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

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aan de Universiteit van Amsterdam
op gezag van de Rector Magnificus
prof. dr. ir. K.I.J. Maex

ten overstaan van een door het
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Faculteit der Geneeskunde

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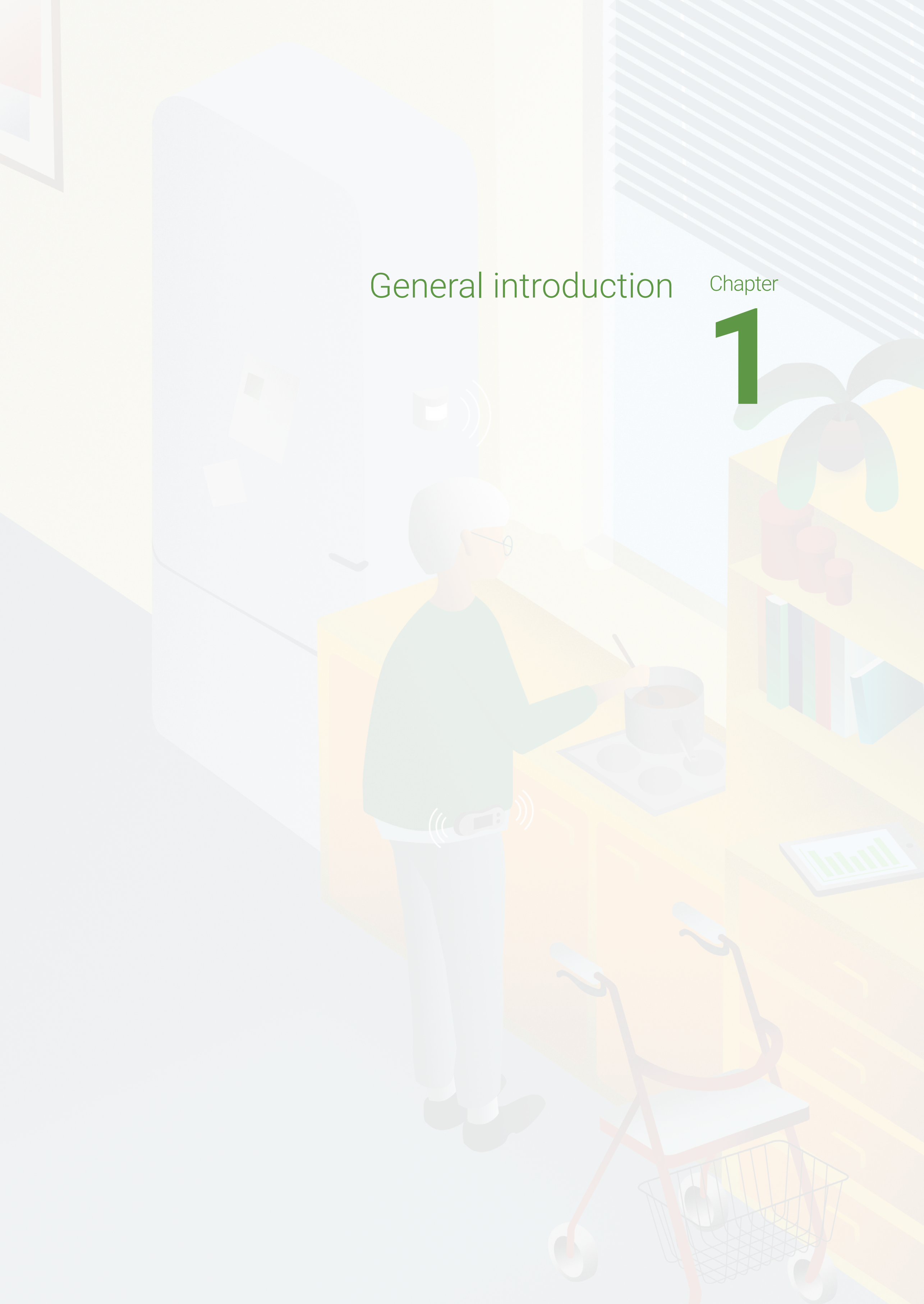
General introduction

Chapter 1



Worldwide, the number of older individuals will rise, and the percentage of older individuals in Dutch society is steadily increasing. The percentage of people aged 65 and over is expected to increase from 3,1 million in 2015 to 4,8 million in 2040, an increase of 55%.[1] Of these, a third will be 80 years and older (Statistics Netherlands [CBS], 2017). Additionally, the proportion of single-living people 80 years and older will double from now to 750 000 in 2040 (Statistics Netherlands [CBS], 2017). In 2015, there were 117 000 older individuals 90 years and older. In 2040, this will increase to 340 000, an increase of 191%.[1]

There is evidence that people live longer without severe disability.[2,3] However, with the absolute rise in the number of older individuals, a considerable number of them will have an increased risk of multimorbidity and disability.[4] As a result, the burden and cost of healthcare is expected to grow enormously.[5] Most people prefer to live independently at home for as long as possible and are also expected to stay in their homes as long as possible, according to the policy of the Dutch government.[6] Moreover, government intervention is decreasing, and health care tasks are being shifted to the local government. Older individuals are increasingly being encouraged to find their own solutions before the local authorities will provide assistance.[6]

This fits in with the new concept of health in which health is no longer considered a static condition but the ability to adapt and to self-manage in the face of social, physical, and emotional challenges.[7] As a consequence, the emphasis has shifted from a focus on diseases to a focus on how individuals function in their daily lives.[8] New technologies will play an important role in health care in the near future by assisting in healthy living and self-management in the home environment.[1,9] These demographic and social changes provide opportunities for developing interventions that enable older individuals to perform everyday activities and to remain healthy and live independently at home, even if they encounter health problems.

Sensor technologies are developed as (health-)monitoring systems to easily provide an observation of daily functioning.[10] These automatic and objective observations of activities of daily living (ADL) can provide important information (e.g., the increase in time to complete ADL tasks, the increase in time spent on activities in the apartment during night time, the decrease in time spent outside) that health care professionals can use in their daily practice.[11] However, the application of these sensor technologies in everyday life and clinical practice by health care professionals is scarce.[12]

In this thesis, we will evaluate the applicability and effectiveness of sensor monitoring for measuring and supporting the daily functioning of older persons (65 years and older) who live independently at home. and we will specially focus on older persons after hip fracture.

This chapter provides an introduction to this thesis. First, we explain the declining health of older individuals and the impact that this could have on their everyday functioning. As we will focus on older persons after hip fracture, we will describe factors that influence functional outcome after a hip fracture. Second, we will give an introduction on measuring everyday functioning; from self-report to sensor monitoring. We describe the concept of sensor monitoring and present two different ways we use this technology in interventions to enable everyday functioning: 1) to focus on the assessment of a person's level of daily functioning and 2) to using sensor monitoring as a feedback and coaching tool in rehabilitation of older individuals after hip fracture to support the rehabilitation (The SO-HIP study). Third, we briefly describe the concept of self-efficacy that is used in one of the two interventions. We end this introductory chapter with an overview and an outline of the thesis following the phases of the Medical Research Counsel (MRC) guideline for developing and evaluating complex interventions (www.mrc.ac.uk/complexinterventionsguidance).[13,14]

Older Individuals and everyday functioning

Although the majority of older individuals feel healthy and are well able to live independently at home, a growing group of mostly very old individuals have become dependent on care and support in the form of informal and formal care.[15] When aging, the prevalence of chronic diseases increases, and older individuals often have multimorbidity, defined as the occurrence of more than one chronic condition in an individual.[16,17] In 2015, 4,3 million of the people in the Netherlands had two or more chronic conditions, and this will increase by 28% to 5,5 million at 2040 (National Institute for Public Health and Environment).[1] Multiple chronic conditions are presumed to have greater health needs and a high healthcare utilization.[18]

Hip fracture is a common injury among older individuals. In the Netherlands, approximately 17.000 individuals are each year admitted to a hospital after a hip fracture, and this is expected to increase.[19] Approximately 15.000 of them are aged 65 and over. For these older individuals, a hip fracture is associated with poor functional outcome, increased morbidity and mortality.[20] Many factors, such as age, pre-fracture functionality, comorbidity and fear of falling, influence functional outcome of after a hip fracture.[20,21] Fear of falling is common among older individuals after hip fracture and hinders their performance of everyday activities needed for a good recovery.[22-24] Because of the fear of falling, people feel insecure while moving and performing activities of daily living, and as a consequence they engage in fewer activities. However, for a good recovery, moving and performing everyday activities are essential.[25-27] Consequences of fear of falling are decreased functional performance, loss of independence, lower participation and lower quality of life.[27]

The International Classification of Function, Disability and Health (ICF) conceptualizes the functioning of persons as an interaction between the health conditions and contextual factors (personal and environmental).[28] However, this current ICF scheme has a strong medical focus, and with the abovementioned demographic and social changes and the new definition of health, the focus of this scheme should be adapted.[29] The following alternative ICF-scheme was developed as one of three alternative schemes proposed by a group of Dutch experts who started the international discussion on the adaptation of the ICF. This alternative ICF-scheme fits well to the needs of the population in our research.[29]

In this proposed alternative ICF scheme, the environmental factors encompass functional and personal factors.[29] Functioning is the central component in this scheme and can be conceptualized from different perspectives: activities,

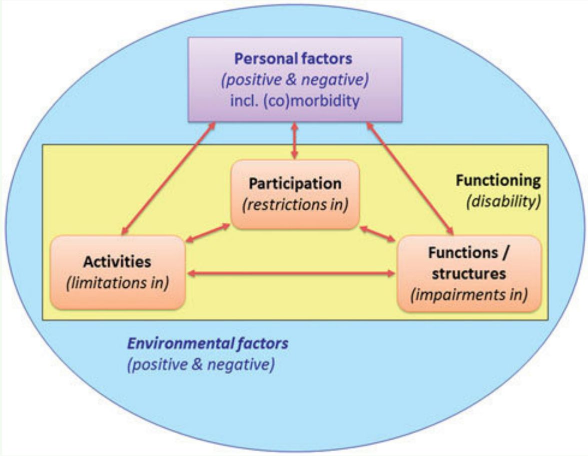


Figure 1. Proposed third alternative ICF scheme[29]

participation and body functions/structures.[29] To indicate the importance of participation, participation is positioned in the middle of the scheme.[29]

Limitations in activities may cause a restriction in participation, whereas strengthening contextual factors can slow the disablement process and enhance participation. For example, environmental factors such as social support (e.g., the presence of informal caregivers) or technical devices can compensate for a person's inability to perform certain activities. Personal factors are positioned in the top of the scheme to emphasize the importance of these factors, such as motivation or other psychological factors, which are important for enabling participation.[29] Comorbidities are added to the personal factors. The scheme as a whole can, looking from the perspective of 'functioning', be used to describe the health state of the individual, which is in line with the reconceptualization of health as described by Huber at al.[7] In older individuals, the activity and participation level in the ICF model is important for being able to function at home and to live independently.

The way older individuals perform their everyday functioning provides a measurement of the functional status of a person and is a major predictor of important outcomes such as mortality, living independently, and long-term care-placement.[30-33] Information on everyday functioning might also be useful to identify older individuals who could benefit from health care interventions to prevent further decline.

Measurement of everyday functioning; from self-report to sensor monitoring

Traditionally, several methods are used for measuring or evaluating everyday functioning, including the use of self-reported questionnaires such as the

Modified Katz ADL index[34] or observations done by health care professionals such as nurses or occupational therapists. An important limitation of measuring a person's everyday functioning by self-report is that many older adults find it difficult to answer questions about how active they are, or to quantify daily activities such as climbing stairs and engaging in household tasks.[35] Another limitation is that measurements are limited to specific time points or are not done in the real situation (e.g. home) of the older individual. As a result, therapists lack precise information on everyday functioning at home and this lack of information hampers the setting of realistic and personalized goals to optimize everyday functioning.

More recently, new health care technologies, such as sensor monitoring, have been developed to measure the everyday functioning of older individuals continuously, 24 hours a day, 7 days a week. These data can be used to support older individuals and promote their independent living.

Sensor monitoring

In sensor monitoring, multiple sensors in the home environment are used to assess the daily functioning of the older individual. In the last decade, different sensor systems have been developed for monitoring health care purposes that could detect daily functioning or changes in health status.[36-41]

Kasteren et al described different types of sensor technology that can be used for monitoring daily functioning such as the use of 1) wearable sensors, 2) wireless sensor networks (ambient sensors) and 3) cameras.[41] 1) Wearable sensors are worn by the user and have the ability to measure directly the activity, vital functions and posture of individuals. Wearable sensors are used to measure vital signs such as blood pressure and heart rate, body movements in activities such as sitting transitions, walking speed, and fall detection.[42-45] Also modern smart mobile phones contain sensors and can be used for measuring and processing the data. In our research the wearable sensor is an accelerometer. Although wearable sensors may well be suitable for measuring activities, a disadvantage is that the individual has to think about wearing the sensor, has to carry or wear the sensor all the time and has to connect it to a charger, which is not always easy to do for (older) individuals. 2) A wireless sensor monitoring system consists of sensors (e.g. motion sensors, magnetic contact switches, bed pressure mat) placed in the home environment at fixed locations. The sensors register in-home activities and are communicating wirelessly with the other sensors in the network and with the internet.[10,46,47] Two advantages of wireless sensors are that it is not necessary for an older individual to do anything with the sensors and that the sensors can be installed outside the view of the users to be less intrusive. 3) Video cameras can be used for activity monitoring.[41] Although the camera provides very informative data and could be very useful for different health care purposes, such as fall detection and wandering detection, privacy is an issue.[48]

Specification of the sensor monitoring system in this research

In our research, we make use of a sensor monitoring system developed by the research group Digital Life from the Amsterdam University of Applied Sciences and the University of Amsterdam in The Netherlands.[10,49-51] This wireless sensor system can easily be placed and replaced and can automatically monitor 24 hours, 7 days per week. The system was developed in co-creation with older volunteers who were living independently in the community.[52] They had a sensor system installed in their home for several years.

An overview of the sensors located in one of the volunteers' apartment is shown in Figure 2. The sensors include 1) passive infrared sensors to detect motion in the rooms, 2) contact switches (reed) on doors and cabinets, for detecting open and closed state of doors and cupboards, 3) a pressure mat to detect lying in bed, and 4) a float sensor to detect the toilet being flushed.

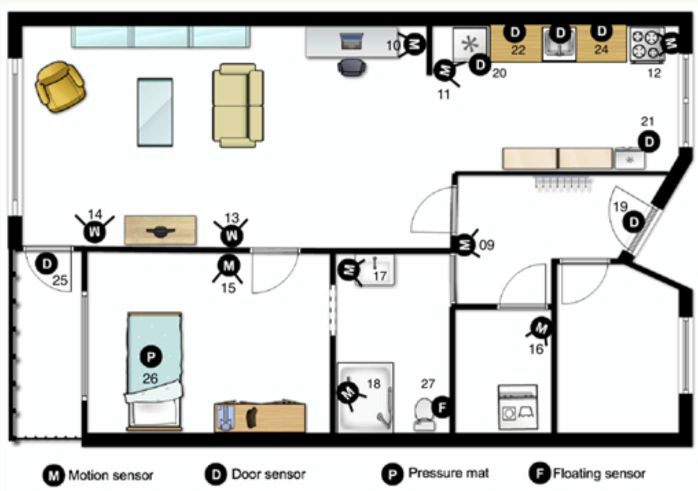


Figure 2. Overview of sensors in an apartment [53]

The sensors register only in-home movement, without a camera or sound recording of the individuals. The sensor data are stored on a base unit in the apartment from which the data are sent to a secure website and a web based application. The sensor data are analyzed by an intelligent software program using data-mining and machine-learning techniques that search for activities of daily functioning and patterns of daily functioning.[10] It is possible to discover most ADL (e.g., bathing, dressing, toileting, transferring, walking and eating) and some of the IADL performed in the home (e.g., preparing meals, doing housework).[12] It is not possible to measure other IADL, such as handling money, shopping and traveling.[12] The results are automatically generated a report on a day-to-day basis. The health care professionals are able to use the reports of the sensor data via a secure web application to evaluate the daily functioning of the individual.[12]

The wireless sensor monitoring system can be combined with a wearable sensor (see figure 3). We use a wearable activity monitor (PAM) (http://www.pamcoach.com) that consists of a 3-dimensional accelerometer, 68 x 33 x 10 mm, wirelessly connected to a base unit, from which the data are sent to a secure database and a web-based application. The base unit consists of a raspberry Pi extended with a Z-wave shield (for communication with the ambient sensors), a Bluetooth adapter (for communication with the wearable sensor PAM) and a 4-g dongle. The PAM is worn on the hip and measures the time of all daily activities in minutes per day.

Figure 3. Door sensor, Passive infrared sensor, Pam-sensor and Base unit and Therapist and client looking together at sensor data

The use of sensor monitoring in two different ways

In this research, we used sensor monitoring into two different ways. The first way to use sensor monitoring was to focus on the assessment of a person's level of daily functioning by sensor monitoring to detect deviations in the ADL patterns and to warn caregivers or health care professionals of such deviations. These deviations could reflect changes in health care status and lead to interventions that support the independence of the older individual.

A second way to use sensor monitoring was using it as a feedback and coaching tool in rehabilitation of older individuals after hip fracture to support the rehabilitation process and, in this way, to increase everyday functioning. Rehabilitation programs for older individuals after a hip fracture may need to focus on targeting fear of falling to optimize functional recovery. Increasing self-efficacy beliefs can reduce fear of falling and can help increase the physical activity needed to recover.[54]

Theoretical concept of self-efficacy beliefs

As described above, self-efficacy beliefs can influence behavior. In this research, our intervention with coaching and sensor monitoring embedded in a rehabilitation program for older individuals after hip fracture is based on the principles of cognitive behavioral therapy (CBT), as developed and proven effective in a program on fear of falling and activity avoidance in community-dwelling older individuals.[54] Key strategies of this programs are i) restructuring misconceptions about falls, ii) setting realistic goals for increasing activity, and iii) promoting daily activities that are avoided because fear of falling.[54]

This program is based on Bandura's self-efficacy theory. In Bandura's self-efficacy theory, perceived self-efficacy is defined as people's beliefs about their abilities to produce designated levels of performance that exercise influence over events that affect their lives.[55] Self-efficacy beliefs determine how people feel, think, motivate themselves and behave.[55] Bandura states that anyone, regardless of their past or current environment, has the ability to exercise and strengthen their self-efficacy.[56]

He describes four ways to build self-efficacy: 1) Performance accomplishments or mastery experiences; the key to mastery is experimenting with realistic but challenging goals. Essential to mastery is also acknowledging the satisfaction of goals that are achieved. 2) Choosing role-models that can demonstrate their self-efficacy. 3) Verbal or social persuasion; this is about having others directly influence one's self-efficacy by providing opportunities for mastery experiences in a safe and purposeful manner. 4) Physiological, or somatic, and emotional states; by recognizing that it is normal and okay to experience such states in life, while working to "relieve anxiety and depression, build physical strength and stamina, and change negative misinterpretations of physical and affective states".[55-57]

Different techniques are used to facilitate the above-described cognitive restructuring program, such as motivational interviews and behavioral change techniques, e.g., goalsetting and action planning.[54,58] Motivational interviewing is a technique to encourage internal motivation and increase the self-efficacy of individuals.[59]

We believe new health care technologies such as sensor monitoring can assist health care professionals in coaching more effectively. The visualization of the sensor data can be used as a coaching and feedback tool to increase self-efficacy and therefore supports the rehabilitation on a day to day basis. However, as far as we know, sensor technologies have not yet been used in the rehabilitation of older patients after hip fracture.

Aim of the thesis

The overall aim of this thesis is to evaluate the applicability and effectiveness of sensor monitoring for measuring and supporting the everyday functioning of older persons (65 years and older) who live independently at home.

Methods

Because sensor monitoring is a new technology and its application in health care consists of several interacting components, it is important to follow a structured development and evaluation process.[13,14] In this thesis, we follow a phased process for developing and evaluating this intervention, according to the new Medical Research Council (MRC) guideline for developing and evaluating complex interventions (www.mrc.ac.uk/complexinterventionsguidance).[14] In this framework, the phased approach will be used, as a guidance on how to design and evaluate the intervention of sensor monitoring as shown in Figure 4.

The first stage is the development phase to identify the evidence base and theory to support the intervention process and outcome.[14] In this phase, we conducted a systematic review and a small pilot study in which we developed in co-creation with the older individuals, health care professionals and technicians, our sensor system and intervention. The second stage is the phase of feasibility and piloting to test procedures of the intervention, the delivering of the intervention, recruitment and to determine sample size.[14] We developed and tested our study protocol of an intervention in a feasibility study in which sensor monitoring was integrated into a rehabilitation program for older people after hip fracture, the SO-HIP study. The third stage is the phase of evaluation to assess effectiveness and to understand the working of the intervention.[14] In this phase, we tested and evaluated our intervention, the SO-HIP trial. The fourth stage is the phase of implementation.[14] This phase we will be working on after finishing this PhD-study.

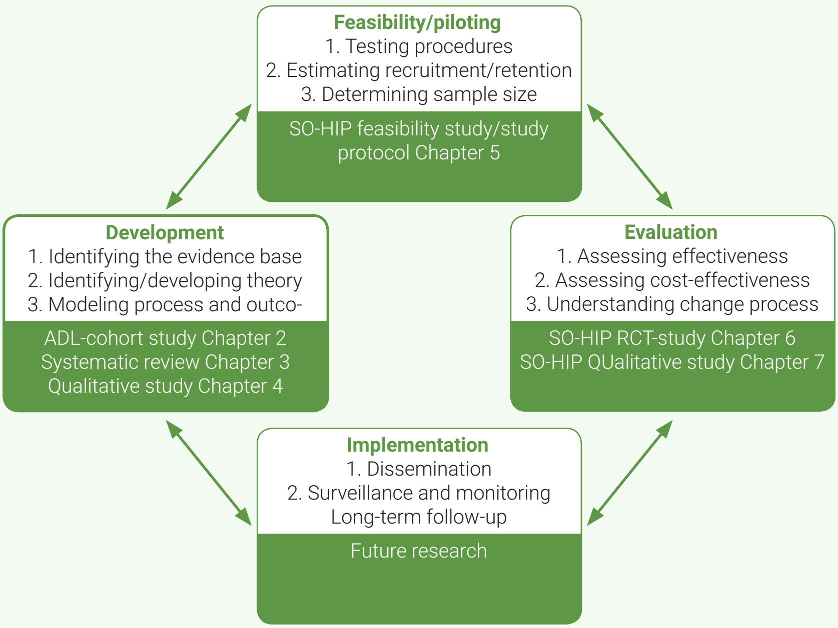


Figure 4. Key elements of the development and evaluation process

Outline of this thesis

Chapter 2 presents the results of a study we conducted for the development phase, regarding patient and proxy agreements on the ADL of acutely hospitalized older adults.
The phase of development of the intervention is described in **chapters 2, 3 and 4**.
Chapter 3 reports the results of a systematic review that addresses the following questions: Which older persons will benefit from sensor monitoring? Which sensor-monitoring technologies are most suitable, and what are the reported uses of these technologies in daily practice?
Chapter 4 describes a qualitative study on the older people's perspectives regarding the use of sensor monitoring in their home. We interviewed 11 older individuals from a pilot study of 23 older individuals who had a sensor system installed in their home for one and a half years. In this pilot study, we interviewed the older individuals and further developed the technique of sensor monitoring and the intervention. We tested the procedures, measurements and feasibility in an uncontrolled study. We compared the information concerning (I)ADL derived from sensor monitoring with the information from subjective and objective observations of (I)ADL. Based on the outcomes of these first three studies, the feasibility/piloting phase is described in **chapter 5**. We developed an intervention of sensor monitoring embedded in a rehabilitation program for older individuals after hip fracture.
Chapter 5 presents the design of a stepped-wedge randomized controlled trial, the SO-HIP trial. We assessed the study protocol in a feasibility study and tested procedures, adherence to the protocol, the intervention and impact on the intervention in 45 older individuals.
Chapter 6 reports the results of the SO-HIP trial, in which 240 older individuals after hip fracture participated. This randomized controlled trial started in April 2016 end ended in December 2017 (www.sohipstudie.nl).
Chapter 7 describes the results of a qualitative study on community-living older individuals after hip fracture who were enrolled in the SO-HIP study. In it, we explored their perspectives, the impact of the hip fracture on their everyday life, their recovery process and which aspects of the recovery process they perceived as most beneficial to the return to everyday life.
Chapter 8 presents the general discussion of the main findings of this thesis and implications for practice, education and research.
A summary in English and Dutch concludes this thesis.

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Chapter

2

Patient and proxy rating agreements on the Activities of Daily Living and the Instrumental Activities of Daily Living of acutely hospitalized older patients

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Abstract

Objective: To investigate the level of agreement between patient-proxy ratings concerning the (Instrumental) Activities of Daily Living ((I)ADL) of hospitalized older patients and to investigate which factors are associated with any disagreements in these ratings.
Design: A prospective cohort study was designed.
Setting: A tertiary university teaching hospital was the setting.
Participants: The participants were patients aged 65 years and older who were acutely hospitalized for at least 48 hours and their proxies.
Measurements: All of the patients and proxies were interviewed using the modified Katz ADL index. The global cognitive functioning of all of the participants was assessed using the Mini-Mental State Examination (MMSE), and each patient's level of delirium was measured using the Confusion Assessment Method (CAM).
Results: Overall, 460 acutely admitted older patients (mean age = 78 years) and their proxies were included in the present study. The patients and proxies exhibited moderate to good levels of agreement on the patients' (I)ADL (70-90%, $p< 0.001$). The differences in the patient-proxy reporting for the (I)ADL were greater ($p< 0.001$) for the patients with severe cognitive impairments (MMSE≤ 15) than for the patients with mild cognitive impairments (a MMSE score between 16 and 23 points) to no cognitive impairment (MMSE ≥ 24). A lower MMSE score (OR= 0.95; 95% CI 0.91 to 0.99) and a lower level of delirium (OR=2.56; (1.38 to 4.75) were associated with a greater level of disagreement between the patients and proxies ratings regarding (I)ADL.
Conclusion: For the patients with mild cognitive impairments at the time of the hospital admission, the results indicate that the self-report of (I)ADL is accurate and can be used for assessing (I)ADL functioning. For patients with a severe cognitive impairment or prevalent delirium, the nearest proxy may provide valid information about the patient's (I)ADL functioning.

