Sensor monitoring to measure and support activities of daily living for independently living older persons

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Citation for published version (APA):

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Download date: 13 Dec 2019
Introduction

The overall aim of this thesis was to evaluate the applicability and effectiveness of sensor monitoring for measuring and supporting the daily functioning of older individuals (65 years and older) who live independently at home. Due to the rapid aging of the population, the group of community-dwelling older individuals with multiple chronic conditions is expanding. Among this group, many will become dependent on care and support, and as a result, the burden and cost of health care will increase. Most older individuals prefer to live independently at home as long as possible, and the Dutch health care policy is supporting this. Older individuals are encouraged to find their own support, first from informal care, before the local authorities will provide support. There is a challenge for developing new interventions that enable older individuals to daily functioning, to remain healthy and to live independently at home. New health care technologies, such as sensor monitoring, are being developed to easily provide a measure of daily functioning, and these could be used to support self-management and health care.

As outlined in the general introduction, for the application of new health care technologies into health care practice, it is important to follow a structured development and evaluation process. We followed a phased process for the development and evaluation of the application of sensor monitoring according to the Medical Research Council (MRC) guidelines for developing and evaluating complex interventions (www.mrc.ac.uk/complexinterventionsguidance). In the end, we tested and evaluated an intervention in which sensor monitoring was integrated into a rehabilitation program for older people after hip fracture. In the SO-HIP trial, we demonstrated that the rehabilitation program, based on occupational therapy coaching and sensor monitoring, was associated with greater improvements in patient-reported daily functioning (measured with COPM) at six months than care as usual.

As a start of this general discussion, we will summarize and interpret the main findings of the development and evaluation of the application of sensor monitoring as described in the thesis. We used the MRC framework to ensure that the intervention was empirically and theoretically founded and that considerations are given both to the effectiveness of the intervention and the underlying working mechanism. Therefore, in our description of the main findings, we will also follow these phases of the MRC framework (i.e., development, feasibility, evaluation and implementation). Hereafter, we will reflect upon issues or mechanisms that may have had impact on the effectiveness of the SO-HIP intervention, including i) intervention fidelity, dose and context; ii) theoretical concept of self-efficacy beliefs; and iii) impact of SO-HIP technology. Finally, we provide some recommendations for clinical practice, future research and education.

Main findings

Predevelopment phase

In the predevelopment phase, we demonstrated in a cohort study of acutely hospitalized older adults (Chapter 2) that patients and proxies had moderate
to good levels of agreement on the patients’ ADL and IADL measured with self-reported Katz ADL-index. Proxy reports are often used to provide substitute data when the patient is not able to perform the self-reported assessment due to illness or acute cognitive impairments. Differences in agreement were greater for the group of patients with severe cognitive impairments or prevalent delirium than for the patients with mild cognitive impairments to no cognitive impairment. The results of this cohort study suggested that at the time of the hospital admission, for patients with mild cognitive impairments, their self-report of (I)ADL is accurate and can be used for assessing (I)ADL functioning. For patients with a severe cognitive impairment (i.e., an MMSE score of less than 15 points) or prevalent delirium, the nearest proxy may provide valid information about the patient’s (I)ADL functioning. A strength of this study was that we divided cognitive functioning measured with the MMSE into three categories (severe cognitive problems (MMSE < 15), mild cognitive problems (MMSE 15-24) and mild to no cognitive problems (MMSE >24)), instead of the two categories with an MMSE cut off <24, which is usually used in research. Our results demonstrated that ADL reports of these more diverse groups of patients (i.e., three categories) provide a reliable self-report of their ADL and IADL than the usual included groups (i.e., two categories), contrary to our expectations. However, we found that the level of agreement in patient and proxy reports was lower for IADL compared to ADL. For evaluating these IADL, objective assessments would give more accurate information. We were interested if sensor monitoring, which had been developed to continuously measure the daily functioning of older people, could be used for measuring and supporting functional health status.

Development phase
In the development stage, we performed a systematic review to investigate the application and effectiveness of sensor monitoring to measure and eventually to support daily functioning in older people living independently at home. This review demonstrated that the use of sensor monitoring in health care practice had promising opportunities although clear evidence is missing (chapter 3). We found that most research has focused on the technical development of sensor monitoring and less on the application in clinical practice. With this knowledge, we proposed a roadmap for the further development of the use of sensor monitoring in health care practice. This road map consisted of different steps based on the literature review and guided the development of our intervention.

