention in patients with lipid metabolism disorders], [Assistive Technology], [2018]
(impact factor: 1.264)

Publikation 2: [Florian Feldwieser, Jörn Kiselev, Sandro Hardy, Augusto Garcia-Agundez, **Cornelia Eicher**, Elisabeth Steinhagen-Thiessen und Stefan Göbel], [Evaluation of biofeedback based bridging exercises on older adults with low back pain: A randomized controlled trial], [Physiotherapy Practice and Research], [2018]
(impact factor: 0.290)

Publikation 3: [**Cornelia Eicher**, Marten Haesner, Matthias Spranger, Olena Kuzmicheva, Axel Gräser & Elisabeth Steinhagen-Thiessen], [Usability and acceptability by a younger and older user group regarding a mobile robot-supported gait rehabilitation system], [Assistive Technology], [2017]
(impact factor: 1.037)

Publikation 4: [**Cornelia Eicher**, Jörn Kiselev, Kirsten Brukamp, Diana Kiemel, Susanne Spittel, André Maier, Thomas Meyer, Ursula Oleimeulen und Marius Greuèl], [Experiences with assistive technologies and devices (ATD) in patients with amyotrophic lateral sclerosis (ALS) and their caregivers], [Technology and Disability], [2020]

Publikation 1:

Steinert, A., Eicher, C., Haesner, M., & Steinhagen-Thiessen, E. (2018). Effects of a long-term smartphone-based self-monitoring intervention in patients with lipid metabolism disorders. *Assistive Technology*. https://doi.org/10.1080/10400435.2018.1493710

Publikation 2:

Feldwieser, F., Kiselev, J., Hardy, S., Garcia-Agundez, A., Eicher, C., Steinhagen-Thiessen, E., & Göbel, S. (2018). Evaluation of biofeedback based bridging exercises on older adults with low back pain: A randomized controlled trial. *Physiotherapy Practice and Research*, *39*(1), 15–25. https://doi.org/10.3233/PPR-170109

Publikation 3:

Eicher, C., Haesner, M., Spranger, M., Kuzmicheva, O., Gräser, A., & Steinhagen-Thiessen, E. (2017). Usability and acceptability by a younger and older user group regarding a mobile robot-supported gait rehabilitation system. *Assistive Technology*, 1–9. https://doi.org/10.1080/10400435.2017.1352051

Publikation 4:

Eicher, C., Kiselev, J., Brukamp, K., Kiemel, D., Spittel, S., Maier, A., Meyer, T., Oleimeulen, U., & Greuèl, M. (2019). Experiences with assistive technologies and devices (ATD) in patients with amyotrophic lateral sclerosis (ALS) and their caregivers. *Technology and Disability*, *31*(4), 203–215. https://doi.org/10.3233/TAD-190227

11. Curriculum Vitae

Mein Lebenslauf wird aus datenschutzrechtlichen Gründen in der elektronischen Version meiner Arbeit nicht veröffentlicht.

12. Publikationsliste

12.1. Publikationen als Erstautor

Eicher, C., Haesner, M., Spranger, M., Kuzmicheva, O., Gräser, A., & Steinhagen-Thiessen, E. (2017). Usability and acceptability by a younger and older user group regarding a mobile robot-supported gait rehabilitation system. *Assistive Technology*, 1–9. https://doi.org/10.1080/10400435.2017.1352051

Eicher, C., Kiselev, J., Brukamp, K., Kiemel, D., Spittel, S., Maier, A., Oleimeulen, U., Greuèl, M. (2019). Expectations and Concerns Emerging from Experiences with Assistive Technology for ALS Patients. In M. Antona & C. Stephanidis (Eds.), *Universal Access in Human-Computer Interaction. Theory, Methods and Tools* (Vol. 11572, pp. 57–68). https://doi.org/10.1007/978-3-030-23560-4_5

Eicher, C., Kiselev, J., Brukamp, K., Kiemel, D., Spittel, S., Maier, A., Meyer, T., Oleimeulen, U., Greuèl, M. (2019). Experiences with assistive technologies and devices (ATD) in patients with amyotrophic lateral sclerosis (ALS) and their caregivers. *Technology and Disability*, *31*(4), 203–215. https://doi.org/10.3233/TAD-190227

Eicher, C., Kiselev, J., Brukamp, K., Kiemel, D., Maier, A., Spittel, S., Greuèl, M., Müller-Werdan, U. (2018). ROBINA - Implementing the Needs of Persons Suffering from Severe Motoric Limitations into a Robot-Supported System. *Innovation in Aging*, *2*(suppl_1), 724–725. https://doi.org/10.1093/geroni/igy023.2678

Eicher, C., Kiselev, J., Brukamp, K., Kiemel, D., Meyer, T., Maier, A., Spittel, S., Greuèl, M. (2018). *Entwicklung eines robotergestützten Assistenzsystems für die amyotrophe Lateralsklerose (ALS) unter besonderer Berücksichtigung der Nutzungsperspektiven*. *1*(1), 22–27.