Introduction

A functional decline in older people after acute hospitalization can severely reduce their quality of life.[1, 2] A functional decline is defined as a loss of independence during an individual's Activities of Daily Living (ADL) and is experienced by 20% to 50% of acutely admitted older people after their hospital discharge.[3,4]

At the time of the hospital admission, the functional status of older people is frequently measured by clinicians who use an assessment of the patient's ability to perform ADL and Instrumental Activities of Daily Living (IADL).[5] This assessment focuses on the patient's actual or premorbid functional status and is often obtained by asking the patient to provide a self-report of his or her (I) ADL functioning.[5] This knowledge of functioning is important for short term care planning and is also predictive of the post-discharge functional status.[6] One of the main problems during interviewing acutely hospitalized older people is that they may have pre-existing or acute cognitive impairments, which affects the accuracy and validity of the self-reported data.[7-9] Therefore, proxy reports are often used to provide substitute data.[5,13]

Several studies have investigated the validity of proxy assessments, primarily in patients who have suffered a stroke.[10-12] Many factors may influence the level of patient-proxy agreement of the ratings of ADL, such as caregiver burden, depressive symptoms, education, a shared residence and the type of family relationship.

The proxy-patient scores exhibited a greater level of consistency when concrete observable behavior and abilities were scored, such as the comparison of ADL and IADL.[10,11] Other authors have shown that proxies systematically overestimate patients' disabilities when the patients exhibit signs of a cognitive impairment, although these findings are not consistent across studies.[10-14]

Little research has been conducted to identify the factors that are associated with the differences in the perception of ADL/ IADL between hospitalized older patients and their proxies. Weinberger et al. found that the level of agreement varied with each patient's cognition; however, this previous study had a small sample (n = 60) from an outpatient-geriatric clinic, focused only on Mini-Mental State Examination scores (MMSE) that were lower than 24 and did not investigate the characteristics of the proxy.[13]

The current study on acutely hospitalized older patients aimed to (i) compare the patients' and proxies' perceptions of the patients' ADL and IADL, (ii) study the differences in the level of patient-proxy agreement and (iii) identify the factors that are associated with the differences in the patient–proxy ratings.

Methods

Setting and study population

This prospective cohort study, the DEFENCE- I- study (Develop strategies Enabling Frail Elderly New Complications to Evade), was conducted from November 2002 to July 2005 at the Academic Medical Center (AMC), a tertiary university teaching hospital in Amsterdam, The Netherlands.[15] All patients who were 65 years and older, were acutely admitted to the internal medicine department and were hospitalized for at least 48 hours were included in the present study. Patients were excluded if they 1) did not speak enough Dutch or English to answer the questions on the questionnaire, 2) were too ill to answer the questions, 3) could not be interviewed in the first 48 hours after admission to the hospital or were discharged from the hospital within 48 hours after admission and 4) (or their relatives) did not provide informed consent for the study. For the current study, only the patient-proxy pairs with complete data sets for the ADL and IADL functioning were included.

The Medical Ethics Committee of the AMC approved the present study.

Data Collection

The research nurses obtained the data for the present study within 48 hours after the patients' admission. Before inclusion in the present study, the patients and their closest proxy provided written informed consent. The data were collected on the patients' demographic characteristics, socioeconomic status, ADL and IADL functioning, cognitive functioning and level of delirium. The proxy was also interviewed. The proxy was defined as an individual who is a primary caregiver as a direct result of a social relationship. Therefore, a professional aid was not defined as a proxy.[16]

The following demographic characteristics were collected at the time of the hospital admission: age, gender, marital status, living arrangement, number of years of education, ethnic background and the patient's relationship to the proxy.

The Socio-Economic Status score (SES-score), which reflected the social status or level of social deprivation of the patient, was based on the patient's area postcode. The SES-score consists of the following three components: income, employment and education. A high score indicated the presence of multiple social deprivations. The SES-scores were derived by the Social and Cultural Planning Office.[17]

The premorbid ADL and IADL functioning, which were defined as the functional status two weeks prior to the time of the hospital admission, were measured using the modified Katz ADL index.[18] The patients and their proxies separately scored the patients' ability to perform eight ADL items (bathing, dressing, grooming, toileting, continence, transferring, walking and eating) and seven IADL items (using the telephone, traveling, shopping, preparing meals, doing housework, managing medications and handling money) on a dichotomous scale. The range of scores varied between 0 and 15, with higher scores indicating a greater level of dependence in terms of functioning (I)ADL.

The presence and the degree of the global cognitive impairment were assessed using Folsteins' Mini-Mental State Examination (MMSE).[19] The range of scores varied between 0 and 30, with higher scores indicating better cognitive functioning. The patients were classified into the following three groups: zero to little cognitive impairment (MMSE ≥ 24), mild cognitive impairment (MMSE16-23) and severe cognitive impairment (MMSE ≤15).[19]

The presence of delirium was assessed using the confusion assessment method (CAM).[20] The patients' medical problems at the time of admission were reviewed and grouped into differential diagnoses of major internal problems that were based on the following ICD-9 codes: neurological disease, infectious disease, malignancy, pulmonary complaints, disease of the digestive system, endocrine problems and cardiovascular disease.

Statistical Analysis

First, the patients' baseline characteristics were analyzed using descriptive statistics. The continuous variables were presented as the mean ± the standard deviation. The differences in the scores for the continuous variables were tested using a Student's t test, and the categorical data were tested with a Chi-square test.

To compare the level of agreement of the patient-proxy perceptions on the ADL and IADL functioning, each rating of a patient-proxy pair was classified into one of the following three categories: agreement in terms of the patients' ability to perform the task, the patient being rated more dependent by the proxy than by the patient and the patient being rated more independent by the proxy than by the patient. These differences were also illustrated using a bubble plot.

We hypothesized that lower levels of cognitive functioning affect the accuracy of patients' own ratings of their ADL and IADL; therefore, the patients' cognitive functioning was divided into three groups based on their MMSE scores. A Chi-square test was used to determine any differences between the three groups.

To identify the factors that were associated with a higher proxy-rated score on the modified Katz ADL index, a logistic regression analysis was conducted. The difference in ADL and IADL total score agreement between the proxies and patients was dichotomized into a new variable. The variables that were found in the literature that contributed to a difference in the scores were included in the analysis. All of the variables with a p-value of < 0.20 in the univariate analysis were entered into the multivariable logistic regression analysis. A manual selection procedure was applied and was cross-checked using a backward selection procedure.

All of the statistical analyses were performed using the Statistical Package for Social Sciences (SPSS) version 17.0.

Results

Baseline characteristics

In total, 617 patients were evaluated for inclusion in the present study. Of these patients, 460 had complete patient-proxy ratings on their ADL/IADL and were, therefore, included in the present study.

Table 1 presents the baseline characteristics of the studied population. The mean age was 78.0 years (SD=7.8), with 23% of the patients being older than 85 years. Overall, 69% of the patients lived independently before the hospital admission. The patients' mean MMSE score was 25, with 17% of the patients scoring below 15. The majority of the proxies were a spouse (38%) or a child (42%) of the patient.

Comparison of the patient and proxy perceptions of ADL and IADL

The patients and their proxies exhibited an 83% agreement on their ADL scores. These two groups were most likely to agree on their ratings of grooming and least likely to agree on their ratings of bathing (Table 2).

Overall, there was a lower level of agreement (79%) between these two

Table 1. Baseline characteristics of the study participants n=460

Variable	M	Patient-proxy pair	Variable	M	Patient-proxy pair
Age in years	78.0 (7.8)		**Social Economic Status (%)***		
Gender (%)			1		41.8
Female		55.0	2		39.8
Marital Status (%)			3		18.4
Single		10.9	**Cognition**		
Married		46.1	MMSE†	25 (0-30)	
Divorced/widowed		41.1	MMSE ≤ 15 (%)		16.5
Missing		2.0	MMSE 16-23 (%)		29.1
Living arrangement (%)			MMSE ≥ 24 (%)		54.3
Independent		68.5	Delirium (%)		
Senior residence		17.6	**Diagnosis at admission**		
Home for elderly people		10.2	Neurological problem		0.7
Nursing home		2.6	Infectious disease		55.4
Intermediate care		0.8	Malignancy		19.8
Education in years	9.1 (3.6)		Pulmonary complaint		8.3
Missing (%)		14.3	**Disease of the digestive system**		34.6
Ethnic group (%)			Endocrine problem		6.7
Caucasian		88.5	Cardiovascular system		8.7
Hindustan/Surinamese		5.7			
Proxies (%)					
Spouse (male)		11.5			
Spouse (female)		26.1			
Daughter		28.5			
Son		13.0			
Grandchild		1.3			
Neighbor		1.1			
Other family member		14.6			
Missing		3.9			

* SES median (range of scores from 0 to 3), a higher score indicates multiple social deprivations
† MMSE score median (range of 0 to 30), a higher score indicates better cognitive functioning

Table 2. **Agreement of the ratings of the Activities of Daily Living and Instrumental Activities of Daily Living from the patients and proxies (n=460).**

Katz item	% Agreement	% Rated more dependent by the proxy than by the patient	% Rated more independent by the proxy than by the patient
ADL			
Bathing	80.0	15.7	4.3
Dressing	81.1	15.0	3.9
Grooming	88.3	9.1	2.6
Toileting	82.4	10.7	6.7
Continence	82.0	11.1	6.1
Transferring	81.1	13.0	5.7
Walking	82.6	6.5	10.7
Eating	86.7	5.9	7.0
IADL			
Travelling	75.4	15.9	8.5
Shopping	78.5	11.7	9.6
Preparing Meals	75.2	11.3	12.4
Housework	83.0	6.5	10.2
Medications	78.5	12.2	9.1
Managing money	74.3	7.6	17.9

ADL = Activities of Daily Living
IADL = Instrumental Activities of Daily Living

groups for the scores of the patients' ability to perform IADL. The patients and their proxies were least likely to agree on their ratings of the ability to manage money and most likely to agree on their ratings of the ability to use the telephone.

Figure 1 shows a bubble plot of the combined ADL scores from the patients and proxies. The proxies tended to rate the patients as more dependent in terms of ADL and IADL compared to the patients' own ratings.

The proxies' perceptions of the patients' ADL performances were affected by the type of the patient-proxy relationship. Spouses were more likely to agree with the patient (89%) than the patients' children (80%) and other family members (79%).

Cognitive functioning and the agreement of the patient-proxy scores

Seventeen percent of the patients exhibited a severe cognitive impairment (MMSE ≤ 15), 29% exhibited a mild cognitive impairment (MMSE 16 – 23) and 54% exhibited no cognitive impairment (MMSE ≥ 24).

Table 3 shows the differences in the ratings between the patients and proxies that were subdivided using the category of global cognitive functioning. Overall, the difference in the patient-proxy reporting of the ADL was greater for the

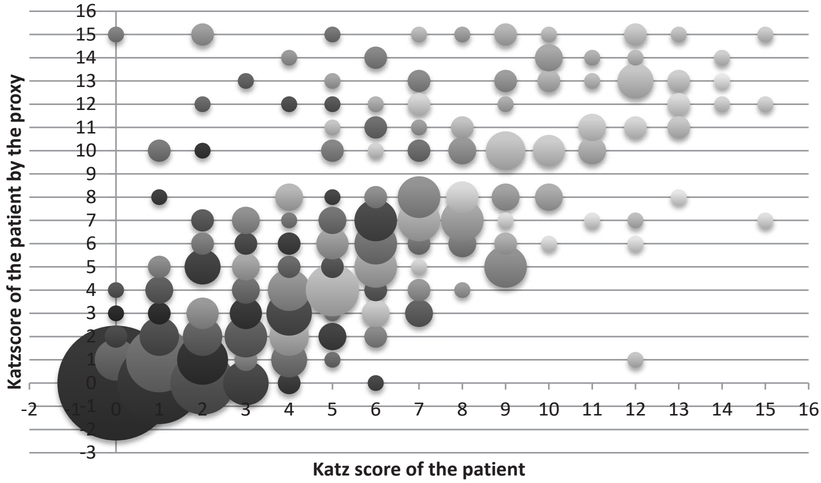

Figure 1. Overall agreement on ratings of the (Instrumental) Activities of Daily Living from the patients and proxies (n= 460)
The diameter of the bubbles indicates the number of times a combination of patient and proxy was given. The smallest bubble indicates a frequency of 1; the largest bubble indicates a frequency of 53.

patients with severe cognitive impairments than the patients with mild to little cognitive impairments. The overall percentage of the patient-proxy agreement on ADL for patients with severe, mild or no cognitive impairments was 70%, 79% and 90% ($p < 0.001$), respectively.

For the performance of IADL, cognitive functioning was also related to the differences in the ratings between the patients and their proxies; however, there were fewer differences in the agreement of the ratings for the IADL than for the ADL domain.

Factors associated with the differences in the patient and proxy scoring

Because the proxies tended to rate the patients as more dependent in terms of the ADL and IADL compared to the patients' own ratings, we explored the factors that were associated with the proxies' ratings.

A multivariate analysis (Table 4) revealed that two factors contributed to the rating that the patient was more dependent by the proxy than the patient's rating. Delirium (OR= 2.56 (95% CI 1.38-4.75)) and a lower score on the MMSE (0.95 (0.91-0.99)), indicating a greater level of cognitive impairment, were significantly associated with the proxy rating the patient as more dependent than the patient.

Table 3. **Agreement on the ratings of the ADL and IADL from patients and their proxies, as stratified by the patients' levels of cognitive functioning (n=460)**

	MMSE ≤ 15 (16.5%)			MMSE 16-24 (29.1%)			MMSE ≥ 24 (54.3%)			
Katz item	**% Agree-ment**	**% Scored as dependent by proxy**	**% Scored as independent by proxy**	**% Agree-ment**	**% Scored as dependent by proxy**	**% Scored as independent by proxy**	**% Agree-ment**	**% Scored as dependent by proxy**	**% Scored as independent by proxy**	**P value**
ADL										
Bathing	63.2	31.6	5.3	74.6	20.9	4.5	88.0	8.0	4.0	<0.001
Dressing	67.1	28.9	3.9	76.1	18.7	5.2	88.0	8.8	3.2	<0.001
Grooming	76.3	22.4	1.3	82.8	11.9	5.2	94.8	3.6	1.6	<0.001
Toileting	67.1	22.4	10.5	75.2	14.3	10.5	91.2	5.2	3.6	<0.001
Continence	69.7	26.3	3.9	78.6	11.5	9.9	88.8	6.4	4.8	<0.001
Transferring	71.1	19.7	9.2	76.9	14.9	7.5	86.4	10.0	3.6	0.01
Walking	77.6	9.2	13.2	80.5	7.5	12.0	85.6	5.2	9.2	0.19
Eating	64.5	19.7	15.8	84.8	4.5	10.6	95.2	2.4	2.4	<0.001
IADL										
Telephone	69.7	23.7	6.6	87.9	9.8	2.3	96.0	3.6	0.4	<0.001
Traveling	77.6	15.8	6.6	73.7	18.0	8.3	76.0	14.8	9.2	0.79
Shopping	80.3	11.8	7.9	77.4	12.8	9.8	78.8	11.2	10.0	0.88
Preparing meals	77.6	15.8	6.6	77.3	12.1	10.6	74.9	9.7	15.4	0.82
Housework	90.8	7.9	1.3	89.5	5.3	5.3	77.6	6.8	15.6	0.01
Medications	65.8	26.3	7.9	75.2	13.5	11.3	84.4	7.2	8.4	0.01
Managing money	75.0	10.5	14.5	68.4	7.5	24.1	77.6	6.8	15.6	0.14

ADL = Activities of Daily Living, IADL = Instrumental Activities of Daily Living

Table 4. Logistic regression analysis on the factors that were associated with a more dependent proxy rating of the patient's ADL and IADL than that of the patient

	Univariate		Multivariate	
	OR (95% CI)	**p-value**	**OR (95% CI)**	**p-value**
Age	1.05 (1.02-1.07)	<0.001		
Gender	1.25 (0.84-1.87)	0.28		
Marital status	1.78 (1.18-2.68)	0.01	-	-
Living arrangement				
Independent	Ref			
Senior residence/Home for elderly people	0.19 (0.05-0.58)	0.01	-	-
Nursing home	0.21 (0.06-0.79)	0.02	-	-
Education in years	0.98 (0.92-1.04)	0.51		
Ethnic groups				
Hindustan / Surinamese	0.50 (0.17-1.44)	0.19	-	-
Other	0.60 (0.15-1.45)	0.45		
Proxy relationship	0.99 (0.99-1.08)	0.77		
Social Economic Status	1.12 (0.97-1.3	0.12	-	-
Katz ADL index score	1.06 (1.00-1.11)	0.03	-	-
MMSE per point	0.93 (0.89-0.95)	<0.001	0.95 (0.91-0.99)	0.03
Delirium present	2.83 (1.78-4.50)	<0.001	2.56 (1.38-4.75)	0.01

Discussion

In the present study, 460 acutely admitted older hospitalized patients and their proxies exhibited a moderate to high level of agreement in terms of their ratings of the patients' ability to perform their ADL and IADL. The difference in the level of patient-proxy agreement was greater for patients with severe cognitive impairments than for the patients with mild to little cognitive impairments. Furthermore, delirium was associated with a more dependent proxy rating of the patients' ability to perform ADL and IADL than the patient's own rating.

The differences in the level of agreement between the patients' and proxies' perceptions of the patients' performance were observed for the ADL and the IADL. These findings indicated a lower level of agreement between the patients' and proxies' perceptions of the patients' performance on the IADL compared to the ADL. These results are consistent with those of earlier studies.[6,8-10,12,13] One explanation for a lower level of agreement between the patients and proxies 'perceptions is that ADL are more concrete and are more directly observable by proxies than IADL, which require a higher level of functioning.[9, 12] It is, therefore, more difficult to determine whether the patient's or proxy's information about the patient's IADL performance is accurate.

The level of agreement on the ratings of the patients' ADL and IADL performances was affected by the patients' level of cognitive functioning. Weinberger et al[13] observed a lower agreement rate when the patients' MMSE scores were below 24 points than when these scores were above this level. The current study further differentiated the patients' level of cognitive functioning by dividing the patients into three groups, which is also a common clinical practice. The difference in the patient-proxy reporting of ADL and IADL was greater for the patients with severe cognitive impairments (a score below 15 points) than the patients with mild to little cognitive impairments.

In addition to impaired cognitive functioning, the presence of delirium was associated with a disagreement in the patient-proxy ratings regarding ADL and IADL. Delirium is defined as a fluctuating consciousness and an acute change in cognition or a perceptual derangement.[21] This definition may explain why the ADL and IADL functioning ratings of patients with delirium differed from the proxies' ratings and why the patients' ratings may be less reliable than those of the proxies.

The practical implication of the present study's results is that a proxy should be interviewed to assess ADL and IADL functioning in patients with delirium or with an MMSE score of less than15 points. For patients with mild cognitive impairments (MMSE 16-23), the patient should be interviewed, and the information should be verified with the proxy. For patients with little to no cognitive impairment (MMSE≥ 24), it is sufficient to interview the patient.

Several limitations should be taken into account when interpreting the results of the present study. First, the data on the proxy characteristics, such as the caregiver burden, mood disturbances, and functional status, were not collected. These factors may also influence the proxy ratings[10-12]; however, no proxy characteristic effects were demonstrated. Furthermore, the data on each patient's living situation, such as the home environment, were not collected. In addition, problems with ADL and IADL may be related to barriers and inaccessible home environments; therefore, these factors may influence the results of the present study.[22-24]

In the present work, the subjective self-reports were not compared with the objective performance ratings of the ADL. The findings demonstrated that the proxies tended to rate the patients as more dependent in terms of their ADL and IADL compared to the ratings of the patients. However, it is unclear whether the patients or the proxies were more accurate. Future research is necessary to identify whether subjective or objective performance ratings are more indicative of actual daily functioning.

Furthermore, in the present study, the self-rated ability to perform ADL and IADL was only assessed in terms of functional independence. Information about the patients' functional independence is important for the planning of future interventions and care. However, functional independence also includes one's ability to exert control over his or her everyday life and to independently manage the ADL, which may be more important to some older persons than the ability to function independently.[23,25] These aspects should be examined in future research.

In conclusion, the present study reveals that the ratings of patients and their proxies exhibited moderate to high levels of agreement for the patients' ADL and IADL performance. For patients with a mild cognitive impairment at the time of the hospital admission, the results indicate that the self-report of the ADL and IADL is accurate and can be used to assess ADL and IADL functioning. For patients with severe cognitive impairments or prevalent delirium, their closest proxy may provide valid information about the patient's ADL functioning.

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Chapter

3

Sensor monitoring to measure and support daily functioning for independently living older people: a systematic review and roadmap for further development

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Abstract

Objectives: To study sensor monitoring (use of a sensor network placed in the home environment to observe individuals' daily functioning (activities of daily living (ADL) and instrumental activities of daily living (IADL)) as a method to measure and support daily functioning for older people living independently at home.
Design: Systematic review
Setting: Participants' home
Participants: Community-dwelling individuals aged 65 and older.
Measurements: A systematic search in Pubmed, Embase, PsycINFO, INSPEC and The Cochrane Library was performed for articles published between 2000 and October 2012. All study designs, studies that described the use of wireless sensor monitoring to measure or support daily functioning for independently living older people, studies that included community-dwelling individuals aged 65 years and older and studies that focused on daily functioning as a primary outcome measure were included.
Results: Seventeen articles met the inclusion criteria. Nine studies used sensor monitoring solely as a method for measuring daily functioning and detecting changes in daily functioning. These studies focused on the technical investigation of the sensor monitoring method used. The other studies investigated clinical applications in daily practice. The sensor data could enable healthcare professionals to detect alert conditions and periods of decline and could enable earlier intervention, although limited evidence of the effect of interventions was found in these studies because of a lack of high methodological quality.
Conclusion: Studies on the effectiveness of sensor monitoring to support people in daily functioning remain scarce. A roadmap for further development is proposed.

Background

The maintenance of daily functioning is important for allowing older people to live independently at home. Daily functioning can be divided into activities of daily living (ADLs) (e.g., bathing, dressing, grooming, toileting, continence, transferring, walking and eating) and instrumental activities of daily living (IADLs) (e.g., using the telephone, traveling, shopping, preparing meals, doing housework, managing medications and handling money.[1] Many older people have two or more chronic diseases[2] and they might experience increasing functional limitations that affect their ability to perform ADL and IADL.[3,4] The way older persons perform their ADLs and IADLs provides a measurement of their functional status and ability to live independently at home.[5]

Several methods are used for to measure or evaluate ADLs and IADLs. These are often limited to measuring daily functioning using self-report such as with the modified Katz ADL scale[1] or a more objective measurement method (e.g., the Assessment of Motor and Process Skills (AMPS).[6] Generally, these assessments are conducted as a small series of measurements at a few time points. More recently, new technologies, such as sensor monitoring, have been developed to measure the daily functioning of older people continuously.

Sensor monitoring is based on sensor network technologies and is used to monitor a person's behavior and environmental changes.[7] Sensor monitors can be wearable and wireless. Wearable sensors, attached to a person or his or her clothes, are often used to measure such vital signs as blood pressure and heart rate[8]; to measure human physical movement, such as walking, sitting transitions and physical exercises; and to monitor rehabilitation progress.[9] Wireless sensor networks, which consists of a combination of simple sensors installed in fixed locations are placed in the home and register in-home movement. The sensor data are processed in a computer that infers the daily functioning that participants perform in their homes.[7]

The use of wireless sensor monitoring enables the measurement of daily functioning and facilitates the early detection of changes in functional status by observing a certain daily activity pattern.[10] A daily activity pattern gives detailed information about which ADLs and IADLs are performed during a regular day and the sequences and variations of these activities.[11] The sensor data are usually analyzed using data mining and machine-learning techniques to build activity models and further enable the measure daily functioning and daily activity patterns.[7] With data mining from wireless sensor data, it is possible to determine most ADLs (e.g., bathing, dressing, toileting, transferring, walking and eating) and some IADLs (e.g., using the telephone, preparing meals, managing medications, doing housework) performed in the home. It is not possible to measure handling money, shopping and traveling. Specific algorithms are available to detect ADLs and IADLs and to detect uncommon patterns and therefore might enable early interventions.

Although several studies have examined the application and evaluation of sensor monitoring, most have focused on the use of wearable sensors and the technical investigation of sensor monitoring or are conducted in laboratory settings.[12] No systematic review was found in the literature focusing on the application and effectiveness of wireless sensor monitoring for older persons living independently at home.

The aim of this systematic review was therefore to study the application and effectiveness of sensor monitoring to measure and eventually support daily functioning in older people living independently at home.

Methods

Data sources and study selection

In collaboration with a clinical librarian (JD), a systematic search was conducted in Pubmed, Embase, PsycINFO, INSPEC and The Cochrane Library for articles published in English between 2000 and 2012. The searches were conducted on October 18, 2011 and updated on January 9, 2012 and October 25, 2012. A customized search strategy was conducted for each database (Appendix S1, available online). A manual search of references in the selected articles was also conducted to identify additional studies.