One of the main conclusions was to involve the target group and health care professionals in the development of technological solutions. Therefore, we conducted a pilot cohort study in which 23 older persons who were living independently in the community or in a senior residence participated. They were willing to have a sensor system installed in their homes for one and a half years. In this development phase, we investigated the use of sensor monitoring from the perspectives of the older persons and health care professionals, and then customized the sensor system to their specific needs of both groups of participants. In this pilot cohort study, we explored the prediction of functional health status of the participants from ambient sensor data and developed a model that related functional health predictors, as determined by health care professionals, to features derived from sensor data, as published elsewhere by
Second, our qualitative study (chapter 4) demonstrated that the interviewed older people of the pilot study were positive about sensor monitoring. Specifically, the participants indicated that the technology helped them to remain living independently at home, contributed to their sense of safety and helped them to remain active. The increased sense of safety outweighed the privacy issues, mainly because the sensors only register the movement within the home, rather than all of the participants’ actions, as done with camera or sound recording. Additionally, the primary care nurses who were involved into the pilot study gave their opinions and suggestions about the sensors and the visualization of the sensor data.

After the pilot cohort study in which we developed and refined the sensor system and their output, we were also interested in using sensor monitoring in rehabilitation for older people after hip fracture to support their daily functioning. Considerations for choosing patients after hip fracture were the following: i) a question out of the health care profession suggested a lack of accurate data on daily functioning of their hip fracture clients at home, since much of the rehabilitation process occurs after a patient has been discharged, and this hampers the progress of rehabilitation at home; ii) we could test the application with a large group of patients in a relatively small time frame; and iii) because of the short duration of the intervention, we could easily implement and maintain the technology.

We therefore customized our sensor system into an easy to install, portable sensor monitoring system, consisting of both a wearable sensor and a set of ambient sensors. We piloted this system and further developed it in collaboration with health care professionals working in four health care organizations. We then developed our SO-HIP intervention based on the results of this pilot, the systematic review, the pilot cohort study and the qualitative study.

A strength of our study is our continuous collaboration with different health care professionals e.g., nursing home physicians, nurses, physical therapists and occupational therapists, as well as the end users, e.g. older persons. As concluded in our systematic review\cite{10} and in a review by Ambient Assistive Technologies (AAL)\cite{11}, the extensive research effort of pilot projects has not yet led to a significant proliferation of technologies into real world usage, and it was advised that the involvement of citizens, caregivers, health care IT industry, researchers, and governmental organizations in the development was important, so that end-users could benefit more from the collaborative efforts.\cite{11-13} In our studies, we worked together with a team of researchers (information technology, artificial intelligence, health care), health care organizations and health care professionals and the end users, older people living independently in the community. This team ensured diversity in areas of expertise, skills and perspectives and implementation into daily practice.\cite{11}

**Feasibility and piloting phase**

In the feasibility and piloting phase, we evaluated the feasibility of the developed SO-HIP intervention in a small study in which 45 older patients, who were admitted after hip fracture to one of the two locations of geriatric rehabilitation of the health care organization Amaris in the Netherlands, participated (non-published...
Fear of falling is common in patients after hip fracture and because of this, people feel insecure in moving and in their daily functioning. Our coaching intervention was based on proven CBT techniques to increase self-efficacy. Increasing self-efficacy beliefs can reduce fear of falling and can help increase the daily functioning that is needed to recover.

We tested the procedures as described in our study protocol (Chapter 5) and tested the SO-HIP training for health care professionals. The positive results of the feasibility study on patient-reported daily functioning as measured with the COPM as the primary outcome, as well as the positive experiences of the therapists and patients with the intervention, justified a large-scale trial.

With the results of this feasibility study we made some small adaptations to our study protocol (e.g., we decided to include six clusters instead of four in our stepped wedge design for a higher inclusion rate of participants, and we adapted our training for health care professionals into a two day session and a booster session). We offered extra training because both the coaching techniques and the use of technology was new for the occupational therapists involved, as well as the application of the protocol with patients with a low MMSE.