12.2. Publikationen als Co-Autor

Feldwieser, F., Kiselev, J., Hardy, S., Garcia-Agundez, A., **Eicher, C.**, Steinhagen-Thiessen, E., & Göbel, S. (2018). Evaluation of biofeedback based bridging exercises on older adults with low back pain: A randomized controlled trial. *Physiotherapy Practice and Research*, *39*(1), 15–25. https://doi.org/10.3233/PPR-170109

Steinert, A., **Eicher, C.**, Haesner, M., & Steinhagen-Thiessen, E. (2018). Effects of a long-term smartphone-based self-monitoring intervention in patients with lipid metabolism disorders. *Assistive Technology*. https://doi.org/10.1080/10400435.2018.1493710

Vorwerg, S., **Eicher, C.**, Ruser, H., Piela, F., Obée, F., Kaltenbach, A., & Mechold, L. (2019). Requirements for Gesture-Controlled Remote Operation to Facilitate Human-Technology Interaction in the Living Environment of Elderly People. In J. Zhou & G. Salvendy (Eds.), *Human Aspects of IT for the Aged Population. Design for the Elderly and Technology Acceptance* (Vol. 11592, pp. 551–569). https://doi.org/10.1007/978-3-030-22012-9_39

Dahms, R., **Eicher, C.**, Dankbar, R., Roeben, B., Vetter, T., & Schröder, M. (2018). NurMut—Evaluation of a music player and a vital sensor for people with dementia. *Innovation in Aging*, *2*(suppl_1), 675–676. https://doi.org/10.1093/geroni/igy023.2515

Dahms, R., **Eicher, C.**, Dankbar, R., Röben, B., & Vetter, T. (2018). Sensorische Erfassung von Gemütszuständen bei Menschen mit Demenz während des Einsatzes von Musik und Musiktherapie. *Zeitschrift für Gerontologie und Geriatrie*, *51*(S1), 39. https://doi.org/10.1007/s00391-018-1435-3

Dahms, R., Haesner, M., & **Eicher, C.** (2017). Wirksamkeit von einer stationären Musik-(therapeutischen) Intervention bei Menschen mit Demenz. *Zeitschrift für Gerontologie und Geriatrie*, *50*(S3), 124. https://doi.org/10.1007/s00391-017-1301-8

12.3. Buchbeitrag

Klebbe, R., **Eicher, C.** (2019): Wer sind eigentlich diese Nutzer? Zur Rolle älterer und pflegebedürftiger Erwachsener in der Entwicklung robotischer Assistenzsysteme. *In:* Hergesell, J., Maibaum, A., Meister, M., & Juventa Verlag. (2019). *Genese und Folgen der »Pflegerobotik«.*

12.4. Weitere Publikationen (Auswahl)

Eicher, C., Greuèl, M. (2019): Pflege durch Robotik? Robotik für die Pflege! Der pflegerisch-assistive Einsatz von Robotik im ambulanten Setting – von der Forschung bis zur Verstetigung. KU Gesundheitsmanagement 2019; 5(2019):24-26.

12.5. Präsentationen (Auswahl)

C. Eicher (2019). BMBF Zukunftskongress - „Souverän in die digitale Zukunft".

C. Eicher (2019). Entwicklung eines Roboter-gestützten Assistenzsystems für Menschen mit ALS. *Kongress für Gesundheitsnetzwerker, Session „Zukunft Pflege: Selbstbestimmt!".*

12.6. Poster (Auswahl)

Christoph Münch, Thomas Meyer, Susanne Spittel, Jörn Kiselev, **Cornelia Eicher**, Marius Greuèl, Diana Kiemel, Kirsten Brukamp, Dagmar Kettemann, Nadine Gajewski, Bertram Walter, André Maier (2018). Robotik bei der ALS – Akzeptanz von Robotik-unterstützten Assistenzsystemen bei Patienten mit ALS-bedingten motorischen Einschränkungen. *Deutsche Gesellschaft für Neurologie.*

C. Eicher, J. Kiselev, K. Brukamp, D. Kiemel, A. Maier, S. Spittel, M. Greuèl. 2018. ROBINA – implementing the needs of persons suffering from severe motoric limitations into a robot-supported system. *The Gerontological Society of America (GSA). Annual Scientific Meeting 2018.*

13. Danksagung

Zuallererst möchte ich meinen Kollegen und Kolleginnen der AG Alter & Technik für ihre immerwährende Unterstützung danken. Der fachliche Austausch mit euch, die Diskussionen um heikle Themen, die guten Tipps und letzten Endes das freundschaftliche Band, das zwischen uns entstanden ist, haben meine Promotionszeit zu einem interessanten und erträglichen Schaffungsprozess werden lassen, der mich geformt aber auch berührt hat. Ich hoffe sehr, dass dieser Teamgeist fortwährt und ich danke euch von ganzem Herzen.

An dieser Stelle möchte ich mich auch bei meinem Doktorvater PD Dr. Nils Lahmann bedanken, der mir bei Bedarf immer mit einem guten Rat zur Seite stand und mir ermöglichte, mein wissenschaftliches Profil in hohem Maße nach meinen eigenen Vorstellungen zu entwickeln.

Großer Dank gebührt meiner Familie und all meinen Freunden, die meinen ungeraden Weg bis zu diesem Punkt begleitet haben, die die nervenzerreißende Zeit ertragen haben, ebenso wie mein Gejammere und Gefluche. Ihr seid die Besten und ohne Euch gäbe es kein >>ich<<.

Der größte Dank gebührt allerdings meiner Mutter und ich verneige mich vor ihr. Du hast es geschafft, mich zu fordern, ohne mich zu überfordern, mich anzuschubsen, ohne mich wegzustoßen und mich zu halten, ohne mich festzuhalten. Wir gegen den Rest der Welt!