Sensor monitoring method

Figure 1 depicts the application process involved in using sensor monitoring to measure and support ADLs.[13]

The activity behavior of an ADL or IADL performed by an elderly person (Figure 1A) is monitored using a wireless sensor system installed in the home (Figure 1B). The sensor network consists of simple binary sensors. Such sensors may be passive infrared motion sensors (to detect motion in a specific area), magnetic contact sensors on doors and cabinets (to measure whether doors are opened or closed) and a flush sensor in the toilet (to measure the toilet being flushed).[13] An intelligent machine (Figure 1C), which looks for ADL and IADL and daily activity patterns in the data (e.g., the sensor system could recognize toileting or bathing but also more complex IADLs such as preparing a breakfast

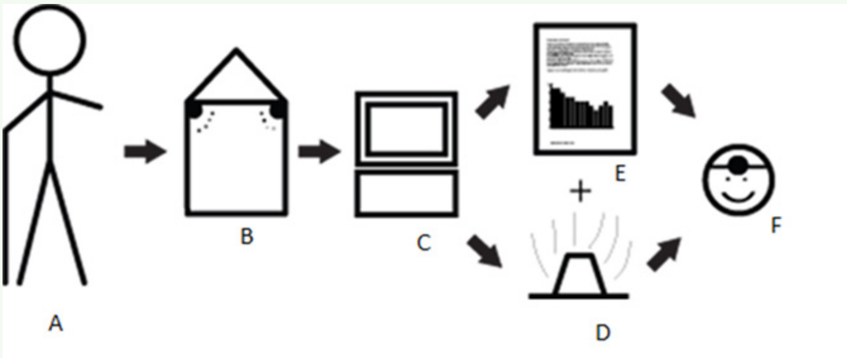

Figure 1. Iconic explanation of the proposed use of sensor monitoring systems to measure and support activities of daily living (ADLs)

(A) Elderly person performing ADLs or instrumental ADLs in his home, (B installed wireless sensor system in home placed at specific points in house and programmed to detect movement, (C) intelligent machine for analyzing sensor data, (D) alarm, (E) report of the sensor data, (F) health care professional. For more details, see Methods, Sensor Monitoring Method.

and other kitchen activities) analyzes these sensor data. A sequence of binary sensor data indicates the activity with the help of an ADL recognition algorithm.

The results of these analyses can automatically trigger an alarm (Figure 1D), for example, when no motion is detected for a long period of time or if an older person is in bed for several days. The automatic generation of a report within a predefined time period based on the sensor data is also possible (Figure 1E).

The reports and the alarms can be given to health care professionals (Figure 1F), who can use them to make better-informed decisions or to design interventions to support the older person.

Study selection

Two reviewers (MP and SP) first independently screened titles and abstracts for inclusion. The same reviewers then read the full text of the eligible articles found during this first selection. Differences between the two reviewers were resolved by consulting a third independent reviewer (BB).

Empirical studies that described the use of wireless sensor monitoring to measure daily functioning or to support older people with daily functioning in which study subjects included community-dwelling older persons aged 65 years and older and daily functioning was a primary outcome measured in the study.

Studies that focused solely on people diagnosed with severe dementia or severe cognitive problems (Mini-Mental State Examination score < 16) were excluded.

Data extraction and quality assessment

For each included study, data on study characteristics were extracted. Data were collected on type of sensor monitoring technology, number and type of sensors used, duration of the sensor monitoring and the aim of the sensor monitoring. Data were collected on participant demographic and clinical (main diagnoses, comorbidities, functional and cognitive status) characteristics.

The same reviewers also independently assessed the quality of the included studies. Because of the variety of non-randomized study designs included in this systematic review, the Newcastle-Ottawa scale (NOS scale)[14] was used to evaluate the risk of bias in the case controlled studies, the pre-post design study and the mixed method study (Appendix S2). Disagreements were discussed; in cases of disagreement, a third reviewer was enlisted.

Data synthesis and analysis

Given the heterogeneity of the reporting and designs of the included studies, a descriptive approach was used to summarize study characteristics and outcomes. The included studies were categorized into those that aimed to measure daily functioning and those that aimed to measure daily functioning and those that aimed to support people in their daily functioning. No statistical pooling was conducted.

Results

Search result

The literature search identified 6,795 articles (Figure 2 appendix S1, available online). After the titles and abstracts were screened, 6,717 studies were excluded because they did not pertain to sensor monitoring, were discussion papers or editorials on the topic of sensor monitoring, or did not meet the inclusion criteria. In the next phase, 78 full-text articles were screened, and 61 of those were excluded, 18 for not meeting the inclusion criteria on design (review or theoretical study), 15 for not meeting the criteria for the intervention (only wearable sensors), eight for not meeting the inclusion criteria for the participant age, and 16 for not meeting the criteria for the outcome measure (ADL and IADL function was not the primary outcome). Four were duplicates. Seventeen studies were included in this systematic review.

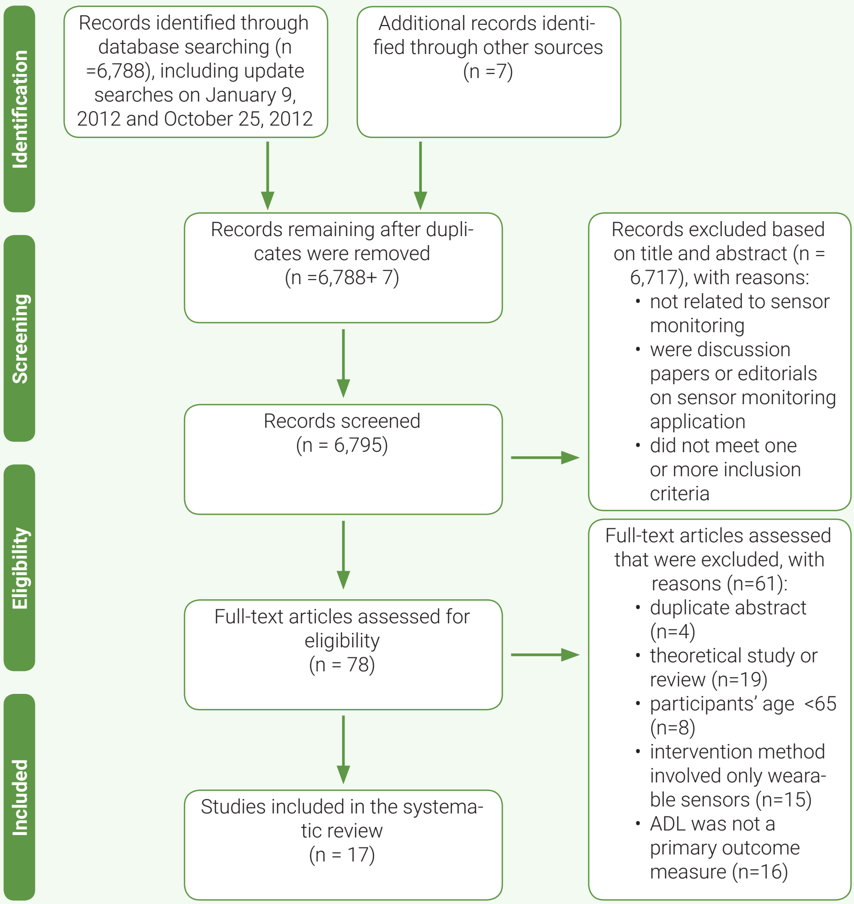

Figure 2. Flow diagram of search strategy and study selection

Quality of the included studies

Appendix S2 shows the results of the quality assessment of the three case-control studies and the pre-post design and mixed method studies included in this review. Three studies were considered low quality, and two studies were considered moderate quality. The studies had a small sample size or unclear inclusion and exclusion criteria or lacked follow-up.

Characteristics of the studies

Table 1 shows the characteristics of the included studies. There were three case-control studies[15-17], one mixed-methods study[18], one longitudinal pilot study[19], one single-group pre-post design study[20], three multiple-case studies[8,21,22], seven case studies[23-29] and one experiment.[30]

The number of people included in the studies varied from one to 52. In seven studies, the mean age of the older participants was not specified. The weighted mean age of the participants in the remaining eight studies was 82.6 years.

Seven of the studies were conducted in senior houses or assisted living settings[8,16,17,21,22,24,25], and four studies were conducted in smart home apartments.[23,26,28,30] Six studies were conducted in an independent living setting in the community.[15,18-20,27,32]

Ten studies did not report or specify clinical data of the participants. Four studies included participants without any reported diseases (healthy volunteers). Of the studies that investigated specific subgroups of older persons, most of the included participants had one or more chronic diseases. Only two studies provided a formal description of the functional or cognitive status of the included participants.

All of the studies focused on ADLs and IADLs as an outcome measure. Among the specific focuses were measurement of ADLs and IADL s[23,28,30], measurements of routines or daily activity patterns[15,20-22,24,26-28,32], ADL and IADL performance[8,18,20], presence of the test person[8,19,28], (in)activity[8,19,25,32], restlessness[8,17,22], functional ability[18,20,22,24,26,28], gait speed[8,15,22], physiological signs[17] and safety[8,16,18-20,22,25].

Characteristics of the sensor monitoring method

The summary characteristics of the sensor monitoring method are described in Table 2. Studies were divided according to whether they aimed solely to measure daily functioning[15,21,23-26,28-30] and whether they aimed to support people in performing their ADL and IADL.[8,16-20,22,27]

The studies that aimed solely to measure daily functioning focused mainly on technological development or investigating the artificial intelligence analysis method behind the sensor monitoring system. The studies that also focused on supporting people in daily functioning included a more- detailed focus on the clinical relevance of sensor monitoring methods. All studies with a technological viewpoint mentioned some future possibilities for the use of sensor monitoring in daily clinical practice.

Three of the identified studies combined the use of a wireless sensor network with wearable sensors[16,20,30] and video.[8,22,28] The most common wireless sensors used were passive infrared (PIR) motion sensors, magnetic contact switches and some other binary sensors, such as pressure, float and temperature sensors.

Chapter 3

Table 1. General characteristics of the included studies

nr	Study, year, ref.	Study design	Number of partici-pants (n)	Age	Setting	Clinical data	Sensor monitoring method	Outcome measure
Studies with the aim to measure daily functioning								
1	Rashidi P., 2011(23)	Experiment (2x) case study	n= 2	ns	Smart home apartment	ns	Passive sensor network	-ADL and IADL (ADL-International scale)
2	Wang S., 2009(24)	Case study	n= 1	>65 ns	Senior housing	ns	Passive sensor network	- Activity level and periodicity of lifestyle - alert conditions - ADL pattern
3	Min CH.,2008 (30)	Experiment	n= 5	ns	Bathroom (lab)	Healthy volunteers	Static wireless sensors and wearable wireless sensors	-ADL (Katz ADL)
4	Poujaud J.,2008 (25)	Case study	n= 1	>65 ns	Smart home (senior apartment)	Healthy volunteer	Passive sensor network	-ADL and IADL -amount of ADL -ADL-pattern
5	Virone G.,2008(26)	Case study	n=1	>65 ns	Smart home	ns	Passive sensor network	-ADL pattern
6	Hayes TL., 2008(15)	Case control study	n=14	age: 89,3 (±3,7 years) female:9	Independent living setting in the community	C:-Healthy cognitive volunteers I:mild cognitive impairments measurements of MMSE, clinical dementia rate, years of education, (I)ADL, Tin balance, Tin gait	Passive sensor network	-Walking speed -amount of ADL -ADL and IADL

Table 1. Continued

nr	Study, year, ref.	Study design	Number of participants (n)	Age	Setting	Clinical data	Sensor monitoring method	Outcome measure
7	Virone G., 2008(21)	Multiple case studies (4)	n= 22 f: 15 case studies: n=4	85 (range: 49-93)	Assisted living apartment	ns 7 participants were memory care unit residents and 15 were non-memory care residents	Passive sensor network	-Circadian activity rhythms (CARs) -ADL and IADL (Katz and Lawton)
8	Zouba N.2010, (28)	Case study	n= 2 f: 1	f 64 m 85	Smart home	Healthy volunteers	Passive sensor network and video sensors	-Presence -recognition postures and events -ADL
9	Yang C. (32)	Case study	n=1	F 75	Independent living setting in the community	ns	Passive sensor network	-ADL and IADL (Katz and Lawton) -rhythm of ADL
Studies with the aim of supporting people in daily functioning								
10	Rantz MJ.,2010 (8)	Retrospective exploratory multiple case study(3)	n= 16 f: 11	88.4 (SD 6.2, range 70-96 years)	Senior housing	Chronic diseases (CHF, falls, kidney disease, COPD)	Passive sensor network and an event-driven video sensor network	-Presence and activity of ADL -ADL and IADL performance -presence and restlessness in bed -falls -gait speed
11	Skubic M.,2009 (22)	Retrospective multiple case study	n= 17	>65 ns	Senior housing	Chronic diseases ns	Passive sensor network and an event-driven video sensor network	- ADL pattern - functional ability - alert conditions - bed restlessness - falls - gait patterns, gait speed, balance, posture

Table 1. Continued

nr	Study, year, ref.	Study design	Number of partici-pants (n)	Age	Setting	Clinical data	Sensor monitoring method	Outcome measure
12	Brownsell S.,2008(16)	Controlled trial	n= 24 (in-tervention group) f: 12 n=28 con-trol group f :17	I:74 (SD10) C: 79 (SD7)	Sheltered housing of sub-jects who lived independently	ns	Passive sensor net-work and telecare	-ADL and IADL -fear of falling -health-related quality of life -feeling safety
13	Alwan M.,2007(17)	Case- con-trolled study	n= 21 (in-tervention group) f:16 n= 21 con-trol group	I: 88 (SD6.4, range 73 – 90) C: 88 (SD 5.7 ran-ge 77-97)	Assisted living apartment	ns	Passive sensor network	-ADL -restlessness in bed -heart and breathing rates -cost of medical care -efficiency and workloads
14	Suzuki R.,2006(27)	Case study	n= 1 f:1	72	Independent living setting in the community	ns	Passive sensor network	-ADL and IADL Rhythm of ADL
15	Ohta S., 2002(19)	Longitudinal study	n= 8	81	Independent living setting in the community	ns	Passive sensor network	-In-house movements -duration of stays in rooms -safety, determined by chan-ges in the duration of stays in rooms
16	Reder S.,2010 (20)	Single group pre-post design	n= 12 and a family member and/ or paid caregiver(-dyads or triads) f:8	> 55 ns	Independent living setting in the community	ns only in terms of receiving assistan-ce with I)ADL	Passive sensor network and wearable sensors	-Physical movement -performing ADL and IADL -regular use of medication -use and satisfaction with the technology -safety and wellbeing, -communication patterns -family caregiver burden

Table 1. Continued

nr	Study, year, ref.	Study design	Number of partici-pants (n)	Age	Setting	Clinical data	Sensor monitoring method	Outcome measure
17	Mahoney DF.,2009 (18)	Mixed methods: -focus group inter-view -interventi-on study	i:n= 10 and their family member, 9 staff mem-bers Fg: n= 13 4 family members, 9 staff members	83 Focus group > 65	Independent living setting in the community	Safety and health concerns, cogni-tive impairment, not specified	Passive sensor network	- The elders, families and staff's understanding of the use of wireless sensor monitoring -measures of the elders' emotional, physical health and activity levels

Passive sensor network; the subject did not need to do anything with the sensor network
Ns= not specified F=female ADL=activities of daily living IADL= Instrumental activities of daily living

Table 2. Characteristics of measurement and support studies

Study nr	Study, year, reference	Technological development	Clinical practice	Possibilities for clinical practice	Wearable and passive sensors	Passive sensors	Only PIR sensors	Diverse binary sensors	Other specific sensors
Studies with the aim of measuring daily functioning									
1	Rashidi P., 2011(23)	y		y				y	
2	Wang S., 2009(24)	y		y		y	y		
3	Min CH.,2008(30)	y			y			y	y
4	Poujaud J.,2008(25)	y		y		y		y	
5	Virone G.,2008(31)	y		y		y	y		
6	Hayes TL., 2008(15)		y			y		y	
7	Virone G., 2008(21)	y		y		y		y	y
8	Zouba N.2010(28)	y		y		y		y	y
9	Yang C., 2012(32)	Y		Y		Y	Y		Y
Studies with the aim of supporting people in daily functioning									
10	Rantz MJ.,2010(8)	y	y	y		y		y	y
11	Skubic M.,200(22)		y			y		y	y
12	Brownsell S.,2008(16)		y	y	y			y	y
13	Alwan M.,2007(17)		y			y		y	y
14	Suzuki R.,2006(27)		y			y		y	y
15	Ohta S., 2002(19)		y			y	y		
16	Reder S.,2010(20)		y		y			y	y
17	Mahoney DF.,2009(18)		y			y		y	y

Y=yes, ns=not specified, PIR=passive infrared, patterns=activity pattern

Effectiveness of sensor monitoring

All of the included studies reported positive results for the use of the sensor monitoring method. These studies investigated the models used to analyze the sensor data or to measure daily functioning or determine ADL patterns for people living alone and to identify changes in their typical ADL patterns. The results are presented in Table 2. Most of the studies reported potential advantages of the use of sensor monitoring to improve healthcare outcomes, although the effects were not studied in randomized clinical trials, and the studies lacked sufficient power to detect changes or effects. Two of the three included case-control studies did report better effects of the sensor monitoring method, such as the early detection of clinically relevant changes, than with the regular care provided to the control group.[15,17] One case-control study reported lower estimated costs of care over a 3-month monitoring period, fewer hospital days, and a positive effect of the method on professional caregiver efficiency, but all of these studies had small sample sizes.

Table 2. Continued

Number of sensors used	Duration of monitoring	Recognized ADL and IADL	Detected changes in patterns	Safety	Reduction of hospital days/costs	Efficiency professionals	Study, year, reference	Study nr
Studies with the aim of measuring daily functioning								
n=48	3 months	y	y				Rashidi P., 2011(23)	1
ns	2-3 years		y				Wang S., 2009(24)	2
ns	< 2 hours	y					Min CH.,2008(30)	3
ns	1 year	y		y			Poujaud J.,2008(25)	4
ns	ns	y	y				Virone G.,2008(31)	5
ns	6 months	y	y				Hayes TL., 2008(15)	6
ns	3 months - 1 year	y	y				Virone G., 2008(21)	7
n=25	4 hours	y	y				Zouba N.2010(28)	8
ns	6 months	Y	Y				Yang C., 2012(32)	9
Studies with the aim of supporting people in daily functioning								
ns	3 years	y	y	y		y	Rantz MJ.,2010(8)	10
ns	3 months - 3 year	y	y	y	y		Skubic M.,200(22)	11
ns	12 months			y			Brownsell S.,2008(16)	12
ns	3 months	y			y	y	Alwan M.,2007(17)	13
n=12	6 months	y	y				Suzuki R.,2006(27)	14
ns	80 months			y			Ohta S., 2002(19)	15
ns	3 months	y		y			Reder S.,2010(20)	16
ns	4-18 months			y		y	Mahoney DF.,2009(18)	17

Discussion

This systematic review provides a comprehensive overview of the use of sensor monitoring to measure and support the daily functioning of older people living independently at home.

It found that half of the included studies used the sensor monitoring solely as a method to measure ADLs and IADLs and to detect changes in these daily functioning for a person living independently. These studies tended to focus on the technical aspects of the sensor monitoring method used. The other half of the studies investigated how the use of sensor monitoring could support people in their daily functioning and allow them to live independently at home, but most of the studies were small in scale, and evidence of the methods' effectiveness was lacking. The included studies demonstrate an important gap between the technological development of sensor monitoring, which is already significant, and its application and effectiveness in daily practice. The included studies illustrated that health care professionals could take advantage of sensor monitoring to detect early periods of physical decline more quickly than when traditional means of measuring functional status are used. This might enable professionals to provide early interventions to prevent the decline caused by falls or immobility, thereby influencing clinical outcomes.

A road map is proposed to further develop and improve the use of sensor monitoring to measure and support daily functioning in independently living older people and to collect evidence about the applicability and effectiveness of sensor monitoring for clinical practice. This roadmap consists of the following steps:

- *Determining the target population that can benefit from sensor monitoring.* Because of the strong focus on the technical considerations of sensor monitoring, a significant number of studies did not specify or even report important demographic and clinical data of the participants. Therefore, it was difficult to study which older people might benefit from sensor monitoring to support their daily functioning. Although this review showed that older people with one or more chronic diseases and those with mild cognitive problems could be a potential target group for sensor monitoring, more specific investigation into the characteristics of the target population is needed to be of value in clinical practice. Future research should include demographic- and clinical data.
- *Investigation of the use of sensor monitoring in community-dwelling older persons*. Early observation of a decline in daily functioning enables health care professionals to provide early interventions or support clinical decisions. Potential goals for the participants can include living longer independently at home, preventing readmission to the hospital and minimizing emergency room visits.[8,22] It has been suggested that sensor monitoring could also be useful to measure and support the recovery of older people after hospital admission[8], although evidence pertaining to the effectiveness of these possible applications is still lacking. Further more research is needed to investigate and validate these applications and their role in influencing clinical outcomes.
- *Guidelines for health care professionals regarding the use of sensor monitoring.* Although all of the included studies illustrated promising possibilities for the use of the sensor data in clinical practice, none of them focused on guidelines for health care professionals to use sensor data with their patients. In a few studies, the sensor data were connected via a secure web-based interface for use by health care professionals. One study developed a visualization application (density map) for health care providers[24] to identify daily activity patterns and changes in patterns. This visualization application was used in two studies by retrospectively viewing and analyzing the data for the periods before and after health events, such as hospitalizations, falls and emergency department visits.[8,22] The focus for future research should be developing and testing visualizations of sensor data for health care professionals for supporting people in daily functioning, and guidelines for health care professionals regarding the use of the sensor data in caring for their patients and for advising caregivers.

- *Involvement of the participants, caregivers and health care professionals in the further development and implementation of sensor monitoring.* Because sensor monitoring is a promising method for supporting older people in their everyday life, the research must address the needs and expectations of the end-users and health care professionals.[31,32] Study participants have indicated that they felt safer having the sensors in their homes and could use the sensor data as feedback, enabling themselves to change their behaviors in an effort to function independently at home for as long as possible.[22] Therefore, future research should involve individuals and health care professionals to customize the use of sensors to the participants' specific needs.
- *Conducting large-scale clinical trials.* The success of sensor monitoring depends on evidence of the method's effectiveness in achieving its goals. If studies are established, they should be of a higher methodological quality than existing studies and should express clear inclusion and exclusion criteria, a proper research design and a power calculation to include a sufficient number of people.
- *Study the cost effectiveness of sensor monitoring.* It has been demonstrated that sensor monitoring provides effective care coordination tools that have a positive effect on professional caregivers' efficiency; reduce caregivers' workloads and result in significantly fewer hospital days, hospital visits and emergency room visits.[17,24] Possible improved outcomes for health care professionals include a positive effect on health care professionals' efficiency and workload[17], although these results were found in just one study with a small sample size, and the results could not be compared with those of other studies. Future research should investigate the cost effectiveness of sensor monitoring.

Conclusion

The use of sensor monitoring could provide promising opportunities in clinical practice by measuring and supporting daily functioning in older persons living independently, although clear evidence is still lacking. This systematic review also showed that the research has focused largely on the technical aspects of sensor monitoring and less on its application in everyday life and clinical practice. Future research should focus on facilitating the use of sensor monitoring in everyday life and clinical practice. To encourage this, a roadmap for future research was proposed that includes the participation of the older people themselves.

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Chapter

4

Older people's perspectives regarding the use of sensor monitoring in their home

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Abstract

Purpose: The early detection of a decline in daily functioning of independently living older people can aid healthcare professionals in providing preventive interventions. To monitor daily activity patterns and, thereby detect a decline in daily functioning, new technologies, such as sensors can be placed in the home environment. The purpose of this qualitative study was to determine the perspectives of older people regarding the use of sensor monitoring in their daily lives.

Design and Methods: We conducted in-depth, semi-structured interviews with 11 persons between 68 and 93 years who had a sensor monitoring system installed in their home. The data were analyzed using Interpretative Phenomenological Analysis.

Results: The interviewed older persons positively valued sensor monitoring and indicated that the technology served as a strategy to enable independent living. The participants perceived that the system contributed to their sense of safety as an important premise for independent living. Some of the participants stated that it helped them to remain active. The potential privacy violation was not an issue for the participants. The participants considered that healthcare professionals' continuous access to their sensor data and use of the data for their safety outweighed the privacy concerns.

Implications: These results provide new evidence that older persons experience sensor monitoring as an opportunity or strategy that contributes to independent living and that does not disturb their natural way of living. Based on the present study, the development of new strategies to provide older people with access to their sensor data must be further explored.

Introduction

In the Netherlands, two- thirds of people between 65 and 75 years have two or more chronic diseases. Among the people who are older than 85 years, at least 85% have more than two chronic diseases.[1] Multiple chronic diseases can limit daily functioning and hinder independent daily living.[2-4] For older persons, the further loss of function can be prevented or delayed if a decline in daily functioning is identified at an early stage. Such identification can enable health care professionals to provide preventive interventions that postpone functional decline. Sensor monitoring in the home environment offers the possibility of early detection. However, the degree to which older people value senor monitoring and what they expect from sensor monitoring remain unknown.

Previous research has shown that healthcare technology such as the use of sensor monitoring can be used to objectively measure and observe the daily functioning of older people who live independently.[5-10] Sensor monitoring is based on sensor network technologies that consist of different simple sensors that are installed in fixed locations and register in-home activities.[11] The use of sensor monitoring facilitates the early detection of changes in functional status through the observation of a daily activity pattern. This provides detailed information about the daily functioning that is performed during a regular day and the sequences and variations of activities. The sensor data are analyzed using data mining and machine-learning techniques to build activity models and further enable the recognition of daily functioning or uncommon patterns of daily functioning in the home. This information might enable health care professionals to provide early interventions to prevent the decline that is caused, for example, by falls or immobility.[5]

Although the literature has shown positive results of the use of sensor monitoring, most studies have largely focused on the technical aspects of sensor monitoring rather than its application in everyday life and clinical practice.[5] To further improve and implement sensor monitoring in daily practice, researchers must address the needs and expectations of the end users and health care professionals to customize the sensor system to their specific needs.[5,12,13] To this end, Kanis, Robben and Kröse (2012) presented an elderly-centered design method.