The evaluation phase

We tested the effect of the SO-HIP intervention in a three-arm randomized stepped wedge design, the SO-HIP trial (Chapter 6). We were able to randomize 6 skilled nursing facilities (12 wards) where 240 older patients with a mean age of 84 years after hip fracture were involved. We demonstrated that the occupational therapy (OT) intervention based on sensor monitoring-informed coaching (OTcsm) significantly improved patient-reported daily functioning compared to the care as usual (CAU). We found no significant difference in patient-reported daily functioning between coaching-based occupational therapy without sensor monitoring (OTc) compared to care as usual. To our knowledge, the current study is the first to describe a randomized trial that investigated the effect of an intervention in which sensor monitoring was integrated in a transitional care rehabilitation program for older patients after hip fracture going from a skilled nursing facility to their own home.

The combination of the objective feedback of the sensors which provide insight in patients’ real-time activity levels together with the evaluation of daily functioning in the patient-centered coaching sessions seemed helpful in shared-decision making realistic goals based on these objective data and for improving daily functioning.

We included a very vulnerable group of patients of high mean age and considerable comorbidity. These groups are often excluded in trials. However, we demonstrated that patients with cognitive restrictions benefit from SO-HIP intervention after hip fracture. Especially for patients with low MMSE (MMSE 15-19), significant differences in treatment effects were found for COPM scores in patients’ reported daily functioning compared to the care as usual group. The mean difference of OTcsm compared to the CAU on COPM scores for the patients with low MMSE was 1.66 (0.54-2.78; P=0.004). For OTc, the mean difference was 1.17 [95% CI 0.25-2.09] P=0.012) for low MMSE.

To understand how this effect occurred and how this effect of the SO-HIP
intervention may be replicated in future interventions, process evaluation is important.\[^{15}\] We learned from our process evaluation with the occupational therapists (Chapter 6 supplement) that the sensor data provided objective information, and therefore, the sensor data gave them more insight into the daily functioning of patients with cognitive restrictions and made the situations more concrete. The occupational therapists had some information before the start of the intervention and found these aspects helpful during the coaching. Patients with less cognitive restrictions were more engaged and more motivated according to the therapists.

Next to the process evaluation we had with the therapists, we conducted a qualitative study alongside the SO-HIP trial (Chapter 7) in which 19 participants out of the three groups of the SO-HIP trial were involved. In this study, we learned, from the perspective of the participants, three resources to be beneficial for recovery; ‘supporting and coaching’, ‘myself’ and ‘technological support’. These resources influenced the recovery process. Having successful experiences during recovery led to doing everyday activities as they did before hip fracture, in the same or on an adapted manner, whereas unsuccessful experiences led to ceasing certain activities altogether. Our findings show that follow-up interventions after discharge are important. We demonstrated that these interventions must be personalized with attention to everyday activities that are meaningful for participants. The COPM is suited to identify, prioritize and evaluate important issues that are meaningful for patients.\[^{16,35}\] We demonstrated that the COPM was suited for the goalsetting and provided both the therapists and the patients with information that was important for recovery in everyday functioning at home (Chapter 5, 6 and 7). A strength of this qualitative study is that we presented a conceptual model to provide an understanding of the participants’ experiences and perspectives concerning their process of recovery to everyday life in the six months following the start of rehabilitation after hip fracture.

The patient-centeredness of the SO-HIP intervention is a crucial aspect of the effectiveness of the intervention that has also proven effective in other complex interventions.\[^{17,18}\] In our qualitative study, we found that the combination of coaching and technology supports the patients’ own roles in their recovery and that they were better able to cope with their restrictions.

**Intervention fidelity, dose and context**

We conducted both quantitative and qualitative methods to investigate intervention fidelity (whether the intervention was delivered as intended\[^{19}\]), the dose (the quantity of the intervention delivered \[^{19}\]) and the reach of the intervention (whether the intended audience comes in contact with the intervention\[^{19}\]) in order to investigate which components and under what conditions the intervention was effective.\[^{19,20}\]

One of the findings was that the mean dose of the interventions given at home was lower than the planned dose, according to the protocol as reported in the log books by the therapists (Chapter 6). There may be several explanations. First, from the interviews with the occupational therapists, we learned that they were not used to giving interventions at home for this group of patients after hip fracture, and they had to incorporate into this new working process.
Second, some therapists perceived that the prescribed amount of intervention at home was not always necessary because they perceived the goals of the patient were reached. However, from our qualitative interviews with patients (chapter 7), we knew from the perspectives of the patients that they appreciated the home visits because they felt insecure in their performing of daily activities even after a few weeks at home. This is also consistent with what we found from the literature; recovery after hip fracture continues throughout the first year after hip fracture.\(^\text{14}\)

Particularly for the group of patients as described in this thesis, our results from the SO-HIP study indicated that a transitional care rehabilitation program that started in the inpatient rehabilitation should have a follow up at home, to maximize functional recovery and return to the highest level of independence in daily functioning. More research is required to determine the optimal duration and intervention intensity of the SO-HIP intervention, including research to determine the intervention duration and intensity for patients with more cognitive restrictions.

Another issue regarding the fidelity of the intervention was that we learned from the interviews with the therapists that they found it difficult to apply coaching techniques and the use of sensors to patients with cognitive restrictions (Chapter 6, supplement). They experienced the extra booster session that focused on how to apply the SO-HIP intervention for patients with cognitive restrictions as helpful. Nevertheless, in the future, more attention should be given to this aspect in training.

Furthermore, we also noted from the process evaluation that the context may have affected the implementation and outcomes of the intervention. Six different health care organizations (twelve wards) were involved in the study. Some of these contexts were more open than others to facilitate the occupational therapists in e.g., conducting extra home-visits or in incorporating a new work routine. There were some differences in the duration of admission across the involved health care organizations that may have influenced the outcome. These aspects should be considered when implementing the SO-HIP intervention.

**Theoretical concept of self-efficacy beliefs**

In our SO-HIP intervention, we used the sensor data as a coaching and feedback tool to increase self-efficacy and therefore, supported the rehabilitation on a day-to-day basis. As outlined in the general introduction, the coaching was based on proven principles of CBT focusing on cognitive restructuring and the use of behavioral change techniques to address psychological, physical and functional factors related to concerns about falls. Behavioral change techniques focus on restructuring self-deviant thoughts to develop positive feelings and attitudes toward increasing daily functioning. Goalsetting, practicing activities (such as performing an activity safely under supervision) and self-monitoring are considered the most promising behavioral change techniques for increasing self-efficacy after falls.\(^\text{21}\)

Occupational therapists were, due to their profession, familiar with these coaching steps such as goal setting, activity planning and practicing. For example, together with the patient, occupational therapists are used to making plans in shared –decision making on how goals could be reached to become
more active in regular daily activities, practicing these activities to overcome concerns about falls and performing activities in a safe manner. However, although the therapists were trained before the start of the intervention, we know from the process evaluation that some of the therapists needed time and experience to incorporate the new way of working into their routines; this routine included both the coaching and all of the coaching steps, e.g., the behavioral change techniques and the motivational interviewing, and the use of the sensor technology. We suggest that extra training and guidance is important for successful implementation of the intervention in the future.  

Impact of the SO-HIP technology on effectiveness of the intervention

As we already mentioned, the sensor technology had an impact on the coaching, and together, they were effective in improving patients’ reported daily functioning. We were also interested in which mechanisms of the intervention were responsible for this improved functioning.

As mentioned in chapter 3, sensor technology, the use of wearable sensors (accelerometers) and ambient sensors, provides opportunities to gain insight in the physical and daily activities of older patients. For most older adults, it is difficult to answer questions about how active they are, and daily activities such as climbing stairs, walking outside, and engaging in household tasks are difficult to quantify (chapter 3). The sensor data provided measures used for self-monitoring, feedback, goalsetting and planning of activities.

The measures of the wearable sensor, e.g., the amount of activity per day, provided quantitative measurements visualized in a score per day, and the data from the ambient sensors gave information about patterns of daily functioning, visualized in sequences where activities took place. From the process evaluation, we knew that the quantitative measurements were easier to handle for goalsetting during the coaching compared to the ambient sensor data because of the concrete measures of both amount of activity per day and the intensity of activities in minutes. However, some therapists found the ambient sensor data helpful to gain more insight into the daily functioning of the older adults.

Our sensor monitoring system does not send digital messages aimed for increasing motivation, such as text messages, reminders or rewards to the end-users. It only gives a visualization of the sensor data. Our target group with a mean age of 84 years were not all used to see their own individualized data. We suggest in the future or for other target groups that the use of these messages could be an added feature to the data visualization for increasing motivation or engagement in rehabilitation.