Only a few articles have been published on older people's perceptions and perspectives on the use of sensor technologies in their home.[14-17] Most of these studies have focused on smart home technologies, volunteers' use of technology in experimental situations, or people living in long-term retirement homes.[12,18] Studies on the perspectives of community-dwelling older people who use sensor monitoring in their home remain scarce.

To the best of our knowledge, only one study evaluated the perspectives of older adults with 'high demand care', using the Unattended Autonomous Surveillance (UAS) system. This system is based on a different type of sensor and healthcare technology, is placed in the home and aims to support aging-in-place.[15] The study of this system revealed that participants experienced a greater sense of safety and security with this system in their homes, although there was little understanding of the interoperability of the system and the healthcare that the participants received.

Consequently, knowledge remains limited about community-dwelling older people's experiences and opinions regarding the use of sensor monitoring, the impact it may have on their daily life and how the sensor data could be used to initiate interventions by attending healthcare professionals. Therefore, this research question was as follows: To what degree do older people value sensor monitoring and what do they expect from sensor monitoring in their daily lives?

Methods

Design

To provide a rich understanding of participants' experiences and opinions regarding the use of sensor monitoring, we used a qualitative interpretative phenomenological study design (IPA).[19] The IPA is useful to explore in detail how participants perceive a particular situation and the main currency for an IPA study is the meaning, which the participant gives to these experiences. Therefore, interpretation is needed to understand the experiences of the participants.[19]

Participants

IPA studies benefit from a small participant sample to allow detailed analyzes of each individual and to enable connections within participants' experiences and perceptions and to investigate the differences and similarities between these experiences.[19] We purposefully sampled eleven participants from a pilot study (n=23), in which the sensor monitoring method was tested during one and a half year. From the 23 participants, 10 were living alone in the community and 13 were living alone in a senior residence. For this study, we sought participants who were living alone in the community because in the future we are moving to the use of healthcare technology at home. Therefore, we contacted them by telephone, informing them of this research and asking them to participate. Seven participants were willing to participate. The three other persons were not able to participate due to aphasia or other personal circumstances. We contacted four more persons from our list living in a senior residence to participate. From this group, there were no refusals.

Before participating in the pilot study, a miniature model of a sensor-equipped house was used to explain how the sensor monitoring works to the participants.[20] The interviewed participants had a sensor monitoring system (see further explanation sensor monitoring system) installed in their home for a few months. Table 1 presents the characteristics of the interviewed participants, seven women and four men. The age of the participants ranged from 68 to 94 years, and the participants were all living alone in the community or a senior residence. Preceding the interviews, the participants provided informed consent and permission to record the interviews. The Medical Ethics Committee of the AMC approved the present study.

Sensor monitoring system

The activity behavior of daily functioning performed by an elderly person is monitored using a wireless sensor monitoring system installed in the home. The sensor monitoring system used, consisted of 16 simple binary sensors, including passive infrared motion sensors (to detect motion in a specific area),

Table 1. Characteristics of the interviewed participants

Participant	Gender	Age in years at time of interview	Living arrange-ment	Comorbi-dity	ADL functi-oning Katz ADL index (1-15 points)	Cognition MMSE (0-30 points)
A	M	84	S	2	3	30
B	F	79	S	5	1	29
C	F	68	S	2	7	29
D	F	85	S	1	1	30
E	F	77	C	4	4	30
F	M	83	C	3	1	29
G	F	91	C	7	4	27
H	F	88	C	4	2	28
I	M	93	C	2	3	29
J	V	78	C	7	6	28
K	M	79	C	2	5	29

M, Male; F=Female; C, living alone in the community; S, senior residence
Katz ADL, range 1-15; a higher score indicates more ADL dependence
MMSE, range 0-30; a higher score indicates better cognitive functioning
Functional Comorbidity Index (FCI); sum of 18 self-reported comorbid conditions with a score of 0 to 18. A higher FCI score indicates greater comorbidity and is associated with impairment in physical function 1 year later.

magnetic contact sensors on doors and cabinets (to measure whether doors are opened or closed) and a flush sensor in the toilet (to measure the toilet being flushed). The sensors register only in-home activities without a camera or sound recording of the participants. These sensor data are analyzed by an intelligent software program using machine learning techniques, that searches for activities of daily functioning and patterns of daily functioning (e.g. toileting, bathing or bed rest could be recognized but also more complex activities of daily living such as preparing kitchen activities could be recognized by the sensor system). The results can automatically generate a report. The report can be given to health care professionals, who can use them to make better –informed decisions or to design interventions to support the older person.[5,21] The sensor monitoring system does not detect emergencies.

During the pilot study, a web-interface for the reporting of the analyzed sensor data was developed for the use of health care professionals. During the interviews, also some examples of the sensor data reports, developed for the healthcare professionals, were presented.

Procedure

Semi-structured interviews were conducted between April and June 2013 at the participants' home for approximately one hour. An interview guide with a list of four topics provided a structure to the interviews. The topics were as follows: (i) motives for exploring the use of sensor monitoring; (ii) perspectives on the sensor monitoring system and the sensor data; (iii) perspectives and experiences with the monitoring of daily functioning; and (iv) sensor monitoring to support daily functioning. No fixed structure was followed and the topics were broad to enable participants to freely reflect on their experiences and share their opinions.[19] The interviews began with general questions, followed by probes to elicit more detailed responses.[19] Some examples of the questions were: "could you tell me in what way do you experience having sensors in your house?" "How do the sensors affect your daily life?" "How do you experience being monitored 24 hours a day?" "What do you think of the privacy aspect?" "What do you think of who should have access to your personal sensor data?" "What do you think how the sensor data could support you in optimizing daily functioning?" Towards the end of each interview a summary was provided to give the participant the opportunity to further clarify or add more information.

Data Analysis

Interpretative Phenomenological Analysis (IPA) was used as a guiding framework.[19] Using IPA, we interpreted how sensor monitoring was perceived in the participants' daily life. Our main goal for this study was to study experiences of older persons regarding the use of sensor monitoring in their daily lives as well as their meanings of these experiences; how they value it, their points of view and their perceptions. We need all of this information to further develop sensor monitoring and how this can be implemented in cooperation with the users and healthcare professionals. Therefore, we especially have chosen to use IPA in our analysis. And because of this each transcript was read and re-read and analyzed for initial codes relevant for the research question. In each transcript, reflective notes were made to develop interpretations. These notes include personal thoughts, comments, observations and reflections that occur while reading the text. In each transcript, initial themes were identified. Connections between themes were noted.[22] Atlas.ti computer software was used to assist in organizing the data (www.atlas.ti.com). From the individual themes of all of the transcripts four main overarching themes were identified. This selection process of forming themes required the interpretation of the researcher. Capturing the meaning of the perceptions (to the participant) was central, but necessarily involved interpretative engagement with the text.[19] This enables the researcher to explore how persons ascribe meaning to their experiences in their interactions with their environment.[19,22] and is therefore suited for this study, which aims to study the experiences and meanings regarding the use of sensor monitoring in their daily lives. The interpretative element, which is the essence of the analysis in IPA studies, may give rise to discussion. However, according to Smith et al[19], audit is there to 'ensure that the account produced is a credible one, not the only credible one'.[22] Discussions and reflections with the research team helped to achieve validity. The four themes were described with using quotations that best captures the essence of the participants' experiences and thoughts.

The titles that were selected for the themes were reflective of the language that was used by the participants. To avoid the loss of meaning in the translation process from the Dutch interview fragments into English during the analysis, we employed the original language (Dutch) as long as possible. We performed the translation of the most important quotations and titles of the themes side-by-side with a professional translator.[23]

Results

Sense of safety and living independently at home

Overall the participants' motives for exploring the use of sensor monitoring in their daily lives were based on the desired results, as sensor monitoring might allow older people to live independently at home as long as possible. All of the participants expressed a strong preference to remain in their own home, in their own neighborhood and responsible for to their self-maintenance. For example, Mrs. C stated: *"it may be useful for the future, I think. People can stay at home longer with the help of sensors because there is more supervision. And this is not so much for me as for all of us in the future. It is always nice to stay in your own neighborhood, especial for elderly people who have neighbors and friends in their neighborhood."*

All of the participants indicated that sensor monitoring was beneficial for their sense of safety at home, especially because they all lived alone and thus experienced a lack of safety. As Mr. A expressed: *"Look there are my sensors, they are my watchdogs and they look after me."* The participants experienced this sense of safety in two ways. Most participants stated that sensor monitoring is important for detecting emergencies such as a fall. Mrs. D explained this as follows: *"Well, you are on your own, so something can happen, like when you fall down and can't get up, and this has quite often happened before, that you can't get up one way or the other. Yes, then I had the idea that this should be watched by someone somewhere."* The second type of sense of safety was the possibility of detecting a decline in daily functioning. The sensors were able to capture things that the participants did not notice. Mr. A expressed this as follows: *"if there should be a slow change in my daily pattern I certainly wouldn't report it. I wouldn't notice, and therefore, I find it important that the nurse's station gets a signal like: keep an eye on that."*

The sensors keep an eye on me and that comforts me

Sensor monitoring contributes to the sense of safety as a premise for living independently alone at home as outlined above. This sense of safety contributes to the easy acceptance of the sensor monitoring system at home. As Mrs. B stated: *"I feel safe with this because without noticing it, somebody is keeping an eye on me"'* According to the participants, the visibility of the sensors in the home did not seem to impact their daily functioning. Most of them indicated that they did not notice the sensors after a period of time. They did not experience the presence of the sensors in their home as a disturbing element. Furthermore, the sensors were not considered to be visually unpleasant as expressed by Mrs. C: *"These sensors are hanging up, and yes you can see them, but they aren't that bad."* Most of the participants forget about the sensors after a period of time and experienced the presence of the sensors as natural in their home. Mr. F expressed this view as follows: *"Well, I don't see them anymore. At first, I did, but later on you just go pass them and that is it. No, it is like when go and live near a train uh, railway line, the first days you hear it and then you don't anymore, but they are still there."*

The social environment's reaction to the sensor monitoring seemed to support the quick acceptance of a sensor system in the home. Most of the participants reported that their visitors or family did not notice the sensors unless the participant called attention to them. One participant, Mr. A stated: *"No these sensors don't attract attention at all. Most think it is a fire alarm, others think it is a spotlight. So, the design is perfect, it doesn't particularly stand out"'*

An added benefit of sensor monitoring in the home is the user- friendliness of the technique. Most of the participants explained that they did not have any technical knowledge and expressed their relief that the sensors did not require any action of them.

The majority of the participants seemed to easily accept the sensors as natural in their daily life. However, at times, one of the participants was reminded of the sensors in her home. She indicated that the sensor base -unit reminded her of having sensors in the home because of a burning LED-light on this unit. This made her feeling uncomfortable. However, when the sensor base unit was placed out of her sight, this problem was solved.

Sense of safety is more important than privacy

The participants did not experience the use of sensor monitoring as an invasion of their privacy. Their privacy matters regarding the data collection and sharing of these data differed. Some of the participants reacted indifferent towards the topic of privacy. Mr. R expressed: *"No, really I have nothing to hide, I have no secrets so it doesn't bother me*." Furthermore Mrs. R stated: *"No, it's of no concern to me, I don't even think of it. I don't mind if they are seeing what I'm doing here in my house."*

Other participants stated that the sensors only registered their in-home movements without cameras or sound recording and, therefore, they did not consider them to be an invasion of their privacy. Mrs. D expressed: *"Well, talking about privacy, they make such a fuss about it. You can only see that I am moving but not what I'm doing."* Mrs. D's quote captured many of the participants' experiences, emphasizing the difference between an individual who can see that one is moving and an individual who can see all of one's actions.

The participants indicated that the safety benefits of the sensor monitoring were far more important than their privacy. The system supported their ability to live independently at home. Therefore, they were willing to make some concessions concerning their privacy. The loss of some of their privacy was balanced with the advantage of having the system. For example, Mr. I expressed: *"yes, this is a guarantee for me, that's how I experience this. I like to live independently as long as possible. This really suits me; I'm in my own environment."*

The participants generally expressed that they did not feel watched or observed by the sensors. However, two participants experienced the monitoring of specific personal daily activities to be difficult to share with others, but they did not reject the monitoring of these activities. Mrs. C explained: *"No, I don't mind, it might be different for me if I had a partner. Then I wouldn't like to have a sensor in my bedroom. I know that it doesn't monitor life pictures but I certainly wouldn't feel happy when everything was recorded. Well it doesn't really matter for me in the kitchen and that kind of activities and how often I go outside, that doesn't bother me at all. No I don't find it an invasion of my privacy."* This was also expressed by

Mrs. E: *"Yes, actually I don't mind but when I think of getting out of my bed to go to the toilet I think: Oh God they see that I'm again going out of my bed and at that moment I find it annoying. Otherwise it doesn't matter to me."*

Although privacy in relation to sensor monitoring was not an issue for the participants, it was an issue for some of their relatives. Two participants mentioned that their children had a problem with the monitoring. These children were afraid that others would know more than necessary about their father or mother. Again, this was not a reason for the participants to reject the sensor monitoring. Both of the above examples illustrate the participants' perceptions of the strong benefits of sensor monitoring for their sense of safety, which they considered to be more important than their privacy concerns.

Sensor monitoring: a support for or a limitation of independence

The participants reported that it was most important that healthcare professionals had continuous access to their sensor data so that the professionals could react in cases of decline or emergencies. Mrs. J reported: *"I would really feel at ease if my community care nurse could see how I'm going on. She is only visiting me three times per week. Lots of things go wrong but they don't see that when they are not here. In this way they might be able to see that there is something different from normal."* One participant indicated that the sensor monitoring could replace unnecessary control visits by healthcare professionals. Specifically, Mr. E stated: *"Yes, that's very useful. The community care nurse doesn't have to come in every time. They can just do the follow up in this way."* Both examples illustrate the use of sensor monitoring as an acceptable system to care for the participant at a distance.

In this study, the web interface with sensor data was designed for healthcare professionals' use. Therefore, all of the participants needed the interviewer to explain the interpretation of their sensor data. Some of the participants did not express the desire to view or have control over their personal sensor data of daily functioning. Several reasons were given for this lack of desire. Some participants stated that they did not have sufficient technological knowledge to understand the sensor data from the computer. As Mrs. C reported: *"such a pattern is, of course very complicated for an outsider. Yes, for me, it is an abstract piece of art. I definitely can't understand it."* Other participants stated that they did not want not see their sensor data because they did not want to think about their health problems. Mrs. E expressed: *"You know yourself how well you are doing during the day. In this way you are going to be so confronted with it and now I try not to pay attention to it."* These participants experienced the sensor system as a readily applicable system, giving them the confidence of accessible help. On the other hand, this system contributes for them to a certain dependency, which can be considered as an unattended side effect of sensor monitoring.

However, other participants were curious about their sensor data and considered this information as helpful to them. For these participants sensor monitoring positively influenced on their movement or performance of exercises. For example, as expressed by Mr. K: *"Well, If I have to move more often and it reveals that you aren't doing this, you can take advantage of it."* Similarly, Mr. I stated: *"there is a sensor hanging above the sideboard. So, when I come downstairs I'm doing my exercises in front of it and I start swinging my legs for*

20 minutes." Both of these examples illustrate the control function of sensor monitoring as a stimulating factor for performing exercises or moving in the home. Mr. K expressed that the sensor data might contribute to a feeling of personal responsibility, as follows: *"it is a good development you get information how you are doing and you can take advantage of this. You don't have to go to your physiotherapist so often."*

When participants were asked whether their children could have access to their personal daily functioning data, the participants had varied reactions. Most of the participants stated that their children were allowed to view the data, but they did not want their children to worry about them. As Mrs. C reported: *"my children are allowed to look into it but I never would ask them to come and help me. No never, both my children are working during the day from morning till evening; they have a busy job, their own company. I just wouldn't want that the children... that your children have to look after you."*

Discussion

This study showed that the interviewed older people with sensor monitoring in their homes placed a positive value on sensor monitoring. Specifically, the participants indicated that the technology helped them to remain 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.

In accordance with previous research, this study highlights the participants' strong desire to remain in their familiar home environment for as long as possible.[24-28] This desire to remain in their home can be understood as older people's personal strategy to have continuity in their routines of daily life.[27,29] This study provides new evidence that older persons experience sensor monitoring as an opportunity or strategy that contributes to independent living and that does not disturb their natural way of living.

The use of sensor monitoring as a strategy that contributes to independent living is clearly explained by Wahl et al.[30] As shown in this study, the role of the environment, including housing, the neighborhood and technology, strongly influences older people's abilities to perform daily activities at home.[30] Wahl developed a conceptual framework for healthy aging that describes, how older people interact with their environment.[30] Within this model, new technologies could become a different resource for older people to enhance independent functioning at home.[30] In line with this model, sensor monitoring is a resource. In addition, the older adults do not need to closely interact with this resource.

This study's participants valued sense of safety as the most important aspect to remain independently at home, and the majority of the participants indicated that sensor monitoring contributed to this sense of safety. This finding is in line with previous research.[12,15,31-33] This increase in sense of safety can be understood in relation to the participants' old age and living situation. The participants all lived alone and experienced some functional health limitations. The participants were quite aware that this health decline could influence their ability to perform their daily functioning and associated this decline with a decrease in sense of safety.

In this research, the older persons associated sensor monitoring with utilities such as detecting early decline and emergencies such as falls. Many participants reported stories of people in their environment who had an emergency such as a fall and experienced a long wait for help. Furthermore, many of the participants feared a slow decrease in decline that they would not notice. Although the participants were informed that the sensor monitoring in this research was used to detect decline in daily functioning and not to detect emergencies, they experienced the sensor monitoring as a contribution to their sense of safety for both aspects. The participants indicated that the sensor monitoring would be more useful, if it monitored both decline in daily functioning and emergencies.

According to older persons living independently at home, the following factors are influential to their sense of safety: having secure relations (relationships in which the person feels respected), sense of control (the knowledge about what is required to cope and manage situations) and perceived health.[34] In this study, the participants perceived a sense of safety due to the sensor system because it was controlled 24 hours per day. This comforted the participants and ensured their sense of safety. For example, Mr. A experienced the sensors as his 'watch dogs'. Due to the participants' strong wishes to age in their own home and the benefits of sensor monitoring for their sense of safety, they readily accepted and adapted to the technique as natural in their home. Furthermore, they considered this technique to be in balance with their privacy.

Privacy is often considered to be an issue in research on monitoring technologies.[12,15,18,30,35] Although privacy issues should not be ignored, this research showed that other aspects such as sense of safety were more important to the study participants. In most studies, the participants reported that privacy was balanced on the level of need and intrusion into privacy at home.[18] However, some formal caregivers and researchers reported that privacy was a serious issue ranged from positive to negative.

Privacy issues have a contradiction. They can be viewed as an invasion into older persons' privacy or as a protecting older people from unnecessary harm and support for independent living.[35,36] Some studies have discussed whether older people have sufficient technical knowledge to fully understand the danger of sharing personal data and the importance of protecting their privacy.[37] Therefore, older persons must be provided with information to reach a good understanding of the sensor monitoring systems.[20] In this study, the participants reported that the safety benefits of sensor monitoring outweighed their privacy concerns. The monitoring supported their ability to live independently at home and therefore they were willing to make some privacy concessions.

The present results also indicated a contradiction concerning whether sensor monitoring supported or limited the older adults' independence. Some of the participants did not express the desire to view or have control over their own personal sensor data of daily functioning. They stated the importance of healthcare professionals keeping an eye on them to detect changes or decline in their daily functioning and thus, care for them at a distance via the sensor system. This provided them with a sense of comfort and safety. Furthermore, these older persons experienced the system as user-friendly merely because it required not any action of them. Although this contributes to a sense of safety and independent living, the system also introduced a certain participant dependency on the sensor system and indirectly on the health care professionals. One important reason for this dependency is the lack of a direct web-interface for the participants. Therefore, these findings indicate the importance that a special interface for older people must be developed, which is in line with Alexander et al.[38]

Future research must attempt to fully understand the degree to which older people wish to have access to their sensor data. This attempt should be made without influencing the user- friendliness of the sensor monitoring system, as older people consider this to be an important outcome that they appreciate. This also contributes to older adults' increased independence.

This study has strengths and limitations. First, strength is that this study provides in-depth insights into the perspectives of eleven single, independently living older people concerning their value of sensor monitoring after experiencing the devices for a few months and their expectations. As with other qualitative research, a limitation is that the generalization to other contexts is limited because the results were obtained from a selected small group of participants. However, these in-depth personal insights provide, both healthcare professionals and researchers with information to further develop and implement sensor monitoring in interventions to support older people to live independently at home. Future research should also involve the expectations of health care professionals regarding the use of sensor monitoring in caring for their patients and for advising caregivers. In line with this, Bruce[39] provided recommendations and practical tools to support health care professionals in their dialogue with the older persons and their family to make informed decisions for the use of monitoring technologies.

Second, we performed only one interview at one time point after the participants had a sensor system installed in their homes for a few months. Therefore, we did not explore changes in their perspectives over time. Third the participants were all old aged and experienced some age- and health-related limitations in their daily functioning. They were aware of their vulnerability and expressed a need for strategies to maintain independent living. Therefore, they easily accepted sensor monitoring in their home. Future research must investigate whether sensor monitoring can be used with older people who do not express their own vulnerability. In this way, the sensor monitoring can be used in a preventive manner to detect changes in daily functioning.

Implication for practice

The findings in this study encourage older people, who experience some age- and health-related limitations in their daily functioning and who are living alone in the community, to the use of sensor monitoring. All of the participants in this study experienced the use of sensor monitoring as contributing to their sense of safety and an early identification of functional decline. Both are important for continuing living independently at home in the community. The findings also encourage technicians and health care professionals to further develop sensor monitoring to meets the requirements mentioned by the end-users, such as the user friendliness of the system and the focus on sense of safety.

Conclusion

Older people with sensor monitoring in their homes believe that monitoring helps to maintain their daily functioning and safety and that their healthcare professionals should have access to their data to detect a decline in daily functioning at an early stage. Future research must be conducted to develop new strategies to provide older people with access to their sensor data. This strategy development should be done in cooperation with the older people. Another important aspect is to integrate an alarm system into the monitoring system, as this is important for older people's sense of safety.

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Chapter

5

Effectiveness of sensor monitoring in an occupational therapy rehabilitation program for older individuals after hip fracture, the SO-HIP trial: study protocol of a three-arm stepped wedge cluster randomized trial

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Abstract

Background: The performance of activities of daily living (ADL) at home is important for the recovery of older individuals after hip fracture. However, 20-90% of these individuals lose ADL function and never fully recover. It is currently unknown to what extent occupational therapy (OT) with coaching based on cognitive behavioral treatment (CBT) improves recovery. The same holds for sensor monitoring-based coaching in addition to OT. Here, we describe the design of a study investigating the effect of sensor monitoring embedded in an OT rehabilitation program on the recovery of ADL among older individuals after hip fracture.
Methods/ Design: Six nursing homes will be randomized in a three-arm stepped wedge cluster randomized trial. All nursing homes will initially provide standard care. At designated time points, nursing homes, successively and in random order, will cross over to the provision of OT and at the next time point, to sensor monitoring-enhanced OT. A total of 288 older individuals, previously living alone in the community, who after a hip fracture were admitted to a geriatric rehabilitation ward for a short-term rehabilitation, will be enrolled.
Individuals in the first intervention group (OTc) will participate in an OT rehabilitation program with coaching based on cognitive behavioral therapy (CBT) principles. In the sensor monitoring group, sensor monitoring is added to the OT intervention (OTcsm). Participants will receive a sensor monitoring system consisting of (i) an activity monitor during nursing home stay, (ii) a sensor monitoring system at home and a (iii) a web-based feedback application. These components will be embedded in the OT. The OT consists of a weekly session with an occupational therapist during the nursing home stay followed by four home visits and four telephone consultations. The primary outcome is patient-perceived daily functioning at 6 months, assessed using the Canadian Occupational Performance Measure (COPM).
Discussion: As far as we know, this study is the first large-scale stepped wedge trial, studying the effect of sensor monitoring embedded in an OT coaching program. The study will provide new knowledge on the combined intervention of sensor monitoring and coaching in OT as a part of a rehabilitation program to enable older individuals to perform everyday activities and to remain living independently after hip fracture.

Background

Each year in the Netherlands, 17,000 people are admitted to a hospital after a hip fracture. The effects of a hip fracture are serious; one year after a hip fracture, 25% of patients have died and 20-90% of older individuals have new Activities of Daily Living (ADL) disabilities, defined as a functional decline.[1-3] Risk factors for functional decline after hip fracture can be divided into non-modifiable and modifiable risk factors. Non-modifiable risk factors are older age, female gender, living alone, cognitive impairment (dementia) and comorbidities. The modifiable risk factors are activities of daily living (ADL), walking ability, and depression.[4-6] Psychological factors such as low levels of self-efficacy and fear of falling have also been associated with functional decline after hip fracture in older individuals.[7,8]

Currently, most multidisciplinary rehabilitation programs for patients after hip fracture concentrate on improving mobility and ADL function but not fear of falling.[7] The evidence on the effectiveness of these rehabilitation programs on the recovery of ADL function is mixed. Exercise interventions have been used to improve physical function (e.g., gait speed, mobilization, balance, and strength), but despite an improvement in physical function, many older persons do not achieve a full recovery of ADL function.[9,10] High-intensity (e.g., 4 times a week physical therapy) and intensive extended supervised exercise programs (e.g., during 12 month) had a significant impact on various physical functions, but the cost-effectiveness of these extended programs is unclear.[11] The main component of effective studies is 'home-based functional task exercises' (e.g., walking stairs, transferring), which results in a modest improvement in physical function post-discharge or at one year after discharge.[12]

Fear of falling may have an important influence on functional recovery after hip fracture.[7] Because of the fear of falling, people feel insecure while moving and performing activities of daily living, and as a consequence, they do less and less. However, for good recovery, performing ADLs is essential.[7, 8,13,14] Therefore, for older individuals, mobility is an essential aspect of quality of life and crucial for the preservation of independence.[15] Fifty percent or more of patients with hip fracture suffer from a fear of falling, resulting in a reduction in physical activities.[7] Therefore, in order to be successful, rehabilitation programs may need to focus on increasing self-efficacy concerning falls and fear of falling. Additionally, programs should focus on setting realistic goals for increasing the performance of daily activities, change the environment to reduce the fall risk and promote physical activity to increase strength and balance.[13]

To coach patients in modifying their patterns of thoughts (cognition) and activities (behavior) that contribute to the fear of falling, CBT principles can be used, consisting of five steps, which together have been proven effective[13,16-18]: 1) to educate individuals about being physically active and to stimulate physical activity and exercise, 2) to ascertain the amount of movement and physical activity during the day and give feedback, 3) to set realistic goals for the performance of daily activities, 4) to plan these activities, and 5) to evaluate progress.