The choice for our wearable sensor that measured activity level was made after several considerations. First, there are many consumer wearable sensors such as Fitbit, Apple I-watch, Garmin, Samsung gear band, etc., however, the data from these sensors are stored at these companies, and without access to the raw sensor data, it is difficult to determine the accuracy, sensitivity and the usability for older adults. Second, research devices such as the Actigraph, ActivePal, and the PAM (The PAM is also a consumer sensor) provide more detailed information and are well validated in the literature, although they were tested in small samples and with younger individuals (chapter 5). Third, we asked a panel of older adults to test different wearable sensors for a few weeks.
Out of these different sensors (Actigraph, ActivePal, Fitbit, Samsung gear band and PAM), the older adults chose the wearable sensor PAM from the company Pamcoach (www.pamcoach.com). They experienced the PAM as the most user friendly, easy to wear, low maintenance (the PAM needed no battery charging) and robust. Additional benefits of the PAM were that it contains a long-life button cell battery that can be used for about one year and the wireless connectedness to a base unit from which the data are sent to a secured server. Finally, we had access to the PAM data via our own server, therefore we could protect privacy and ensure security.

Although we carefully selected and piloted our technical system, we also faced some technical problems during the trial that might have influenced the results of the study. Some patients lost their PAM in a toilet, in a washing machine or on a getaway-trip with family or forgot to wear the sensor. In some villages where the patients lived, there was bad 3G reception or bad communication from the ambient sensors due to solid concrete walls making the visualization of the ambient sensor data difficult to interpret or resulted in missing sensor data.

Finally, in the SO-HIP trial, we tested the effectiveness of the use of the sensor data (both the PAM and ambient sensors) as a tool in coaching. Future research should investigate the collected sensor data to gain more insight in population norms of physical and daily activity of older adults after hip fracture that could be helpful for the improvement of rehabilitation.

Methodological Considerations

Study Design

The methods that we used in this research were a mix of quantitative and qualitative designs and were according to the phases outlined in the MRC guidelines.\textsuperscript{5,20} By doing so we were able to carefully develop and build up a new intervention, test the feasibility and in the end, test the effectiveness in a randomized controlled trial and show positive results.\textsuperscript{20} Using these mixed methods of research helped us to understand the outcomes and the relevance of the intervention for the end users. We conducted the trial according to the consort guidelines and controlled for possible confounders as we reported in the consort checklist for randomized controlled trials.

The positive effects of the intervention were still present at six months justifying further implementation of the SO-HIP intervention. In future studies, a one-year follow up is recommended because the recovery period after hip fracture can take one year.\textsuperscript{14}

For our trial we used a stepped wedge design, which is used with increasing frequency in the evaluation of service delivery interventions.\textsuperscript{31} A strength of the pragmatic stepped wedge design was that we were allowed to implement the intervention in groups at the different starting points before the start of the intervention. A further benefit of the design is that the direction of crossover from care as usual to both interventions was unidirectional. Every cluster received all the interventions and were implemented in all clusters which may alleviate ethical concerns.\textsuperscript{32} Because all patients receive only one intervention during the study there were no crossover effects. We were the first, to our knowledge, to conduct a stepped wedge design with three groups.
Study population
The study population was community-living older adults with a mean age of 80 years and older and who were living alone. As outlined in the general introduction, the proportion of single living people, 80 years and older, will double from now to 750,000 in 2040 (Statistics Netherlands [CBS], 2017). It is a challenge to support these people, so they can stay and do their daily functioning at home as long as possible in their own way. The two qualitative studies (chapter 4 and 7) allowed us to better understand the perspectives of the study population in the use of technology, the relevance of the intervention and what aspects of the intervention they experienced to be important for their support in their everyday functioning.

A strength of our trial was that we could involve a large group of 240 older patients after hip fracture that strengthens the reliability of our results. However, the target group in our trial was a vulnerable group with a high mean age and comorbidities, and as a result, we had many missing data and a relatively high dropout rate. This resulted in missing data and loss to follow up that can reduce generalizability and limit power. To account for the missing data, we used multiple imputation. We ran the analysis with and without imputations, and we found largely similar results. We also performed a sensitivity analysis to test the robustness of our findings to patients dropping out early, which showed slightly higher intervention effects after adjustment for dropout (chapter 6).

Outcome measures
In this thesis, we focused on daily functioning, because limitations in daily functioning are a result of the process of aging and an immediate result that older patients experience after hip fracture. As outlined in the general introduction, limitations in daily functioning may cause restrictions in participation, whereas strengthened contextual factors e.g. support and empowering of the older persons (coaching and the use of sensors) (as we did in this thesis) can enable participation.

In our trial, we used a patient-reported outcome, the COPM, as a primary outcome measure. The COPM is suitable for helping patients to identify, prioritize, and evaluate important issues they encounter in their daily functioning. The findings of the trial indicated that the COPM was suited for capturing the impact of the SO-HIP intervention on patient-reported daily functioning. We found large individual variations in daily functioning and differences in what activities patients wanted to regain, and the COPM accounted for this. Additionally, from the qualitative research (chapter 7), we learned that patients perceived the personalized approach of the intervention, which was focused on their everyday functioning, as important for regaining more confidence during the recovery process and for engaging in the activities that are important for them.

Some of the patients experienced the scoring of the COPM as difficult, however, during the follow-up assessments, the scoring became easier. In addition, our results of the trial showed that the COPM was suitable for detecting improvements in patient-reported daily functioning, which is consistent with other research.

External validity
We included in our trial a vulnerable group of community-living older patients after
hip fracture with half of them having comorbidities and cognitive restrictions. This is a representative group of older patients who were admitted after hospital admission into a nursing home for short-term geriatric rehabilitation after hip fracture. Another factor that indicates the external validity of the results of the trial is that six health care organizations with geriatric rehabilitation (12 wards) were involved. Taken together, we believe that the study results can be applied to other geriatric rehabilitation settings with these populations after hip fracture.

Implications for clinical practice and education and suggestions for future research.

Implementation of the SO-HIP intervention in geriatric rehabilitation
Given the positive results of the SO-HIP trial, the implementation of the SO-HIP intervention is justified and recommended. For a successful implementation of this intervention, it is advisable to determine an implementation framework or strategy which is suitable for the implementation of complex interventions in health care situations. From our process evaluation, we know that different aspects are important to incorporate, e.g., involving the organizational context and stakeholders in the implementation strategies.

Training in working with the SO-HIP intervention
The coaching (e.g., the motivational interviewing and the use of cognitive behavioral change techniques), together with the sensor technology, is a new element for therapists to work with. Based on our trial and process evaluation, we learned that more training for health care professionals is needed to incorporate the intervention into the daily working process and to master the therapists’ skills in working with this intervention. It is recommended to start with a two-day training, as we already developed for the SO-HIP study, followed by monthly sessions on the job during the first six months, and while doing so, to accompany the therapists in working with the intervention. Additionally, a good working helpdesk is needed for adequate support with the technology.

Special focus is needed on the rehabilitation of patients with cognitive restrictions, the interpretation of the sensor data, SO-HIP and multidisciplinary teams working together. The exchange between therapists of experiences in the working of the intervention is suggested to facilitate the working of the intervention.

Research into treatment fidelity and dose of the SO-HIP intervention
Further research is needed to investigate treatment fidelity and dose. The SO-HIP trial was protocolized to conduct four home sessions and four telephone consultations. Further research is needed to identify the recommended required dose and the number of sessions needed to improve rehabilitation outcomes.

Explore the SO-HIP intervention for other target groups in geriatric rehabilitation
Therapists provided suggestions to explore the effectiveness of using the intervention with other target groups in geriatric rehabilitation, such as patients
with Parkinson's disease, COPD, and CVA. As already said, most older people prefer to live at home as long as possible, and this is also the Dutch government policy within our participation society. Geriatric rehabilitation is adapting to these developments, e.g., incorporating shorter rehabilitation trajectories and exploring trajectories to continue rehabilitation at home, and thereby improving sustainability of health care delivery. The SO-HIP intervention might be suited for these trajectories. The intervention fits well within the concept of health and the new Dutch policy on health, in which people have to take more responsibility for their own health and care and to adapt and self-manage in the face of social, physical and emotional challenges.

The SO-HIP intervention fits conveniently into these new health developments for the following reasons: i) the intervention focuses on supporting daily functioning; ii) the intervention is based on shared decision making, e.g., the goal setting; iii) the intervention takes place at home, and iv) the intervention is based on technology that enables people to their daily functioning.