New healthcare technologies, such as sensor monitoring, can assist healthcare professionals in coaching more effectively without increasing their time expenditure. The sensors provide an objective continuous measurement of daily functioning and provide automatic feedback via a web-based application.[19] This can be combined with the coaching of the daily functions of the client.[20,21] Older individuals who had a sensor system in their home during a long period of time appreciated having sensors at home and indicated that the technology supported their ability to live an independent life and contributed to their sense of safety.[22-25] However, as far as we know, sensor technologies have not yet been used in the rehabilitation of older patients after hip fracture.

The aim of the present study is to investigate the effect of sensor monitoring, embedded in a multidimensional OT rehabilitation program, on the recovery of physical ADL function among community-dwelling participants after hip fracture 6 months after the start of the rehabilitation in the nursing home compared to OT without sensor monitoring and to standard care.

Methods

Design and setting

The study is a three-phase, cross-sectional, complete design (data are collected from each cluster throughout the trial), stepped wedge, cluster randomized trial (SW-CRT). Clusters are nursing homes, which are the units of randomization. Table 1 shows the design matrix of the trial.

Six clusters (nursing homes) will be randomized to one of three fixed sequences, each containing the three interventions. All clusters will start with providing standard care (control condition) at the beginning of the study. At predetermined time points, two clusters cross over from the control condition (C) to the first intervention, the OT intervention with coaching based on CBT (OTc). At other predetermined time points, two clusters cross over to sensor monitoring embedded in an OT intervention based on CBT (OTcsm). The interval between the different time points will be two months. One advantage in terms of the willingness to participate applicability of the trial to the nursing homes is

Table 1. Design of the three-phase stepped wedge cluster randomized trial

		Month					
		1-2	3-4	5-6	7-8	9-10	11-12
Nursing home	NH1	C	OTc	OTc	OTcsm	OTcsm	OTcsm
	NH2	C	OTc	OTc	OTcsm	OTcsm	OTcsm
	NH3	C	C	OTc	OTc	OTcsm	OTcsm
	NH4	C	C	OTc	OTc	OTcsm	OTcsm
	NH5	C	C	C	OTc	OTc	OTcsm
	NH6	C	C	C	OTc	OTc	OTcsm

C Care as usual, OTc Occupational therapy with coaching, OTcsm Occupational therapy with coaching and sensor monitoring, NH= Cluster=Nursing home
Trial duration =12 months (recruitment), 18 months (including exposure and measurements
Number of clusters = 6. Number of groups =3. Number of clusters per group =2 (cross over simultaneously)
Pre-rollout period=2 months. Rollout period=8 months. Post-rollout period=2 months.
Step length (intervention 1-2) = 2 months. Number of participants per step=8
Reporting following Copas et al 2015 (Trials, Fig 1).[26]

that all of the nursing homes will have implemented the intervention at the end of the study.

The feasibility study started October 20, 2015 with the Amaris Health group in two locations in Laren and Hilversum and will end September 2016. The methods and procedures are feasible. We made minor improvements to some of the procedures for the main study. The main study has started April 1, 2016 and will end September 2017. The following nursing homes, situated in the Northwest and Midwest part of the Netherlands, are involved in the main study: the Omring with locations in Hoorn and Lutjebroek, Magentazorg with locations in Alkmaar and Bergen, Amstelring with locations in Amstelveen and Hoofddorp, Zorgbalans with locations in Ijmuiden and Haarlem, Careyn with locations in Utrecht and Vinkeveen and Evean with a location in Zaandam and two locations in Amsterdam.

Study population/ Eligibility

Nursing homes were invited to participate if they fulfill all of the following criteria: 1) have a geriatric rehabilitation ward for hip fracture rehabilitation, with a multidisciplinary team that consists of at least two OT professionals; 2) community-based occupational treatment is provided by the nursing home or can be provided by a community-based OT; and 3) are able to enroll at least 48 patients (8 patients per step) in total.

Participants are eligible if they meet the following criteria: 1) are admitted to a geriatric rehabilitation ward in a nursing home after hip surgery and have an indication for short term rehabilitation; 2) are at least 65 years old; 3) are living alone in the community or in a senior residence; 4) have a minimal-mental state examination (MMSE) score of 15 or higher (cognitive functioning).

Participants are excluded if at least one of the following applies: 1) terminal illness; 2) awaiting permanent placement in a nursing home; 3) no written informed consent.

Recruitment of patients

After admission to the nursing home, the nursing home physicians will identify potential patients on the basis of the inclusion criteria. A research assistant will provide oral and written study information. The research assistant will contact interested patients and their caregiver(s) to provide further detailed information on the study and to check the inclusion criteria. Written informed consent obtained in the presence of the research assistant will be required prior to enrollment. A copy of the signed informed consent form will be given to the participant. The original signed consent document will be retained by the investigator. Then, baseline measurements will be performed.

All recruitment procedures will comply the Dutch Medical Research Involving Human Subjects Act and the WMA Declaration of Helsinki(27).

Randomization procedure

Randomization was performed, four weeks before the start of the study, by the second author, who was not involved in the day to day logistics of care delivery. A dedicated program was written using the sample command in Stata version 13.1 (Stata Corp LP, College Station, TX) applying the following principles: (i) centers were ranked as to their size and likely patient recruitment potential; (ii) three strata were formed, 2 largest, 2 intermediate-sized and the 2 smallest centers; (iii) these were allocated in a way that would enhance the likelihood of collecting similar amounts of information the 3 strata across the 6 time periods; (iv) in particular, we forced the intermediate-sized centers in the 2-2-2 months periods; (v) we randomized the remaining 4 centers such that 1 large and 1 small center followed the 1-2-3 months periods and the other pair the 3-2-1 months periods, respectively.

Figure 1 shows the flow of clusters and participants through the trial using an adapted CONSORT diagram.[28]

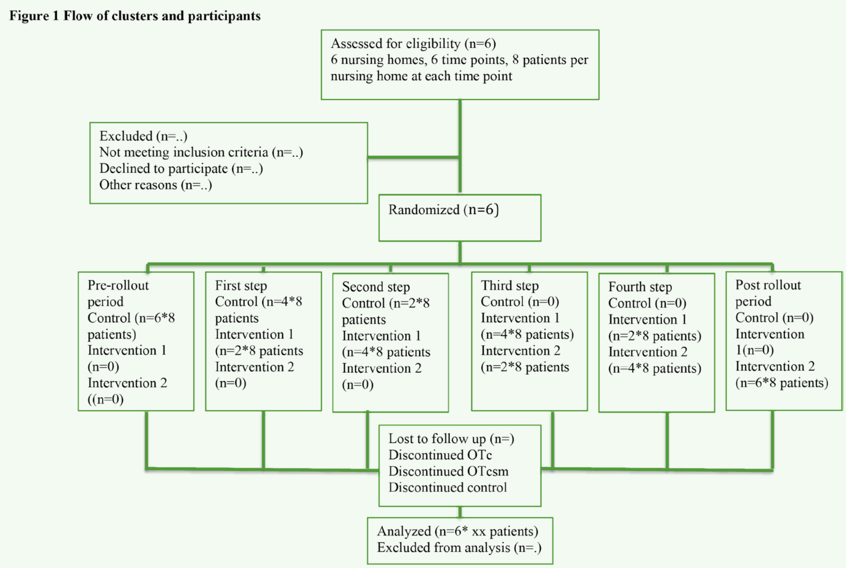

Figure 1. Flow of clusters and participants

The intervention

Table 2 shows the components of the standard care group (C) and the two intervention groups – OTc and OTcsm.

<u>Care as usual (C): rehabilitation provided to all patients included in the study</u>

After admission to the nursing home, a multidisciplinary assessment including a consultation of the different disciplines begins. The multidisciplinary team in the nursing homes will comprise a nursing home physician, a nurse, a physical therapist (PT) and an occupational therapist (OT). If required, other professionals, such as a dietician or psychologist, will be consulted. Within 48 hours after admission to the nursing home, the nursing home physician, together with the nurse, will conduct a comprehensive geriatric assessment and also coordinates wound care, pain management and the mobilization plan. S/he will also coordinate the patient's multidisciplinary care and treatment team.

The PT assessment will focus on mobility, muscle strength, balance transfer and walking. The OT assessment will focus on the performance of daily functions and safety at home. After the assessments, a multidisciplinary care and treatment plan will be made together with the patient. All patients will follow the evidence-based multidisciplinary rehabilitation program. Currently, in the Netherlands, the focus of rehabilitation after hip fracture is PT. Patients will be discharged after 3-6 weeks, as soon as they are able to function independently or with the assistance of formal or informal care at home. If needed, some of the patients receive rehabilitation at home or at a rehabilitation ward outside of the nursing home, but this is provided to a minority of patients.

Table 2. Components of the control arm care as usual, OT with coaching and OT with coaching and sensor monitoring

	Time frame	Intervention component	Professional involved	Control arm	OTc	OTcsm
Nursing home	<48 h after admission	Geriatric assessment Preliminary care and treatment plan	Elderly care physician/Nurse	X	X	X
	Week 1	Multidisciplinary assessments	Nurse, PT, OT	X	X	X
	Week 2	Multidisciplinary care and treatment plan	Multidisciplinary team	X	X	X
	During NH	Multidisciplinary rehabilitation	Multidisciplinary team	X	X	X
	During NH	Wearing of the activity sensor	OT			X
	During NH	Once a week coaching by the sensor data	OT			X
	During NH	Once a week coaching	OT		X	
Home	<1 day after NH discharge	Installing sensor system and wearing activity monitor	Sensor installer			X
	Week 1	H1 Coaching	OT		X	X
	Week 2	H2 Coaching	OT		X	X
	Week 3	H3 Coaching	OT		X	X
	Week 4	H4 Coaching	OT		X	X
	Week 5, 6, Week 8, 10	Telephone consult Telephone consult	OT OT		X X	X X
	Week 12	Removal of the sensor system	Sensor installer			X

OTc Occupational therapy with coaching, OTcsm Occupational therapy with coaching and sensor monitoring, NH Nursing home, PT Physical therapist, OT Occupational therapist, H1 Home visit 1, H2 Home visit 2, H3 Home visit 3, H4 Home visit 4

Chapter 5

Intervention arm 1: OT with coaching without sensor monitoring (OTc)
On top of the multidisciplinary rehabilitation, participants in this intervention group will receive an OT intervention with coaching (OTc). The primary role of OT is to optimize performance and engagement in meaningful activities and to improve participation. The OT interventions will focus on individual patients' needs and include teaching patients strategies to improve task performance.[29-32]

The coaching is based on evidence-based principles of a cognitive behavioral therapy (CBT) program concerning fear of falling.[13,22] As fear of falling is very common in patients after hip fracture, a main aim is to reduce that fear and improve recovery. To coach patients in modifying their patterns of thought (cognition) and activities (behavior) that contribute to the fear of falling, the occupational therapist integrates the following five CBT principles (which have proven to improve fear of falling) in the rehabilitation: 1) to give information and education about the importance of physical activity and daily exercise; 2) to ascertain the amount of movement and physical activity during the day and give feedback 3) to define, together with the patient, realistic goals for the performance of daily activities; 4) to make an activity plan together with the patient and, if needed, practice exercises and daily activities in a safe manner accompanied by the occupational therapist. Patients will select the activities in which fear of falls are experienced that they consider relevant and important to practice; 5) to evaluate progress.

OT will take place once a week while a patient is still in nursing home. After discharge, the participants receive four home visits by an occupational therapist in the first four weeks after discharge, followed by four telephone consultations.

The first home visit takes place within two days after discharge from the nursing home and will cover changing to the environment to reduce fall risk and setting realistic goals for increasing daily physical activities. The duration of this first home-visit will be approximately 60 minutes.

The next, 45-60 minute home visits in weeks 2, 3 and 4 will address the same five steps.

After the last visits in weeks 5, 6, 8, and 10 a 15-minute telephone consultation is planned along the same lines.

Intervention arm II: OT with CBT-coaching using sensor monitoring as a coaching tool (OTcsm)
Participants in intervention arm II receive an OT intervention in which sensor monitoring is used to enhance coaching. The occupational therapist will use sensor monitoring as a tool to coach the patient during rehabilitation in the nursing home and as a 'transitional care program', focusing on the transition from the nursing home to the home during the post-discharge period.

Technical details of sensor monitoring using the SO-HIP tool

The SO-HIP tool consists of two different sensor systems: 1) a wearable activity monitor, and 2) a sensor monitoring system placed in the home of the participant (environmental sensor system). The development of the SO-HIP tool is based on the experiences in a preceding proof-of-concept by the University of Amsterdam and Amsterdam University of Applied Science (AUAS) that was started in 2011.[23,33-35]

1) The wearable activity monitor (PAM) (http://www.pamcoach.com) consists of a 3-dimensional accelerometer, 68 x 33 x 10 mm, wirelessly connected to a base unit from which the data are sent to a secure database and a web-based application (see figure 2). The PAM is worn on the hip and measures the time of all daily activities in minutes per day. We tested the feasibility. Older individuals experienced the PAM is extremely easy to use: e.g. easy to clip on a waistband, comfortable to wear during the day and individuals don't have to adjust anything to the device. The PAM measures the acceleration of the body movements and expresses the measured movements in the score. The PAM score is an index representing the ratio of energy expended through physical activity to resting metabolism.[36]

The occupational therapist monitors these activities via a secure website and uses the sensor data as feedback for coaching the participant by following the five steps of CBT once a week during one of the rehabilitation sessions. In each visit, the progress with regard to physical daily activities will be discussed. A new goal will be set, and a discussion what happened during the week will take place, addressing what was easy, what were difficult activities, and why. (See further coaching details regarding the use of sensor monitoring).

2) The sensor monitoring system consists of a wireless sensor network with a base unit with 16 simple Benext sensors, covering the main spaces in a house. This system will be placed in the home when the participant is discharged from the nursing home. The sensors are passive infrared motion sensors (to detect motion in a specific area), contact switches (reed) on doors and cabinets (to measure whether doors are opened or closed), energy switch sensors (to measure the use of appliances such as the TV or washing machine), and one float sensor in the toilet (to measure the flushing of the toilet). The activity patterns of the daily functioning of participants are monitored using the wireless sensor monitoring system and are sent to a local base unit and stored in a secured database. These sensor data are analyzed by a computer program, which looks for activities of daily functioning and daily patterns in the data. (e.g., toileting or bathing can be recognized, but more complex activities such as preparing a breakfast, and other kitchen activities will also be recognized by the sensor system). A sequence of binary sensor data indicates the activity with the help of a recognition algorithm. The occupational therapist can use the reports of the sensor data via a secure web application to evaluate the daily functioning of the patient and by doing so appropriately coach the patient in performing daily functions and exercises following the same five steps learned during the nursing home rehabilitation (see figure 2).

The participants in the intervention OTcsm group receive information about the sensor monitoring at the start of the rehabilitation in the nursing home. This information includes a short manual and daily instruction on how to wear the activity monitor. In the week of discharge, the patients receive further information pertaining to the sensor monitoring at home.

Details for the use of sensor monitoring embedded in the OT intervention with coaching

From the start of the rehabilitation in the nursing home, the patient will wear

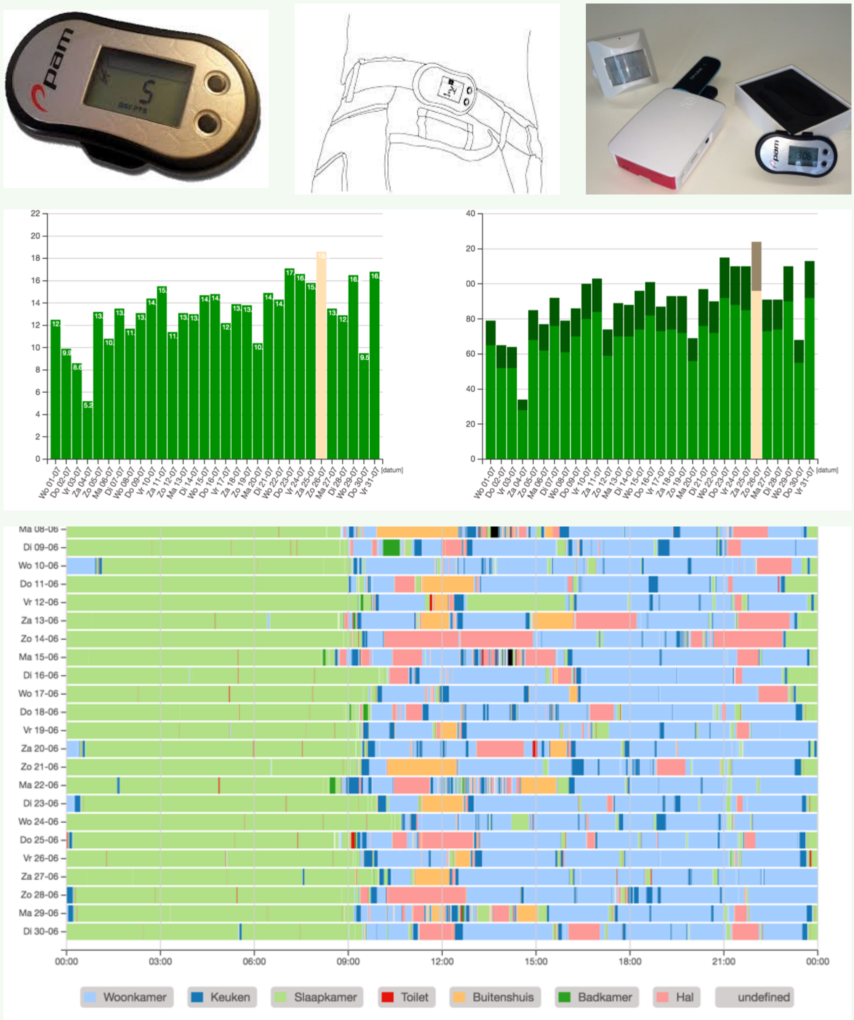

Figure 2. Sensor monitoring system and web application.
a Pam sensor. b PAM sensor worn on a waist band. c Motion sensor, data box, sensor. d Measured movements per day expressed in a score. e The number of minutes active movements per day. f Visualization of an activity pattern measured by the wireless sensor monitoring system during one month. The different colors correspond with the different locations where activities took place. Each line corresponds with one day.

an activity monitor (see technical details of the SO-HIP tool). The occupational therapist monitors the activities via a secure website and uses the sensor data as feedback for coaching the participant by following the five steps once a week during a coaching session. The sensor data reports can be used in the coaching as objective information about the current state of the amount of movement and activities performed during the day. The sensor data reports form a starting point for discussion about the daily patterns and activities that are important to practice and for making new realistic plans for activities based on the objective reports. The daily and weekly reports of the sensor data can also be used to evaluate progress of the rehabilitation.

During the rehabilitation in the nursing home, the patient learns, with the help of the occupational therapist, to make use of the sensor monitoring by following the five consequent steps of CBT.

As a tool for the 'follow-up care' at home, a wireless sensor monitoring system (see technical details of the SO-HIP tool) will be installed in the home of the participant on the first day after discharge from the nursing home for a period of three months. After being discharged, the participants also receive four home visits by an occupational therapist, which are then followed by four consultations by telephone, and in doing so, following the five steps mentioned above with the input of the sensor data, according to the same structure. The contents of the different sessions are described in a manual for the occupational therapist.

Training and education of the trial occupational therapists

All occupational therapists of the two intervention groups in the nursing homes will receive information about the study, including a manual with the procedures and a two-day training session (first day before the start of OTc and the second day before the start of OTcsm) regarding how to make use of the CBT principles in coaching the participant and how to make use of the SO-HIP tool in instructing and coaching the patient (face to face and by telephone), following the five steps of CBT. Along with the coaching on the use of the sensor data, the occupational therapists will be instructed about the technical aspects of the SO-HIP tool and the use of the web-based application. Details of the training program can be found at www.sohipstudie.nl. The occupational therapists are all registered, have a bachelor's degree and have experience in the rehabilitation of patients after hip fracture.

Use of co-interventions

Patients are allowed to receive concurrent interventions during the study period (e.g., medications, dietician). Details of the concurrent intervention(s) will be registered.

Outcome and measurements

Table 3 gives a detailed overview of outcome measures at each time point.

Medical and demographic variables

The self-reporting questionnaire that participants fill out at baseline and T4 contains determinants of functional decline (e.g. comorbidities) and the elements of a minimal data set (www.topics-mds.eu) consisting of demographic data (e.g. age, gender, marital status), physical functioning, self-perceived health status, psychological and social functioning, health-related quality of life and health care utilization.

Primary outcome measure

The primary outcome measure is the perceived daily functioning six months after the start of rehabilitation compared to baseline functioning (the first week after admission). The primary outcome measure will be measured using the Canadian Occupational Performance Measure (COPM).[37] The COPM is a client-centered, occupation-focused outcome measure for the detection of change in perceived occupational performance over time. It is a generic measure suitable for all clients with perceived problems in daily activities. It uses a semi-structured interview format and a structured scoring method. The COPM results in two main scores, Performance and Satisfaction, each out of total of 10. The patient prioritizes up to five problems s/he deems that are the most urgent or important and rates the problems on an ordinary 10-point scale regarding performance (1 = not able to do at all and 10 = able to do extremely well) and satisfaction (1 = not satisfied at all and 10 = extremely satisfied). The mean scores will be obtained by summing the ratings for performance and satisfaction and dividing them by the number of prioritized problems. Change in scores can be calculated after a reassessment interval to measure the change in the perception of occupational performance. For evaluation at a later time, the patient rates the performance regarding the prioritized problems outlined in the first interview. The COPM is a standardized instrument, with specific instructions and methods for administering and scoring. The reliability and validity of the COPM have been shown in many studies, and the COPM is widely used as an outcome measure for individuals and interventions.[38-42] A 1.3-point difference between pre- and post-measurement indicates a minimally clinically important difference.[41,42]

In this study, a trained research assistant will do the COPM interview and score the results.

Secondary outcome measures

The secondary outcome measures are the level of physical activity and independence in activities of daily living, the level of sense of safety, fear of falling, self-rated health and the use of healthcare resources at one, four and six months after start of the rehabilitation, compared to functioning at baseline at the beginning of rehabilitation in the nursing home.

<u>Physical functioning will be measured based on the following:</u>
<u>1) Performance oriented mobility</u> will be measured using the Tinetti Performance Oriented Mobility Assessment (POMA). The POMA is an easily administered, generic and widely used task-oriented test that measures the gait and balance abilities of older adults and their association with the risk of falling (high risk of falls (Tinetti score ≤18 points), moderate risk of falls (Tinetti score between 19 and 23 points), and low risk of falls (Tinetti score ≥24 points).[43] It is clinically used to determine the mobility status of older adults or to evaluate changes over time. The POMA score ranges from 0 to 28, with a higher score indicating better balance and walking ability.[43] The inter-rater and test–retest reliability of the POMA is excellent, and the correlation with reference performance tests indicates the satisfactory construct validity of the POMA.[44]
<u>2) Functional mobility and balance</u> will be measured by the Timed Up and Go (TUG). The amount of time to rise from a chair with arm rests, walk 3 meters,

cross a line on the floor, turn, walk back, and sit down again will be measured.[45] The test will be performed twice, and the mean time will be used as the outcome.[46] The TUG range for people aged 80 to 99 years expressed as the mean has been estimated to be 11.3 (95% confidence interval 10.0-12.7) seconds[47] and 11 to 20 seconds in frail elderly and disabled patients.[45] The TUG is well validated and has been used in several studies on hip fracture patients to predict falls, to assess functional mobility and to assess the effects of home-based therapy and comprehensive geriatric care.[3,45,48-50]

3) Independence in Activities of Daily Living (ADL) and Instrumental Activities of Daily Living (IADL) will be measured using the modified Katz-ADL 15 index score. This index is based on six basic ADLs and nine IADL items. Each item is scored 0 (independent) or 1 (dependent), with an overall score ranging from zero to 15; a higher score indicates a higher dependence in ADL and IADL.[51,52]

Sense of safety

The visual analogue scale for sense of safety (VAS-SAFE) will be used to measure sense of safety levels. The respondents answer the question “How safe do you feel at home?” The participants are instructed to select the number that best reflects their perceived sense of safety, with 1 representing feeling safe and 10 representing feeling extremely unsafe.

Fear of falling will be measured with the visual analogue scale for fear of falling (VAS-FOF) and the Falls Efficacy Scale International (FES-I).

1) The VAS-FOF is a simple and easy-to-use instrument that uses a numeric scale (1-10) to measure the perceived FOF. The participants are instructed to select the number that best reflects the intensity of FOF experienced, with 1 representing no FOF and 10 representing an extreme FOF.[53]

2) The Falls Efficacy Scale-International (FES-I) is a short, easy-to-administer tool that measures the level of fear of falling during social and physical activities inside and outside the home, whether or not the person actually does the activity. The level of concern is measured on a four-point Likert scale (1=not at all concerned to 4=very concerned).[54]

The reliability and structural validity of the FES-I in patients after a hip fracture are good.[55] The Falls Efficacy Scale-International (FES-I) is commonly used to the measure fear of falling in community-dwelling older adults but can also be used to assess the fear of falling in patients after hip fracture.[40]

Health-related Quality of Life

Self-reported health-related quality of life will be measured with the EQ 5D (EuroQol), comprising a visual analogue scale (VAS) and a health status instrument. EQ-5D is a validated, generalized and standardized instrument for use as a measure of health outcome. The EQ 5d compromises the following 5 dimensions: mobility, self-care, activities, pain/ discomfort and anxiety/ depression, and one question about cognition. Each dimension has three levels: no problems, some problems or extreme problems.[56] A respondent’s EQ-VAS indicates self-rated health on a scale in which the endpoints are labeled ‘best imaginable health state’ (100) and ‘worst imaginable health state’ (0).

It was found that the EQ-5D could be used to measure outcomes for patients recovering from hip fracture, including those with cognitive impairment.[57]

Process evaluation

In addition to the primary and secondary outcomes, additional qualitative data will be collected, which will give insight into the feasibility of the SO-HIP tool at the level of both the older participants after hip fracture and the professionals using this intervention. Participants' experiences and opinions with the standard care, OTc and OTcsm will be evaluated in a qualitative study, which will be done

Table 3. Variables and outcome measures and time points of assessment in the SO-HIP study

Measures	Baseline NH1	T1 NH2	T3 H1	T6 H2
Primary outcome measure				
Daily functioning; self perceived performance in daily activities:				
o COPM	x	x	x	x
Secondary outcome measures				
Physical functioning;				
o Performance oriented mobility: POMA	x	x	x	x
o Functional mobility and balance: TUG	x	x	x	x
Independence in Activities of Daily Living (ADL) and Instrumental Activities of Daily Living (IADL)				
o Katz-15 index	x	x	x	x
Sense of safety;				
o VAS-SAFE	x	x	x	x
Fear of falling;				
o VAS-FOF	x	x	x	x
o FES-I	x	x	x	x
Health related quality of life;				
o EQ 5D	x	x	x	x
Additional measures				
Information gathered of determinants of functional decline (e.g., comorbidities) and a minimal data set (MDS) consisting of;				
o Demographic data,	x			
o Psychological and social functioning; subscale Rand 36	x	x	x	x
o Cognitive functioning; MMSE	x			x
o Healthcare utilization	x		x	x

Baseline, NH1=within 1 week after admission nursing home; T1, NH2= before discharge from nursing home; T3, H1four months (post-intervention) at home; T6, H2=six months after the start rehabilitation. COPM Canadian Occupational Performance Measure, POMA Performance Oriented Mobility Assessment, TUG Timed Up and Go, Katz 15 index Modified Katz 15 index, VAS-SAFE Visual analogue scale for sense of safety, VAS-FOF Visual analogue scale for fear of falling, FES-I Falls Efficacy Scale International, EQ5D EuroQol health related quality of life, MDS Minimal Dataset, MMSE Mini Mental State Examination alongside the feasibility study of the SO-HIP study. From the professionals we will collect data using standardized evaluation forms. For each participant, each therapist will record the content of their intervention, the number of sessions, time spent and their views of effectiveness of the intervention. At the end of the study we will conduct a focus group with all professionals involved in the study exploring their experiences and opinions regarding the use of coaching and the use of coaching combined with sensor monitoring.

Sample size calculation

Stepped wedge designs with more than two interventions have, to our knowledge, never been reported. The methodology for sample size and power calculations are still being developed. Dr. Steven Teerenstra, PhD (Biostatistics, Radboud University Medical Center) performed a simulation-based power calculation based on the primary outcome – the COPM performance outcome. Specifically, with 8 patients per cluster (nursing home) per step (six steps of two months duration each), an assumed treatment effect 1 (occupational therapy without sensor monitoring (OTc) versus usual care (control, C) of 1.5*SD) and an assumed treatment effect 2 (occupational therapy with sensor monitoring (OTcsm) versus OTc of 0.75*SD), and an intracluster correlation coefficient of 0.05, we will collect observations on 288 patients and achieve a power of 100% for treatment effect 1 and a power of 85% for treatment effect 2. We expressed the treatment effect sizes relative to the standard deviations (SD) because similar data are currently lacking.

Data entry and quality control

We will collect the data using standardized forms and measurements. A trained research assistant will collect data at baseline (T0), before discharge from the nursing home (T1), four months (post-intervention) (T3) and at six months (follow-up) (T4). All data will be entered into a database (Castor, http://castoredc.com), according to Academic Medical Centre Good Clinical Practice Guidelines with an identification code for each patient.

The sensor monitoring data of the patient will be kept under the identification code and stored in a secured database.

According to the good clinical practice guidelines, data will be stored for 15 years and archived according to the regulations of the Netherlands Federation of University Medical Centers (NFU)(http://www.nfu.nl).

Statistical analysis

An adapted CONSORT flow diagram will detail the flow of clusters and patients through the trial (see figure 2). Baseline comparability at the level of clusters (immediately after randomization) and patients (at recruitment) will be assessed. Descriptive data will be used to assess any time trends of patient characteristics at recruitment since patient selection bias is a threat in cluster trials that cannot be blinded for allocation.

The treatment effects (OTc vs control, OTcsm vs OTc, and OTcsm vs control) on the various outcomes will be estimated with mixed linear models using dummy variables for the two treatments, random intercepts for the clusters, and time as a fixed effect. For each outcome, the baseline values of that outcome will be used as a covariable.[58] The trial will have limited power to explore treatment by time or treatment by cluster interactions. If feasible, we will explore these. Two sided 95% confidence intervals will be calculated.

An intention-to-treat analysis will be the primary analysis. Per-protocol analyses based on degree of compliance with the study protocol will be used in an exploratory fashion.

A descriptive qualitative and quantitative analysis will be conducted on the data from the evaluation forms of the participants and the assessors and the data from the therapists of a given intervention. We will analyze the qualitative data based on the constant comparative method.[59]

Discussion

The present three-arm stepped wedge randomized trial combines CBT principles that have been successful in the treatment of fear of falling and the multidisciplinary rehabilitation of older adults with hip fracture with the incorporation of sensor monitoring in the intervention as a coaching tool (monitoring and feedback tool) to improve daily functioning, physical activities, sense of safety and reduce the fear of falling at home. To our knowledge, this is a first trial evaluating the effectiveness of these interventions in older individuals after hip fracture.

Stepped wedge designs with more than two interventions have, as far as we know, never been used. Because we make use of restricted randomization we will reduce the between-cluster variation and improve balance, which is advisable when there are few clusters.[26]

The use of a stepped wedge design provides us some methodological and practical advantages. First, the intervention effect can be estimated using between and within cluster comparisons and the professionals are their own controls in the interventions.[60] Second, each participating nursing home will have implemented both interventions at the end of the study while in a traditional cluster randomized trial some clusters will have received only a control intervention. This increased nursing homes' willingness to participate. Third, in order to provide training in each cluster before the start of the interventions, the staggered start of the interventions makes a better time allowance. The same accounts for the technical support of the tool if needed. Last, because of the crossover from control to OTc and OTcsm and each participant receives only one condition, we may assume that there are no carryover effects.[26]

For older adults, the ability to remain mobile is an essential aspect of quality of life and is crucial for the preservation of independence.[15] An important aspect of the intervention using sensor monitoring is to apply CBT principles. Sensor monitoring embedded in the OT intervention with CBT coaching is expected to have an impact directly at the level of the patient's ability to perform activities in his or her own context. A characteristic of the use of sensor monitoring in an OT intervention is that goals related to daily activities are formulated that are relevant and important to the person and are based on the objective measurement of daily functioning by sensors. The coaching by the occupational therapist will target these particular issues. Our hypothesis is that the person's self-perceived performance in daily activities, measured using the COPM, will alter as a result of the intervention.

This study will provide new knowledge regarding the combined intervention of CBT coaching by occupational therapists and CBT coaching by occupational therapists using sensor monitoring, enabling older individuals to perform everyday activities and to remain living independently after hip fracture.

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Chapter

6

Effectiveness of sensor monitoring in a rehabilitation program for older patients after hip fracture: the SO-HIP three-arm stepped wedge randomized trial

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Submitted for publication

Abstract

Importance: Many older patients do not fully recover in terms of daily functioning after hip fracture. Sensors that measure daily functioning can inform the rehabilitation of older patients after hip fracture beyond the direct observation of therapists or the self-report by patients. However, the effect of a rehabilitation program based on sensor monitoring-informed coaching on daily functioning is unknown.

Objectives: To test the effects of an intervention involving sensor monitoring-informed occupational therapy on top of a cognitive behavioral treatment (CBT)-based coaching therapy on daily functioning in older patients after hip fracture.

Design, Setting and Patients: Three-armed randomized stepped wedge trial in six skilled nursing facilities (12 wards) in the Netherlands, with assessments at baseline (during admission) and after one, four and six months (at home). Eligible participants were hip fracture patients ≥ 65 years old.

Interventions Patients received care as usual (CAU), CBT-based occupational therapy (OTc) or CBT-based occupational therapy with sensor monitoring (OTcsm). OTcsm patients wore an activity monitor during inpatient rehabilitation and at home as well as a sensor monitoring system at home. Both interventions comprised a weekly session during institutionalization, followed by four home visits and four telephone consultations over three months.

Main outcomes and measures The primary outcome was patient-reported daily functioning at 6 months, assessed with the Canadian Occupational Performance Measure (COPM).

Results: A total of 240 patients (mean[SD] age, 83.8[6.9] years; 129[54%]) completed 6 months of follow up. At baseline, the mean COPM performance scores (range 1-10) were 2.92 (SE 0.20) and 3.09 (SE 0.21) for the CAU and OTcsm groups, respectively. At six months, these values were 6.42 (SE 0.47) and 7.59 (SE 0.50). The mean patient-reported daily functioning in the OTcsm group was larger than that in the CAU group (difference 1.17 [95% CI (0.47-1.87) *P*=0.001]. We found no significant differences in daily functioning between OTc and CAU. There were no significant differences in secondary outcomes.

Conclusions and relevance: Among vulnerable older patients recovering from hip fracture, a rehabilitation program of sensor monitoring-informed occupational therapy was more effective in improving patient-reported daily functioning at six months compared to care as usual.

Intoduction

Annually, over 300.000 older Americans break their hip.[1] This number is increasing, particularly in high-income, aging countries.[1-3] Approximately 40% of patients are discharged to a skilled nursing facility (SNF) for short-term rehabilitation.[4] Long-term intensive physical therapy in outpatient clinics appears to be the mainstay of effective rehabilitation but is time-consuming and expensive.[18,19] Most rehabilitation programs focus on improving mobility and activities of daily living (ADL) to help ensure independent living and are often provided during inpatient stay only.[5] However, the effectiveness of these programs is modest.[6-9] A review estimated that 42% of hip fracture survivors had not returned to their pre-fracture mobility one year after rehabilitation.[5,10] Approximately one in five older patients are admitted to a long-term care facility within one year after breaking a hip.[11] Moreover, in the US, the average direct medical healthcare costs are US $40,000 ($41,053 in Europe [12,13]) in the first year following hip fracture and are almost US $5,000 annually thereafter.[2,11]

Many older people experience fear of falling after breaking their hip, and this hinders their functional recovery.[2,14-16] Cognitive behavioral treatment (CBT) strategies have been proven effective in fall prevention in community dwelling older adults who had fallen.[17-19] Therefore, the incorporation of CBT into rehabilitation programs tackling fear of falling during SNF stay and at home may be useful.

CBT strategies include emphasizing the importance of physical activity to increase strength and balance [17] and setting realistic goals for increased ADLs at home. However, since much of the rehabilitation process occurs after a patient has been discharged, often therapists lack accurate data on daily functioning at home. This lack of data hampers the setting of personalized and realistic goals. Remote activity monitoring systems using sensors that measure patients' ADLs may fill this gap. However, as far as we know, CBT- and sensor monitoring-based programs have not yet been used in geriatric rehabilitation for older patients after hip fracture.

In this SO-HIP randomized trial, we tested the effects of a systematically developed intervention involving sensor-monitoring informed occupational therapy on top of a CBT-based coaching program on patient-reported daily functioning in older patients after hip fracture.[18]

Methods

Design, Setting and Patients

From April 1, 2016 to December 1, 2017, we conducted the SO-HIP three-arm stepped wedge cluster randomized trial in six SNFs (12 wards) in the Netherlands. The rationale and design of the trial have been published previously[18], and the trial protocol appears in Supplement 1. The study protocol was approved by the Medical Ethics Committee of the Academic Medical Center (AMC) (protocol ID: AMC 2015_169).

Eligible participants were patients with traumatic hip fracture who were > 65 years and were admitted to an SNF with an indication of short-term geriatric rehabilitation. Additional inclusion criteria were as follows: living alone in the community and having a minimal-mental state examination (MMSE) score of 15 or higher. We excluded patients if they were terminally ill, were waiting for permanent placement in a nursing home, or did not give written informed consent. A trained research assistant asked patients admitted to a participating SNF to participate in the study after explaining its objectives and procedures.

Randomization

Three pairs of SNFs were randomized to one of three fixed sequences (see eTable 1). Each sequence started with providing CAU (the control condition), followed by OTc and ending with OT csm. An epidemiologist (GtR) randomized the SNFs using the *sample* command in STATA version 13.1 (Stata Corp LP, College Station, TX) and applying the following principles: i) the sites were ranked according to their size; ii) three pairs of centers were formed: largest, mid-sized and smallest; iii) sequence 1 and sequence 3 were randomly assigned as one large center and one small center, respectively. The two middle-sized centers were forced into stratum 2. This approach increased the probability of collecting similar amounts of information on the three treatment strategies in each time period.

Intervention

eTable 2 shows the details of the CAU and the two interventions. CAU in the SO-HIP trial is described in eTable 3. Briefly, patients in the OTc group received coaching aimed at the highest level of recovery in daily functioning based on the principles of CBT [17,19] and motivational interviewing as well as the CAU. As fear of falling is common in these patients, the main aim was to reduce this fear and increase self-confidence. Five strategies were integrated to positively shift patients' attitudes and beliefs about falls and activity restriction.

> Attitude and thoughts before CBT
> *"I better not go walking so often because the chance of falling will then be as small as possible"*
>
> Attitude and thoughts after CBT
> *"Walking is good for my condition and ensures that my muscles stay strong; because of this, the chance of falling is less. If necessary, I make use of a walker".*

The five strategies involved include the following: 1) education about the importance of physical activity; 2) ascertainment of daily physical activity and awareness elicitation to restrictive symptoms and their cognitive and behavioral effects; 3) collaborative definition of realistic goals for ADLs; 4) joint definition of an activity plan; and 5) joint evaluation of progress.

While in the SNF, patients received weekly OT coaching. After discharge, the patients received four home visits followed by four telephone consultations over two and a half months (see trial protocol supplement 1).

Patients in OTcsm received the same OT program as the first intervention group as well as sensor monitoring. The technical details of sensor monitoring and its use in the SO-HIP trial are described in our study protocol[18] and Supplement (1 and 3). Briefly, the sensor monitoring system comprised a wearable physical activity monitor (PAM), a sensor monitoring system placed in the patient's home and a web-based application for data visualization. The PAM measured the acceleration of the body movement expressed by the PAM-score. The sensor monitoring system comprised a sensor network of motion sensors covering the main spaces in the house. eTable 4 describes the interventions of the OTc and OTcsm. Supplement 4 shows some examples of how the sensor data were used in the coaching intervention.

Supplement 5 describes the SO-HIP trial procedures with which participating occupational therapists familiarized themselves during a two-day training.

Measurements and Outcomes

The primary outcome was the patient-reported daily functioning at 6 months after the start of the geriatric rehabilitation measured with the Canadian Occupational Performance Measure (COPM).[20] The COPM has excellent test-retest reliability and measures (changes in) the performance of daily activities.[21-24] The COPM results in a performance score (COPM-p) and a satisfaction score (COPM-s). Through a semi-structured interview, patients prioritized up to five daily activities that they deemed most important and rated each on a 10-point scale regarding perceived performance (COPM-p) (1 = not able to do at all and 10 = able to do extremely well). This approach worked similarly for the satisfaction score (COPM-s). The mean COPM-p and COPM-s were obtained by summing the ratings and dividing them by the number of prioritized activities.

Secondary outcomes for patients included physical functioning measured using the Tinetti Performance-Oriented Mobility Assessment (POMA)[25]; Timed up and Go (TUG)[26]; modified Katz ADL 15 index score[27]; level of sense of safety (VAS-scale)[28]; fear of falling (VAS-scale); Falls Efficacy Scale international (FES-I) [29]; and health related quality of life (EQ5D).[30]

All patient outcomes were assessed by trained research assistants blinded to treatment allocation at baseline (T0), discharge (T1), post-intervention, 4 months (T3) and 6 months (T6). At baseline, medical and demographic variables were collected as well. All instruments used are described in Supplement 1.

Power calculation

The simulation-based power calculation was based on the COPM-p, our primary outcome. We assumed an intraclass correlation of 0.05, a treatment effect of OTc versus a CAU of 1.5 standard deviation, a treatment effect of OTcsm versus OTc of 0.75 standard deviation, and a common standard deviation in the three groups. Given these assumptions, the inclusion of 288 patients yielded 100% power for the treatment contrast OTc *vs*. CAU and 84% power for treatment contrast OTcsm *vs*. OTc.

Statistical analysis

We finalized our statistical analysis plan (eTable 5) on November 12, 2017, before the start of the statistical analyses (on December 18, 2017). Briefly, missing values were multiply imputed using chained equations, creating between 50 and 80 imputed data sets. Linear mixed models including the same covariables that were used for the imputations were performed to produce graphs of the treatment effects over time. We used mixed linear models with two, two, and five dummy variables for the three treatment strategies, the three measurement intervals after baseline and the six SNFs, respectively, as well as random intercepts and slopes for the patients. In all models, the baseline value of the outcome in that particular analysis was used as a covariable. For ten of the 11 pre-specified outcomes, we performed three pre-specified subgroup analyses, namely, by time, COPM-performance score at baseline and MMSE scores at baseline (for cutoff values, see eTable 5). Likelihood ratio tests were used to decide whether the treatment effects varied by time or subgroup (p-value threshold at 0.05). We expressed the treatment effects as the mean differences and their two-sided 95% confidence intervals. We also performed a sensitivity analysis of the intervention effects on COPM-p and COPM-s over time using joint modeling (through Stata's stjm command, with time as a linear variable and a Weibull distribution for the survival sub model) to assess the influence of dropout (due to, e.g., death or permanent admission).[31,32] We present the main results based on the multiple imputed analyses. Other results are presented in the supplemental material. All analyses were performed in Stata 13.1 (StataCorp. 2013. Stata Statistical Software: Release 13. College Station, TX: StataCorp LP.)

Results

Patient inclusion

In total, 240 patients were enrolled. Figure 1 shows the flow of clusters and patients in the trial (77 CAU, 87 OTc and 76 OTcsm). The three arms were well balanced in terms of baseline characteristics (Table 1). Overall, the patients had a mean age of 84 years, 80% were female, and the median MMSE score was 24 (IQR 21 to 27). Table 1 shows patients' baseline characteristics across the three arms. During the study, 47, 43 and 22 patients had dropped out after 1, 3 and 6 months, respectively. The reasons are reported in figure 1 and eTable 6.

Adherence to the intervention protocol

During admission to the SNF, 97.6% patients in the CAU, 100% patients in the OTc and 95.8% patients in the OTcsm group received the OT sessions. The median inpatient number of OT sessions was 4 (IQR 2-5) for the CAU, 4 (IQR 2-6) for the OTc and 2.5 (IQR 1-5) for the OTcsm.

At home, the median number of OT sessions (range 1-4) was 2 (IQR 0-4) for OTc and 4 (IQR 2-4) for OTcsm. The median duration of OT sessions at home was 41 (IQR 0-60) minutes for OTc and 45 (IQR 38.5-60) minutes for OTcsm. (see eTable 7).

Primary outcome (COPM-p) and co-primary outcome (COPM-s)

A total of 47.1% of the patients (113) formulated one or more goals concerning basic ADL, while 88.3% (212) chose one or more goals concerning IADL, and 55.5% (132) formulated one or more goals concerning leisure activities. A total

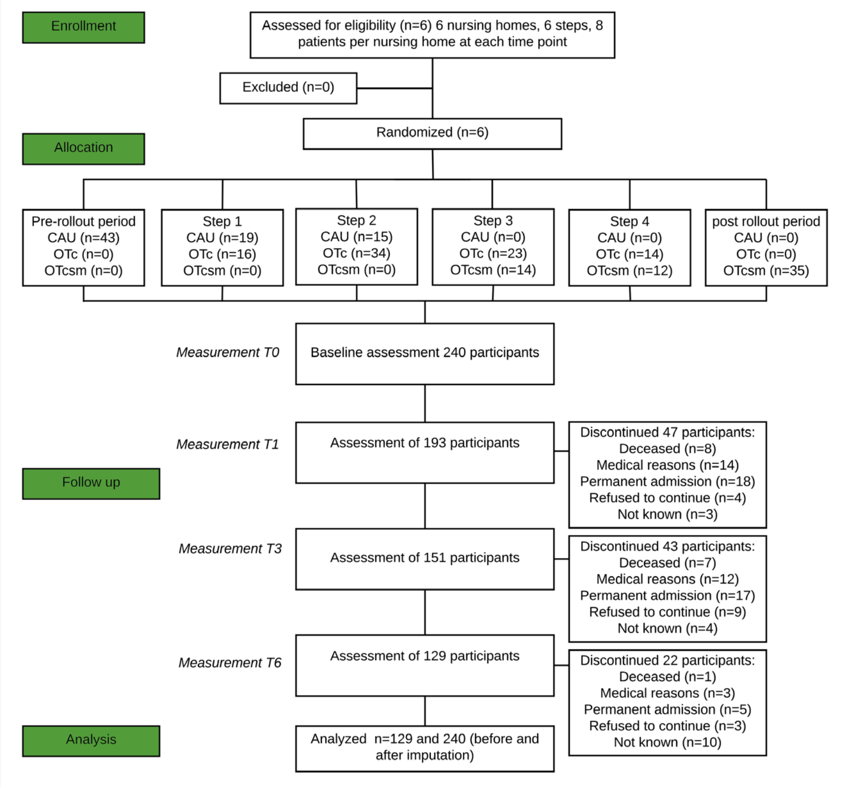


Figure 1. **CONSORT diagram, Flow-chart of clusters and participants**

Table 1. **Baseline characteristics of the study population SO-HIP trial**

Variables	Total study population (N= 240)	Care as usual (N= 77)	OT coach (N= 87)	OT coach and sensor (N= 76)
Study sites (%)				
SNF 1 (n)	23.8 (57)	11.7 (9)	20.6 (18)	39.5 (30)
SNF 2 (n)	19.6 (47)	13.0 (10)	21.8 (19)	23.7 (18)
SNF 3 (n)	14.2 (34)	18.2 (14)	13.8 (12)	10.5 (8)
SNF 4 (n)	9.2 (22)	6.5 (5)	10.3 (9)	10.5 (8)
SNF 5 (n)	17.1 (41)	24.7 (19)	17.2 (15)	9.2 (7)
SNF 6 (n)	16.3 (39)	26.0 (20)	16.0 (14)	6.5 (5)
Demographics				
Age in years, mean (SD)	83.8 (6.9)	85.0 (7.2)	83.0 (6.7)	83.5 (6.7)
Female % (n)	79.6 (191)	79.2 (61)	75.0 (66)	85.5 (65)
Education (%)				
Fewer than 6 years of primary school	3.4	2.6	4.7	2.7
6 years of primary school	24.6	23.4	26.7	22.7
More than 6 years primary school	11.0	16.9	7.0	10.7
Vocational school	26.3	20.8	26.7	32.0

Table1. Continued

Variables	Total study population (N= 240)	Care as usual (N= 77)	OT coach (N= 87)	OT coach and sensor (N= 76)
Demographics				
Secondary professional education	25.8	26.0	26.7	24.0
High school/Gymnasium	7.2	9.1	4.7	8.0
University	1.7	1.3	3.5	0.0
Living situation prior to admission % (n)				
Independent	81.7 (196)	79.2 (61)	76.1 (67)	90.8 (69)
Independent with others	1.7 (4)	-	4.5 (4)	-
Senior residence	16.6 (40)	20.8 (16)	19.3 (17)	9.2 (7)
Widowed % (n)	75.0 (180)	71.4 (55)	75.0 (66)	78.9 (60)
Born in the Netherlands % (n)	93.3 (224)	89.6 (69)	97.7 (86)	92.1 (70)
Cognition (%)				
MMSE (0-30)[a]	24	24	24	24.5
MMSE 15-19	15.2	16.0	17.2	11.8
MMSE 20-24	35.9	37.3	33.3	38.2
MMSE > 24	48.9	46.7	49.4	50.0
≥2 morbidities (%)	89.8	89.4	95.0	82.9
Number of comorbidities (mean) (SD)	3.3 (1.5)	3.3 (1.5)	3.4 (1.4)	3.2 (1.7)
Perceived daily functioning COPM[b]				
mean COPM-p (SD)	3.0 (1.7)	2.9 (0.5)	3.2 (1.7)	3.0 (1.8)
mean COPM-s (SD)	4.3 (1.8)	4.2 (1.8)	4.5 (1.8)	4.3 (1.8)
Physical functioning				
POMA-mean (SD)[c]	14.9 (3.4)	14.2 (3.3)	15.1 (3.5)	15.4 (3.3)
TUG-mean (SD)[d]	38.5 (19.2)	43.3 (20.9)	36.4 (18.1)	36.8 (18.8)
Modified Katz ADL index[e]-mean (SD)	9.5 (2.6)	9.4 (2.7)	9.4 (2.6)	9.6 (2.4)
Level sense of safety				
SOS-VAS mean (SD)[f]	2.5 (1.8)	2.7 (2.0)	2.4 (1.7)	2.3 (1.5)
Fear of falling				
FES-I mean (SD)[g]	26.7 (10.0)	24.8 (7.8)	24.6 (9.7)	29.8 (16.0)
FOF-VAS-scale (SD)[h]	4.7 (2.7)	4.8 (2.7)	4.6 (2.6)	4.6 (2.8)
Health-related Quality of life				
EQ5D-mean (SD)[i]	0.45 (0.26)	0.43 (0.25)	0.44 (0.26)	0.48 (0.26)
EQ5D-VAS[j]	59.4 (19.4)	58.3 (18.9)	58.1 (19.9)	62.2 (19.4)

MMSE[a] Mini Mental State Examination. score median (range of 0 to 30); a higher score indicates better cognitive functioning
COPM[b] Canadian Occupational Performance Measure. Range 1-10; 1= not able to do at all and 10 =able to do extremely well) COPM-p = performance measure COPM-s= satisfaction measure
POMA[c] Performance Oriented Mobility Assessment. ≤ 18 indicates high risk of falls; 19-23 moderate risk of falls; ≥24 low risk of falls
TUG[d] Timed Up and Go; calculated in seconds, ≤ 20 indicates normal to good mobility. A lower score indicates better functional mobility and balance
Katz-ADL indexe Range 0-15; a higher score indicates a higher dependence in ADL and IADL
SOS[f] Sense of Safety. VAS- score 1-10; a higher score indicates feeling safe
FES-I[g] Falls Efficacy Scale international. Range 16-64; a higher score indicates a greater fear of falling
FOF-VAS[h] Fear of falling. VAS- score 1-10; a higher score indicates more fear of falling
EQ5D-mean[i] ranges from -0.33 to 1.0 and higher scores indicate better health related quality of life
EQ5D-VAS[j] Scale 0-1; a higher score indicates better health related quality of life

of 71.3% of the patients (171) chose one or more goals concerning spirituality, social activities or social participation.