Investigating cost effectiveness of the SO-HIP intervention
More insight into a cost analysis and cost effectiveness is needed. The cost effectiveness of the SO-HIP trial will be further investigated. In addition, further study is needed on how the intervention and the technology can be financially supported, e.g., by health care organizations or by health care insurance companies.

Refinement of the technology
Further exploration of which elements of the intervention and under what circumstances the intervention is effective is needed. First, the visualization of the environmental sensor data needs to be further explored so that therapists and patients can easily interpret the data. It was suggested that quantitative sensor data as visualized by the PAM sensor is easier to use for goal setting and feedback compared to the data of the ambient sensors that is visualized by colors and had to be interpreted by looking for patterns in the data or changes in these patterns. Exploration of other visualization possibilities of the environmental data into more quantitative measures or pictures would be recommended.

Second, further exploration is needed on which features of the cognitive behavior change techniques are needed to integrate into the visualization of the sensor data on the dashboard and which features can be different for various target groups or subgroups. In addition, the sensor technology comprised two type of sensors, the PAM and the ambient sensors, and it should be further explored if there are differences in the need for both sensor types for all rehabilitation target groups.

Finally, in this research, we looked only at the sensor data as a tool in coaching for rehabilitation. However, insight into the sensor data as an outcome measure for rehabilitation would be interesting for further research.

Implication for education
This research plays an important role in health care education. Future health care professionals must be prepared for the use of health care technology and for the role of their profession in implementing these health care technologies
into daily practice. The knowledge gained with this research will be used in the Minor Degree in Health Care Technology at the HVA, the Bachelor degree in Occupational Therapy and the Lifelong Learning Education program for occupational therapists.

**Final conclusions**

This thesis focused on the applicability and effectiveness of sensor monitoring for measuring and supporting the daily functioning of older individuals (65 years and older) who live independently at home. First, we demonstrated in a cohort study of acutely hospitalized older adults that patients and proxies, even patients with mild cognitive restrictions, had moderate to good levels of agreement on the patients’ ADL and IADL measured with the self-reported Katz ADL index. However, the level of agreement between patient and proxy was lower for IADL compared to ADL. For evaluating these IADL, objective assessments would provide more accurate information and sensor monitoring was suggested (Chapter 2).

Second, we concluded from a systematic review that the use of sensor monitoring in health care practice had promising opportunities although clear evidence was missing. Because much of the literature focused on the technological development of sensor monitoring and less on the application in health care, a roadmap with five steps was recommended for further development for application in health care practice (chapter 3).

Third, community-living older people who experienced some age- and health-related limitations and participated in our pilot cohort study that involved having a sensor monitoring system in their home for one and a half years concluded that they felt positive about sensor monitoring in their daily lives. They experienced the sensors as important into two ways: for detecting emergencies, such as a fall, or for detecting a decline in daily functioning. They experienced the sensor monitoring contributing to their sense of safety as a premise for living independently at home, and this sense of safety contributed to the easy acceptance of the sensor system at home and outweighed the privacy issues (chapter 4).

Fourth, we designed and evaluated, in a small feasibility study, a three-arm stepped wedge cluster randomized trial for older patients who were admitted for short-term geriatric rehabilitation in a skilled nursing facility after a hip fracture. We wanted to compare three arms: i) care as usual rehabilitation, ii) occupational therapy with coaching based on cognitive behavioral treatment principles and iii) occupational therapy with coaching based on cognitive behavioral treatment principles and sensor monitoring (chapter 5).

Fifth, we found evidence from a stepped wedge randomized trial that included 240 older patients after hip fracture, that a rehabilitation intervention of sensor monitoring-informed OT coaching was more effective in improving patient-reported performance of daily functioning at six months than an intervention with coaching without sensor monitoring and usual care (chapter 6).

Finally, we concluded from our qualitative study that more attention should be paid to follow-up interventions after discharge from inpatient rehabilitation to support older adults in finding new routines in their everyday activities. These interventions must be personalized with attention to everyday activities.
that are meaningful for participants. Interventions that make use of both coaching and technology support the participants’ own roles in their recovery, thereby empowering them so that participants are better able to cope with their restrictions (chapter 7).

Moreover, this work in this thesis provided knowledge and evidence in the application of sensor monitoring to support older community-living individuals in their everyday functioning.
Chapter 8 | General discussion

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