After multiple imputation, the mean COPM-p in the CAU was 2.92 (SE 0.20) at baseline and 6.42 (SE 0.47) at 6 months. The mean COPM-p for OTcsm at baseline was 3.09 (SE 0.21) and 7.59 (SE 0.50) at 6 months. The mean patient-reported daily functioning in the OTcsm was larger than that in the CAU (difference 1.17 [95% CI (0.47-1.87) *P*=0.001]. The same outcome applied to COPM-s (difference 0.94 [95% CI [0.37-1.52] *P*=0.001] (see Table 2). The treatment effect of OTc on COPM-s compared to the CAU group was 0.55 [95% CI 0.00-1.08] 0.047). The difference between OTcsm and OTc was 0.53 [95% CI -0.11-1.17] *p*=0.103), in favor of OTcsm (see Table 2).

Table 2. Treatment effects (mean difference) on COPM-p and COPM-s at six months (N=240, primary and co-primary outcome)

COPM (95% CI; p value)	CAU vs OT Coach	CAU vs OT Coach and Sensor	OT coach vs OT coach and sensor
COPM-p	0.64 (-0.07-1.34; 0.077)	1.17 (0.47-1.87; 0.001)	0.53 (-0.11-1.17; 0.103)
COPM-s	0.55 (0.00-1.08; 0.047)	0.94 (0.37-1.52; 0.001)	0.40 (-0.11-0.92; 0.126)

Treatment effects are expressed as mean differences between groups, compared to the scores in the CAU group (reference group). aCOPM-p=Canadian Occupational Performance Measure-performance scale score 1-10; bCOPM-s=Canadian Occupational Performance Measure-satisfaction range: 1-10, where higher values indicate better performance).

Subgroup analysis

For all outcomes, the treatment effects did not vary by baseline COPM-p level (1-3 *vs*. > 3). Treatment effects differed by cognitive functioning level at baseline. We used the highest cognitive level (MMSE >24) as the reference. For COPM-s, significant differences in treatment effects were found for low (MMSE 15-19) and intermediate (MMSE 19-24) cognitive levels. The mean difference of OTcsm compared to the CAU on COPM-s for the patients with low MMSE was 1.66 (0.54-2.78; P=0.004) and 1.29 [95% CI 0.48-2.10] *P*=0.002) for patients with intermediate MMSE. For OTc, the mean difference was 1.17 [95% CI 0.25-2.09] *P*=0.012) for low MMSE and 1.05 [95% CI 0.18-1.9] *P*=0.018) for patients with an intermediate MMSE at baseline (see Table 3).

Secondary outcomes

For the OTcsm group, the treatment effect on COPM-p and COPM-s was not constant over time (see Figure 2 and Table 3). In particular, compared to the effect at one month, the treatment effect increased from 1.96 at four months to 2.37 at six months (all *P values for interaction < 0.001*). A similar phenomenon was observed for the OTc, where the effect increased from 1.53 at four months to 1.76 at six months (all *P values for interaction < 0.001*). In addition, for COPM-s, compared to the effect at one month, the treatment effect increased from 1.69 at four months to 1.96 at six months (all *P values for interaction < 0.001*), and, finally, for the OTc group, the treatment effect increased from 1.42 to 1.52 at six months (all *P values for interaction < 0.001*). The results of the sensitivity analyses (joint

Table 3. Treatment effect variation over time and by cognition levels at baseline (mean differences on COPM-p and COPM-s)

COPM-performance[a]	CAU vs OT Coach	CAU vs OT Coach and Sensor
4 months vs 1 month	1.53 (0.89-2.17; <0.001)	1.96 (1.30-2.63; 0.001)
6 months vs 1 month	1.76 (1.11-2.41; <0.001)	2.37 (1.72-3.01; 0.001)
COPM-satisfaction[b]		
4 months vs 1 month	1.42 (0.85-1.98; <0.001)	1.69 (1.12-2.26; 0.001)
6 months vs 1 month	1.50 (0.97-2.03; <0.001)	1.96 (1.40-2.52; 0.001)
In subgroup with low MMSE[c]	1.17 (0.25-2.09; 0.012)	1.66 (0.54-2.78; 0.004)
In subgroup with intermediate MMSE[d]	1.05 (0.18-1.92; 0.018)	1.29 (0.48-2.10; 0.002)

Compared to the treatment effect at one month, treatment effects for the occupational therapy and coaching groups, and the sensor monitoring-informed occupational therapy and coaching group were larger after 4 and 6 months, with the largest increases between months 1 and 4. Compared to the patients at the best cognitive level at baseline, treatment effects for both intervention groups were larger for patients who entered at low and intermediate cognition levels

models) largely confirmed the results of the main analyses (see eTable 9).

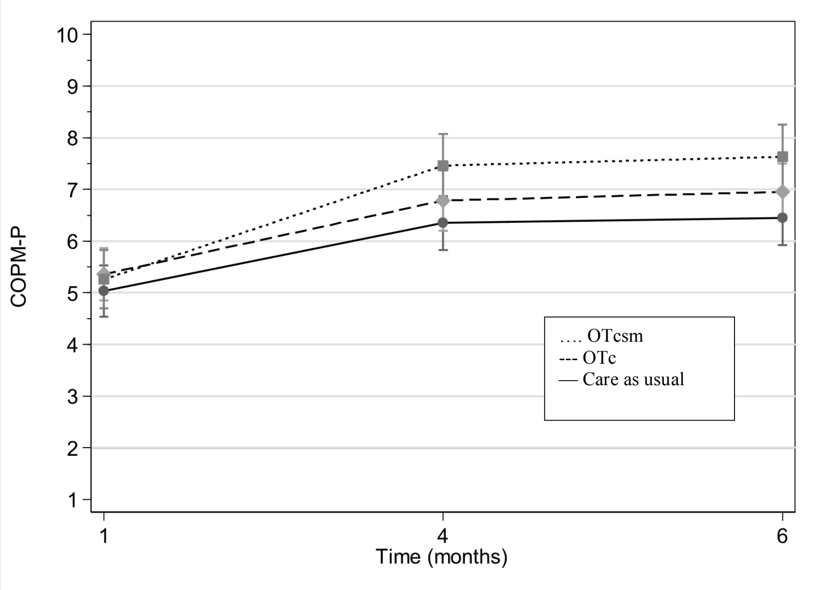
We found no statistically significant differences for physical functioning, POMA and TUG (see eTable 10). However, the longitudinal mean difference for Katz ADL was significantly larger in the OTcsm than in the CAU (mean difference -0.99 [95% CI -1.85—0.13] *P*= 0.024). Levels of sense of safety did not differ significantly between groups. Fear of falling was -1.15 (95% CI (-1.83—0.4; p=0.001) less in the OTc group than in the CAU group. We noted no significant between-group differences in health-related quality of life. We did not find longitudinal treatment effects on the secondary outcomes (see eTable 11) for the OTcsm group. The effect of OTc on FOF was -1.15 (95% CI -1.80 – 0.50; p=0.001) points.

Discussion

The “SO-HIP” rehabilitation program, based on sensor-informed OT coaching, was associated with greater improvements in patient-reported daily functioning at six months than those with CAU. We found no significant difference in daily functioning between OT without sensor monitoring compared to that of CAU. The treatment effects increased over time. No statistically significant differences in the OTcsm were found for secondary outcomes, except for KATZ ADL.

Our intervention was designed to target fear of falling, boosting self-confidence by exploiting sensor-based information to improve the rehabilitation process. The coaching component of the intervention was based on CBT, which had already proven effective for community dwelling older people who had fallen.[17-19] Our findings demonstrate that the use of these techniques embedded within a coaching program and supported by the use of sensor data can improve daily functioning. By using the sensor data, the therapist could use objective feedback about patients’ real-time activity levels to evaluate daily functioning and to make realistic plans for improving daily functioning. In contrast, coaching

A. COPM-performance score over time



B. COPM-satisfaction score over time

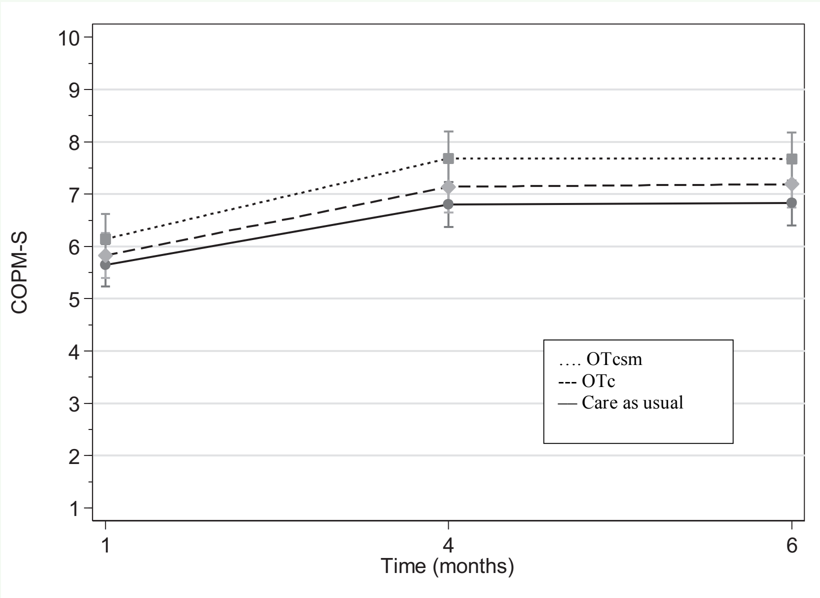


Figure 2. COPM scores over time

in the OTc group (without sensors) was based on patients' self-reported memories of their activities. Second, therapists reported that for older patients with cognitive restrictions, coaching without sensors was difficult. The objective information by the sensors was helpful in this group. Finally, because patients can follow their own level of activity and progress on a tablet or computer, they may be more engaged in their rehabilitation.[33]

Patient-reported daily functioning was chosen as the primary outcome because limitations in daily functioning are an immediate result that older patients experience after hip fracture. Our target group had a mean age of 84 and had multiple chronic conditions. These patients have large variations in functioning, and there are differences in what activities patients want to regain. The COPM captures activities that are important to the patient, how those activities are performed and the patient's satisfaction with them. Moreover, the COPM has good measurement properties.[20] The minimal important difference (MID) is 1; therefore, the statistically significant benefits for OTcsm of 1.17 at six months compared with that of the CAU represents a clinically meaningful effect.[23,34] Patients chose very different goals in (I)ADL. The COPM accounts for these individual variations.[20,23,34]

There is a large amount of research and data available on the recovery of mobility and basic ADLs for people after hip fracture, but the research on the impact on daily functioning and participation is scarce.[35] Most of the research uses objective patient outcomes to evaluate interventions to improve physical functioning. We did not find statistically significant benefits of the OTcsm on objective physical functioning measured with the POMA and TUG. This outcome may be explained by the fact that the content of our intervention was focused on increasing self-confidence for improving daily functioning and not directly on improving mobility or balance. The OTc intervention was significantly in favor of decreasing fear of falling. This result is consistent with studies of preventing falls based on CBT, which was the basis for our intervention, with a focus on patients' values and preferences.[19,36]

Our findings have important implications for health care practices in supporting older patients after hip fracture during the transition from inpatient rehabilitation to home. The implementation of a rehabilitation program focusing both in the SNF and rehabilitation at home seems crucial as patients have to apply their newly learned skills at home and regain confidence to perform those activities safely as already demonstrated in other patient groups (e.g., stroke, Parkinson's disease and dementia).[34,37-39] The first months are crucial for recovery, and the effect over time of this program increases.

Our study has several strengths. A major strength is the pragmatic stepped wedge randomized controlled design with all the sites receiving all interventions. Because all patients received only one intervention during the study, there were no crossover effects in switching from one intervention to another. Another strength is that we included a very vulnerable group of patients of high mean age and considerable comorbidity. These groups are often excluded in trials.

Limitations

An important limitation is the high dropout rate due to different reasons mentioned before as well as missing data for some outcome measures, e.g., POMA and

TUG, due to patients being unable to perform these tests. We therefore ran the analysis with and without imputations, and these analyses provided largely similar results. The joint model analyses served as a sensitivity analysis to test the robustness of our findings to patients dropping out early. These analyses showed that our main analysis was probably somewhat conservative, given the slightly higher intervention effects after adjustment for dropout.

Conclusions

In conclusion, in this stepped wedge cluster-randomized trial among older patients after hip fracture, 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. Future research examining the long-term effect and cost-effectiveness of the intervention is recommended.

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Supplementary Materials

Effectiveness of sensor monitoring in a rehabilitation program for older patients after hip fracture: the SO-HIP three-arm stepped wedge randomized trial

Supplementary files

Supplementary eTables

Methods

Results

Evaluation

Supplementary file 2. Hip fracture and geriatric rehabilitation care in the Netherlands

Hip fractures and indicators of good hospital care

Older patients with hip fracture are generally admitted to the hospital through the Emergency Department. The Dutch Health Care Inspectorate has formulated several quality indicators to define the care that older hip fracture patients are entitled to while in the hospital.[a] The first indicator is the presence of a co-management model for hip fracture patients, whereby the orthopedic surgeon and geriatrician are jointly responsible for clinical management. This co-management model is widely implemented in the Netherlands. The second indicator is the proportion of these patients whose daily functioning three months after hip fracture is back to the preoperative level. This level is measured with the Katz-ADL Index. In addition to these hip fracture-specific indicators, other quality indicators include the assessment of pain, delirium, fall risk and post-operative complications.

Geriatric rehabilitation in the Netherlands

In the Netherlands, approximately 40% of older patients with hip fracture receive rehabilitation care in a geriatric rehabilitation unit within a skilled nursing facility (SNF).[1,2] Geriatric rehabilitation in the Netherlands is defined by the Dutch Association of Nursing Home Physicians (Verenso) as "integrated multidisciplinary care aimed at expected functional recovery and participation of frail older people, after an acute ailment or functional decline".[3] The Dutch association of nursing home physicians states that to be eligible for geriatric rehabilitation, older patients must have an indication for multidisciplinary rehabilitation care and have sufficient cognitive abilities. Geriatric rehabilitation units are part of integrated joint care and traumatic injury services in collaboration with a university or general hospital. A multidisciplinary team, coordinated by a nursing home physician, comprises nurses, a physical therapist and an occupational therapist.[4] The nursing home physician is responsible for the treatment plan. Hip fracture rehabilitation includes a treatment plan for pain and comorbidity, ADL training by the occupational therapist and physical therapy. In the Netherlands, the focus is mainly on physical therapy. The PT will usually focus on mobility, muscle strength, balance transfer and walking ability. The primary role of the OT is to focus on the performance of daily functioning and safety at home. If required, a social worker, psychologist or dietician is consulted. The duration of the hip fracture rehabilitation is approximately 4-8 weeks.

Continuing therapy at home

Patients are discharged when they can function independently or with assistance of (in) formal care at home. If needed, patients can continue with physical or occupational therapy in an outpatient clinic or at home. A minority of patients receive a transitional care rehabilitation program after discharge from a geriatric rehabilitation unit.

a) https://www.igj.nl/documenten/indicatorensets/2017/01/01/basisset-medisch-specialistische-zorg

Financing of health care and geriatric rehabilitation

The Netherlands has universal health coverage for all inhabitants. Every Dutch inhabitant is required to buy his or her own health insurance. A standard health insurance costs approximately €100 (approx. US$119) per month and covers basic health care, e.g., visits to primary care physicians, hospitals, specialists, occupational therapy (maximum of 10 hours per year) and many prescribed medications. In addition to standard insurance, a person can buy additional insurance for dental care, physical therapy and other care. There is a deductible fee of €385 per year (US$459), which patients have to pay for a hospital or emergency department visit as well as some medications. Geriatric rehabilitation is paid out of the Dutch Health Insurance Act for a period of six months at most.

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Supplementary file 3. Technical description of the sensor monitoring system

The SO-HIP sensor monitoring system consisted of a) a wearable physical monitor; b) an activity sensing system in the home environment; c) a data storage and data analysis unit on a remote server and; and d) a web-based application for visualization of the data (see fig. S6).

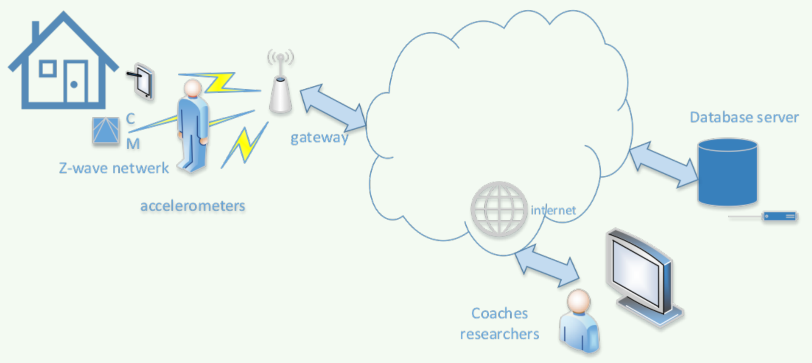


Figure 1. Sensor monitoring system

Sensor monitoring system

The sensor monitoring system comprises 1) a wearable physical activity monitor (PAM-sensor); 2) a network of ambient sensors placed in the home of the patient; and 3) a gateway that collects data from the sensors and sends these to the server.

1) The wearable activity monitor (PAM) (http://www.coach.com) comprises a 3-dimensional accelerometer, 68 x 33 x 10 mm that is worn on the hip. The sensor measures the activity level per day, expressed in a PAM score, which is the ratio between the amount of energy used while active and the amount of energy used while at rest, multiplied by 100. Furthermore, the sensor gives the number of minutes of regular activity and of vigorous activity per day. The data collected by the PAM-sensor is stored in the PAM itself and is synchronized with the gateway using Bluetooth when the patient is in the neighborhood of the gateway. The PAM-sensor can collect data for 64 days without synchronizing and runs on a single battery for 5 months.
2) The network of ambient sensors comprises BeNext passive infrared motion sensors (http://www.benext.eu) and a BeNext, contact sensor on the front door. The motion sensors give a binary signal at the onset of motion in a range of approximately 3 m in front of the sensors. The contact sensor gives a binary signal that indicates the opening or closing of the door. The sensors communicate wirelessly through a Z-wave protocol with the gateway that collects and stores the binary data.
3) The gateway is a Raspberry Pi with a Z-wave shield for communication with the ambient sensors, a Bluetooth adaptor for communication with the PAM

sensor and a 4 G dongle to make connection with the remote server. Once daily the gateway sends the collected data to the server using a secured communication of 4 G.

Data and remote server

The stored data files of the PAM and the environmental sensors did not contain personal references from whom the data came. This information was stored in a MySQL database.

The database made a connection between patients and the gateway (through an ID) and PAM (through an ID), which was available to the patients and therapists during the rehabilitation period. The name, surname, username and password of the client were stored in the database.

The database stored the following information of the therapists and researchers involved: username, email address and password. This enabled a connection between patient and her or his therapist.

The passwords of all users were hashed before being stored in the database. The password made by the user could not be retrieved from the database. For safety reasons, resetting the system to a new password was impossible. This could only be done through contact with an administrator.

Web based application

The SO-HIP web application gives therapists access to the collected data. With the web application, therapists can log on to a patients' portal, administer patients' data, see a visualization of their patients' sensor data and ask their patients questions.

The API is accessible after a user logs in. If a user has successfully logged in, a cookie will be placed on the system of the user together with a session key. To prevent session hijacking, on each API call, the session key will be checked for validity. The API communicates with the database. Taking into account the danger of SQL-injection, prepared statements will only be used.

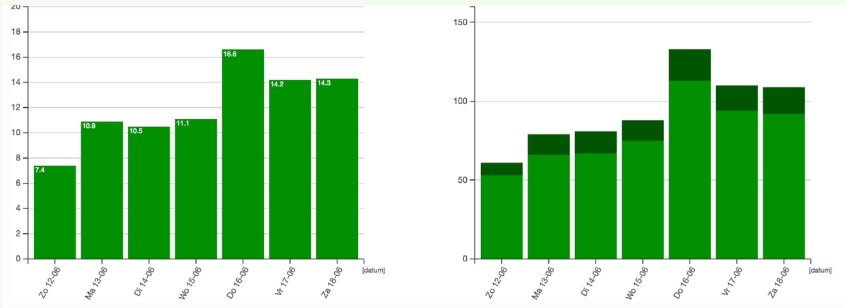
Supplementary file 4. Some examples of the use of the sensor monitoring data in the occupational therapy intervention with coaching

The patient in the intervention group with OT-coaching and sensor monitoring starts wearing the PAM-sensor in the skilled nursing facility in the first week after admission. After discharge from the skilled nursing facility, in the first week at home, the ambient sensor monitoring system was additionally installed in the home of the patients for a period of two and a half months.

The SO-HIP-website gives the OT and the patient access to the collected data through a personal log on.

The issues and priorities that are related to daily activities and which are relevant and important to the patient, are the basic assumption of the coaching sessions. The sensor data can be used to discuss current activity levels performed during a day or per week as shown in the picture below.

Case 1



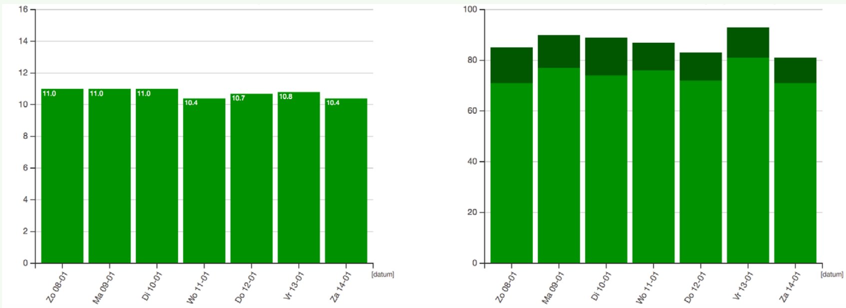
A. Measured movements per day expressed in a PAM score.

B. The number of minutes, active movements per day.

This patient has a PAM-score that increased each day from PAM-score 8 to PAM-score 14. This result was used to evaluate the patient's daily functioning and to plan for realistic levels and types of daily activities for the following week.

Case 2

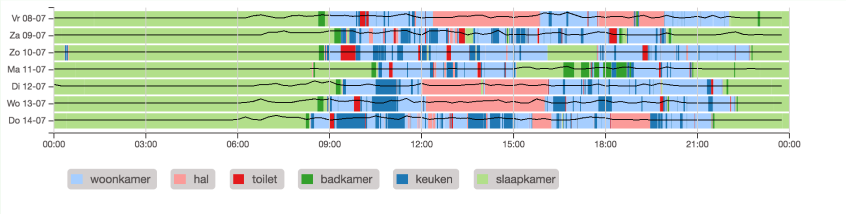
This patient had been at home for two weeks. The web application shows the PAM-score, which was fairly constant across that week.



A. Measured movements per day expressed in a PAM score.

B. The number of minutes, active movements per day.

While discussing this visualization of the PAM-data, the patient was disappointed because he had been hoping he had moved more. The OT and the patient talked about the pattern of activities during the week with the help of the visualization of the environmental sensors as shown below.

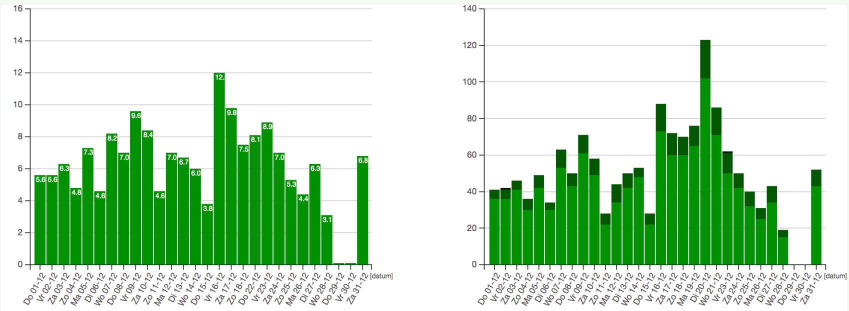


Visualization of an activity pattern (patient case 2) measured by the wireless sensor monitoring system during one week. The different colors correspond with the different locations where activities took place. Each line corresponds with one day. The thin black line shows the movements of the PAM-sensor. Light green corresponds to the bedroom, dark green to the bathroom, dark blue to the kitchen, light blue to the living room and pink to the hall.

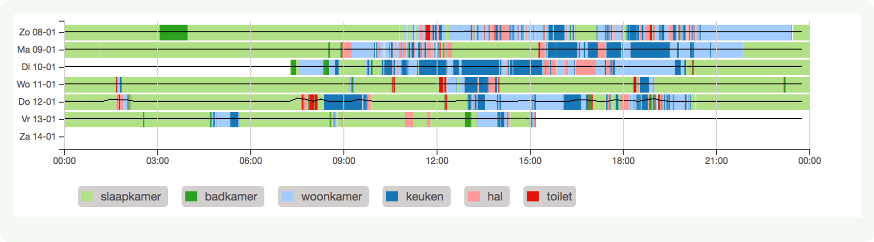
This visualization of daily functioning after a week of this patient being at home shows a very regular daily routine. When talking about daily activities, it is striking that this patient had not been going outside the house. The OT discussed this in relation to the initial issues (COPM-goals: going shopping, visiting family, going to the gym), as were assessed at the start of the rehabilitation. The OT used the five coaching steps to improve performance and independence of these activities.

Case 3

A last example shows a decline in movement after discharge (December 16) from the geriatric rehabilitation to the home.



The web application at the OT's office showed that the patient was not wearing the PAM anymore during the second week of January, as seen on the visualization below. The PAM-sensor shows a straight constant black line, and the abundance of light green indicates that much time was spent in the bedroom during the day as well. Upon seeing this, the OT made an appointment with the patient and discovered that s/he was ill and needed more care.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Supplementary file 5 Description of the training of occupational therapists involved in the SO-HIP trial

All occupational therapists (n=34) who provided the intervention had a bachelor's degree in OT and were registered occupational therapists, having median practice experience of 10 years (range 1-18) in geriatric rehabilitation of patients after hip fracture. A two-day training and booster session was developed to prepare the OTs for work according to the method and procedures of the SO-HIP trial. The training was developed by the Research Group Occupational Therapy of the Amsterdam University of Applied Sciences in Amsterdam, the Netherlands, in partnership with a trainings consultation bureau called 'de Vraag Centraal'; known for support for client-centered innovations in long-term care.

The two-day training comprised the following items:
1) Introduction of the SO-HIP trial and how to make use of CBT-principles in coaching;
2) The sensor monitoring system, how to use the sensor monitoring system in instructing and coaching following CBT-principles.
The first meeting was just before the start of first intervention OTc. The second meeting was just before the start of the second intervention OTcsm (see figure 1A - Recruits of patients in each cluster and period in the main article stepped wedge design). During both meetings, the training of coaching skills was the main focus of attention. The training was given for each pair of two randomized skilled nursing facilities randomized in the same cluster. In total, three courses were given.

Training day 1

The first part focused on taking participating in a stepped wedged randomized trial, the ethical issues with regard to research and the methodological aspects of the trial. The second part focused on the impact of a hip fracture on the daily functioning of older patients. Most common health care complains such as fatigue, pain and fear of falling were explained.
Basic information about cognitive behavioral therapy (CBT) of fear of falling [1,2], based on the proven effective program 'Zicht op evenwicht (https://www.zichtopevenwicht.nl/), was explained and discussed.
Part three; the coaching as performed in the intervention of the SO-HIP trial, was explained to the OT. The five steps taken in the coaching path of the SO-HIP trial based on the elements of CBT and motivational interviewing were thoroughly explained and practiced (see eTable 2). In addition, discussions were about starting points of a coaching conversation style, the basic patient-centered conversation techniques, tips for coaching on motivation and the reports of progress and plans for and by the older patients. The training was based on: 1) elements of CBT; 2) motivational interviewing; and 3) the promotion of self-management.

Training day 2

The first part (approximately two hours) introduced the use of sensor monitoring

as a coaching tool. The technical aspects of the SO-HIP tools were explained and demonstrated. The access to the SO-HIP website and the use of the different sensor data reports were explained. All procedures in the SO-HIP intervention were discussed.
The second part was targeted on the use of the SO-HIP tool as a tool for coaching by occupational therapists within the rehabilitation and how the SO-HIP tool fits in within the five coaching steps based on the elements of CBT. This part of the meeting was focused on training the OTs on patient-centered practice to increase the motivation of the patient by practicing the principles of motivational interviewing, the five steps according to the elements of CBT and simulating some cases.

Booster session

Half-way to the end of the study, when each cluster was working with the last intervention OTcsm, a booster session was organized in partnership with trainings consultation bureau called 'de Vraag Centraal'; known for support for patient-centered innovations in long-term care, to discuss the OTs experience and questions about the intervention and the use of the sensor monitoring. Two cases were presented to discuss and practice the principles of motivational interviewing and the five coaching steps. A special topic was the OTs experience with coaching and the use of sensor monitoring of patients with cognitive impairments.

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Supplementary file 6 Process Evaluation of the SO-HIP trial

The aims of the process evaluation were:

A) To assess the delivery of the intervention and to ensure it was provided in accordance with the protocol and delivered consistently

B) To explore patients' experiences with and their opinions about the intervention

C) To explore occupational therapists' experiences with and their opinions about delivering the intervention

A) Intervention delivery - Quantitative and qualitative data

The occupational therapists were asked to fill out the following standardized evaluation form for each patient.

Occupational therapist checklist for intervention delivery

1.	Patient record, nursing facility	Intervention group 1/2/3
		Session at skilled facility 1/2/3/4
		Session at home 1/2/3/4
		Telephone consultation 1/2/3/4
2.	Session duration in minutes	
3.	The intervention was targeted on	
4.	Coaching Coaching is delivered yes/no If no, the reason was: Coaching steps stage 1/2/3/4/5 If Yes, the following topics were discussed during coaching step: 1. to give information and education about the importance of physical activity and daily exercise 2. to ascertain the amount of movement and physical activity during the day and give feedback 3. to define realistic goals 4. to make an activity plan and if needed practice 5. to evaluate	
5.	Did the intervention have a connection with the originally formulated COPM goals? Yes/no If no, for what reason? If yes, with which COPM goals?	
6.	Was the intervention successful according to you? Yes/no If yes, what factors affected this? If no, give reason.	
7.	What are your experiences in using the SO-HIP tool? How did the technology affect the intervention, according to you?	

B) Patients' experiences with and opinions about the intervention- Qualitative data

Semi-structured interviews were carried out with 18 patients from the three arms of the SO-HIP trial after the intervention at approximately 6 months after the rehabilitation had started. See qualitative study: Everyday life after a hip fracture: What community living older adults perceive as most beneficial to their recovery (Pol. M. et al, submitted September 2018).

C) Occupational therapists' experiences with and opinions about delivering the intervention- Qualitative data

A focus group was conducted with the occupational therapists involved in the study. This focus group took place after all occupational therapists completed their interventions. A focus group guide (figure 1) was developed to explore therapists' experiences and opinions regarding the use of coaching and the use of coaching combined with sensor monitoring.

Nine female OTs participated in the focus group with a median practice experience of 10 years (range 1-18). The analysis of the experiences and opinions in delivering the SO-HIP intervention will be described elsewhere.

eTable 1. Recruits of patients in each cluster and period

Cluster	SNF	Pre-rollout period	Step 1	Step 2	Step 3	Step 4	Post-rollout period	Total SNF
1	1	9	7	11	7	12	11	57
	2	10	9	10	7	7	4	47
2	3	7	7	8	4	3	5	34
	4	3	2	5	4	5	3	22
3	5	7	6	6	6	9	7	41
	6	7	4	9	9	5	5	39
$Total_{step}$		43	35	49	37	41	35	240

SNF=Skilled Nursing facility

Care as usual

OT with coaching

OT with coaching and sensor monitoring

eTable 2. Exposure to the various components of the SO-HIP trial treatments, by group SO-HIP trial

Time frame	Intervention component	Professional involved	CAU	OTc	OTcsm
SNF ≤ 48 hours after admission	Comprehensive geriatric assessment. Coordinated wound care, pain management and mobilization plan	Nursing home physician & nurse	Y	Y	Y
Week 1	Multidisciplinary assessments	Nurse, occupational therapist, physical therapist	y	y	y
Week 2	Multidisciplinary care and treatment plan	Nursing home physician, occupational therapist, physical therapist	y	y	y
Week 1-4	PT, focusing on mobility, muscle strength, balance, transfer and walking	Physical therapist	y	y	y
Week 1-4	OT, focusing on performance of daily functioning and safety at home	Occupational therapist	y	y	y
Week 1-4	Weekly coaching based on CBT, including 5 steps: -Educate on the importance of physical activity and daily exercise -Ascertain the amount of movement and physical activity during the day and give feedback -Define realistic goals for the performance of daily activities - Agree on an activity plan with the patient and, if needed, practice exercises and activities safely - Evaluate progress	Occupational therapist	n	y	y
Week 1-4	Wearing of the PAM-sensor, sensor monitoring, daily instructions how to wear the PAM	Occupational therapist	n	n	y
Week 1-4	Weekly coaching based on CBT, including use of the PAM to: - Ascertain objectively the amount of movement and number of activities during the day and give feedback - Use as a starting point for discussion about the daily patterns and activities that are important to practice; - Make new plans for activities; and - Evaluate the progress	Occupational therapist	n	n	y

eTable 2. Continued

Time frame	Intervention component	Professional involved	CAU	OTc	OTcsm
Home Week 1	Installing sensor monitoring and wearing PAM	Sensor installer	n	n	y
Week1-10	Coaching based on CBT following 5 steps with the use of sensor data		n	n	y
Week 1	Home visit 1; evaluation of home environment to reduce fall risk and setting of realistic goals for increased daily activities	Occupational therapist	n	y	y
Week 2	Home visit 2; coaching following 5 steps	Occupational therapist	n	y	y
Week 3	Home visit 3; coaching following 5 steps	Occupational therapist	n	y	y
Week 4	Home visit 4; coaching following 5 steps	Occupational therapist	n	y	y
Week 5,6	Telephone consultation following 5 steps	Occupational therapist	n	y	y
Week 8,10	Telephone consultation following 5 steps	Occupational therapist	n	y	y
Week 11	Removal of the sensor monitoring system	Sensor installer	n	n	y

CAU=care as usual; OTc= Occupational therapy with coaching; OTcsm= Occupational therapy with coaching and sensor monitoring; SNF= Skilled nursing facility; H= Home; OT= Occupational therapy; PT= Physical therapy; CBT= Cognitive behavioral change techniques; PAM= Physical activity monitor

eTable 3. Care as usual in the SO-HIP trial

	SNF 1	SNF 2	SNF 3	SNF 4	SNF 5	SNF 6
MDS-team (physician, occupational therapist, physical therapist, nurse) in place	yes	yes	yes	yes	yes	yes
Discharge planned at admission	yes	yes	partial	yes	yes	yes
How goals are set?	MDS	MDS	MDS	MDS	MDS	MDS
Family involvement	yes	mostly	yes	yes	yes	yes
Mean duration hip-rehabilitation in days	15-28	36	29-56	21-70	45	42
Mean duration of PT-intervention per week (in minutes)	260	240	150	120	90	120
Treatment frequency PT (times per day)	2	1-2	1	1	1	1
Mean duration OT- intervention per week (minutes)	60	60	60	60	30	60
Treatment frequency OT (number of sessions per week)	2	1	1	1	1	1
Use of hip fracture guidelines	yes	yes	yes	no	yes	yes
Rehabilitation therapeutic climate that involves exercises and practicing daily functioning during the day	yes	yes	yes	no	yes	yes
Content of PT intervention	Mobility, muscle strength, balance transfer and walking	Mobility, muscle strength, balance transfer and walking	Mobility, muscle strength, balance transfer and walking	Mobility, muscle strength, balance transfer and walking	Mobility, muscle strength, balance transfer and walking	Mobility, muscle strength, balance transfer and walking
Content of OT intervention	Intake, wheel-chair/ mobility, Performance ADL, Advice safety at home	Intake, wheel-chair/ mobility, Performance ADL, Advice safety at home	Intake, wheel-chair/ mobility, Performance ADL, Advice safety at home	Intake, wheel-chair/ mobility, Performance ADL, Advice safety at home	Intake, wheel-chair/ mobility, Performance ADL Advice safety at home	Intake, wheel-chair/ mobility, Performance ADL, Advice safety at home
PT after discharge	occasionally	yes	yes	occasionally	occasionally	yes
OT after discharge	occasionally	occasionally	occasionally	occasionally	occasionally	occasionally

SNF=skilled nursing facility; m=mean, PT=physical therapy; OT=occupational therapy; MDS=multidisciplinary

eTable 4. Components of the OT intervention with coaching and sensor monitoring

Setting	Week	Activities
SNF	1	**Starting point for the intervention:** Assessment of issues and priorities that are related to daily activities that are relevant and important to the patient (COPM).
	1-2	**OT assessment** focuses on exploring needs, performing daily functioning and safety at home using interviews and observation of activities. **OT gives information of sensor monitoring:** a short manual and a daily instruction how to wear the PAM. **Patient starts** with wearing the PAM on a daily basis.
	2	**Goal setting and planning** together with the patient, based on COPM issues, priorities and OT's assessment
	3-4	**OT interventions with coaching and sensor monitoring** are focused on patients' COPM-issues and include informing and training patients' strategies to improve task performance. Coaching includes modifying patterns of thoughts (cognition) and activities (behavior) that contribute to the fear of falls and consists of five steps, integrated in the rehabilitation: 1) to give information and education over the importance of being physical active and doing exercises and daily activities. 2) to ascertain the amount of movement and physical activity during the day and give feedback. The sensor data reports can be used as objective information about the current state of the amount of movement and activities during the day and form a start to talk about daily patterns and activities that are important to practice, to make new realistic plans for activities based on the objective reports. 3) to set realistic goals for the performance of daily activities; 4) to make a plan for these activities and if needed practicing exercises and daily activities on a safe manner together with the OT. The activities, in which concerns about falls are experienced, are chosen by the patients that they consider relevant and important to practice; 5) to evaluate the progress. The daily and weekly reports of the sensor data can also be used to evaluate the progress of the rehabilitation.
Home	1	A wireless sensor monitoring system will be installed in the home of the patient. The patient continues wearing of the PAM during the day. Home-visit 1 OT intervention with coaching and sensor monitoring will address the following themes: changing the environment to reduce fall- risk, setting realistic goals for increasing daily activities and physical activities with the help of the daily and weekly sensor data reports. The duration of this first home-visit is 60 minutes.
	2,3,4	**Home-visits 2, 3 and 4 OT intervention with coaching and sensor monitoring** are focused on practicing exercises and daily activities safely. The activities, in which concerns about falls are experienced, are chosen by the patient themselves and which they consider relevant and important to practice.
	5,6, 8,10	**Telephone consultation 1-4** OT-intervention coaching by using the sensor data, addressing the same 5 steps. **Evaluation of goals** and **finish intervention**

OTc = Occupational therapy with coaching; OTcsm = Occupational therapy intervention with coaching and sensor monitoring. NH = Nursing Home; W = Week; COPM = Canadian occupational Performance Measure

eTable 5. Statistical analysis plan SO-HIP trial

Outcome	Data type	Statistical model (STATA command(s))	Covariates	Subgroup analyses (by treatment) / sensitivity analyses
1. COPM-performance at 6 months (primary outcome)	Ordinal treated as continuous (theoretical range 1-10)	Linear regression model with 2 treatment indicators (regress)	Confounder set¶	COPMP[1] and MMSE[2] at baseline
2. COPM-satisfaction at 6 months (co-primary outcome)	Ordinal treated as continuous (theoretical range 1-10)	Linear regression model with 2 treatment indicators (regress)	Confounder set¶	COPMP[1] and MMSE[2] at baseline
3. COPM-performance at 1, 3, 6 months	Ordinal treated as continuous (theoretical range 1-10)	Longitudinal mixed linear effects model with 2 treatment indicators (mixed)	Confounder set¶	COPMP[1] and MMSE[2] at baseline
4. COPM-satisfaction at 1, 3, 6 months	Ordinal treated as continuous (theoretical range 1-10)	Longitudinal mixed linear effects model with 2 treatment indicators (mixed)	Confounder set¶	COPMP[1] and MMSE[2] at baseline
5. POMA at 1, 3, 6 months	Ordinal treated as continuous (theoretical range 2-28)	Longitudinal mixed linear effects model with 2 treatment indicators (mixed)	Confounder set¶	COPMP[1] and MMSE[2] at baseline
6. TUG at 1, 3, 6 months	Continuous	Longitudinal mixed linear effects model with 2 treatment indicators (mixed)	Confounder set¶	COPMP[1] and MMSE[2] at baseline
7. Katz at 1, 3, 6 months	Ordinal treated as continuous (theoretical range 0-15)	Longitudinal mixed linear effects model with 2 treatment indicators (mixed)	Confounder set¶	COPMP[1] and MMSE[2] at baseline
8. VAS-SAFE at 1, 3, 6 months	Ordinal treated as continuous (theoretical range 1-10)	Longitudinal mixed linear effects model with 2 treatment indicators (mixed)	Confounder set¶	COPMP[1] and MMSE[2] at baseline

eTable 5. Continued

Outcome		Data type	Statistical model (STATA command(s))	Covariates	Subgroup analyses (by treatment) / sensitivity analyses
9.	VAS-FOF at 1, 3, 6 months	Ordinal treated as continuous (theoretical range 1-10)	Longitudinal mixed linear effects model with 2 treatment indicators (mixed)	Confounder set¶	COPMP[1] and MMSE[2] at baseline
10.	FES-I at 1, 3, 6 months	Ordinal treated as continuous (theoretical range 1-10)	Longitudinal mixed linear effects model with 2 treatment indicators (mixed)	Confounder set¶	COPMP[1] and MMSE[2] at baseline
11.	EQ-5D at 1, 3, 6 months	Continuous (theoretical range 0 -100)	Longitudinal mixed linear effects model with 2 treatment indicators (mixed)	Confounder set¶	COPMP[1] and MMSE[2] at baseline

[1] COPM performance and satisfaction categories used will be 1-3 versus 4 and higher
[2] MMSE categories used will be 15-19, 20-24, and 25-30
We will consider performing multiple imputation (MI) or inverse probability weighting (IPW) to deal with missing values, if the number of missing data exceeds 5% of data points.
Random intercepts: patient id; random slope: time (2 indicators)
¶ Confounder set = time (2 indicators), nursing home (5 indicators), corresponding outcome measure's score at baseline.
Explorative analyses: (either as fixed or as random effects): time by treatment ('Do the treatment effects vary by time period (1-6)?')

eTable 6. Overview and reasons for drop-out in the SO-HIP trial

Variables	Total study population	CAU	OTc	OTcsm
Patients T0, n	**240**	**77**	**87**	**76**
Patients T1 - % (n)	**80.4 (193)**	**84.4 (65)**	**77.0 (67)**	**80.3 (61)**
Dropout T1 - % (n)	19.6 (47)	15.6(12)	23.0 (20)	19.7 (15)
Died	3.3 (8)	1.3 (1)	6.9 (6)	1.3 (1)
Medical reasons	5.8 (14)	3.9 (3)	4.6 (4)	9.2 (7)
Permanent admission to SNF	7.5 (18)	6.5 (5)	9.2 (8)	6.6 (5)
Refused to continue	2.5 (4)	2.6 (2)	-	2.6 (2)
Not known	1.3 (3)	1.3 (1)	2.3 (2)	-
Patients T3 - % (n)	**57.9 (151)**	**70.1 (55)**	**60.9 (53)**	**56.6 (43)**
Dropout T3 - % (n)	27.8 (43)	13.0 (10)	16.1 (14)	25.0(19)
Died	2.9 (7)	2.6 (2)	4.6 (3)	2.6 (2)
Medical reasons	5.0 (12)	3.9 (3)	1.1 (1)	7.9 (6)
Permanent admission to SNF	7.1 (17)	2.6 (2)	9.2 (8)	7.9 (6)
Refused to continue	3.8 (9)	2.6 (2)	2.3 (2)	6.6 (5)
Not known	1.7 (4)	1.3 (1)	-	-
Patients T6 - % (n)	**53.8 (129)**	**61.0(47)**	**52.9(46)**	**47.4 (36)**
Dropout T6 - % (n)	17.0 (22)	10.4 (8)	8.0 (7)	9.2 (7)
Died	0.4(1)	1.3 (1)	-	-
Medical reasons	1.3 (3)	2.6 (2)	-	1.3 (1)
Permanent admission to SNF	2.1 (5)	3.9 (3)	1.1 (1)	1.3 (1)
Refused to continue	1.3 (3)	-	2.3 (2)	-
Not known	4.2 (10)	2.6 (2)	4.6 (4)	6.6 (5)

CAU= care as usual; OTc= occupational therapy with coaching; OTcsm = occupational therapy with coaching and sensor monitoring

eTable 7. Process evaluation of the treatment fidelity in the SO-HIP trial based on therapists' logbooks

Variables	CAU (N= 76)	OTc (N= 85)	OTcsm (N= 79)
Log file completed-% (n)	53.9 (41)	48.2 (41)	60.8 (48)
OT Session Intramural			
Sessions delivered-% (n)	97.6 (40)	100.0 (41)	95.8 (43)
Session duration in minutes-median (IQR)	32 (29.5 - 38)	30 (30.0- 39)	30 (26.2- 40)
Number of sessions delivered-median (IQR)	4 (2 - 5)	4 (2 - 6)	2.5 (1 - 5)
OT coaching session at home			
Sessions delivered-% (n)		87.8 (30)	93.8 (44)
Session duration in minutes-median (IQR)		41 (0 - 60)	45 (38.5 - 60)
Number of sessions delivered-median (IQR)		2 (0 - 4)	4 (2 - 4)
Coaching delivered week 1-% (n)		61.0 (25)	81.3 (39)
Coaching delivered week 2-% (n)		48.8 (20)	75.0 (36)
Coaching delivered week 3-% (n)		36.6 (15)	62.5 (38)
Coaching delivered week 4-% (n)		26.8 (11)	50.0 (24)
OT Telephone consultations			
Sessions delivered-% (n)		82.0 (23)	87.5 (27)
Number of sessions delivered-median (IQR)		1 (1 – 1.5)	1 (0 - 2)
Telephone consultations week 5 -% (n)		48.8 (20)	54.2 (26)
Telephone consultations week 6 -% (n)		41.5 (17)	35.4 (17)
Telephone consultations week 8 -% (n)		22.0 (9)	25.0 (12)
Telephone consultations week 10 -% (n)		14.6 (6)	10.4 (5)
Intervention had connection with originally formulated COPM goals-%		78.0	87.5
Intervention successful according to OT		73.0	85.4
Reasons intervention was not successful according to OT		cognitive impairment, comorbidities, patients' incapability to formulate goals, unrealistic goals	

eTable 7. Continued

Variables	CAU (N= 76)	OTc (N= 85)	OTcsm (N= 79)
Experiences in using the coaching and the SO-HIP tool			Added useful objective information about the activities of the patient, made situation more concrete More insight into the daily functioning of patients with cognitive restrictions More information of daily functioning by the sensor data was helpful during the coaching
Technology affected the intervention, according to the OT-% (n)			72.9(31)

Total study population (N= 240) 54.2 % (130) completed log file. CAU = care as usual; OT = occupational therapy; OTc = occupational therapy with coaching; OTcsm = occupational therapy with coaching and sensor monitoring

eTable 8. Treatment effects on COPM-p and COPM-s at 6 months (N=129)

	CAU	OTc	OTcsm
COPM-p[a] (95% CI; p value)	reference	0.59 (-0.17– 1.34; 0.129)	1.18 (0.35 – 2.00; 0.006)
COPM-s[b] (95% CI; p value)	reference	0.47 (-0.17 –1.11; 0.149)	0.91 (0.21 – 1.61; 0.011)

Treatment effects, expressed as mean differences between treatment groups. [a]COPM-p = Canadian Occupational Performance Measure-performance scale (range 1-10); [b]COPM-s = Canadian Occupational Performance Measure-satisfaction (range: 1-10), where higher values indicate better performance). CAU = care as usual; OTc= occupational therapy with coaching; OTcsm= occupational therapy with coaching and sensor monitoring

eTable 9. Treatment effects based on joint models, accounting for drop-out (N=240, upper table) compared to a mixed model without adjustment for drop-out (N=240, lower table)

COPM-p	OT Coach vs CAU	OT Coach and Sensor vs CAU	OT Coach and Sensor vs OT Coach
T1	0.34 (-0.13–0.81; p=0.155)	0.61 (0.10–1.10; p=0.018)	0.26 (-0.18–0.70; p=0.241)
T3	1.40 (0.81–1.99; p<0.001)	2.20 (1.52–2.87; p<0.001)	0.80 (0.08–1.51; p=0.029)
T6	2.11 (1.32–2.89; p<0.001)	3.26 (2.34–4.18; p<0.001)	1.15 (0.09–2.22; p=0.034)
COPM-s			
T1	0.31 (-0.08–0.70; p=0.117)	0.45 (0.03–0.87; p=0.035)	0.14 (-0.23–0.50; p=0.460)
T3	1.25 (0.76–1.74; p<0.001)	1.75 (1.19–2.31; p<0.001)	0.50 (-0.09–1.09; p=0.096)
T6	1.87 (1.22–2.52; p<0.001)	2.61 (1.85–3.38; p<0.001)	0.74 (-0.14–1.62; p=0.098)

Model included treatment (2 dummies, reference is CAU), time (continuous), treatment by time interaction, center (5 dummies), baseline values of the dependent variable. Models were run on one (randomly selected) multiply imputed dataset.

COPM-p	OT Coach vs CAU	OT Coach and Sensor vs CAU	OT Coach and Sensor vs OT Coach
T1	0.21 (-0.45–0.86; p=0.538)	0.11 (-0.56–0.79; p=0.744)	-0.09 (-0.69–0.50; p=0.757)
T3	1.33 (0.75–1.91; p<0.001)	1.69 (1.06–2.31; p<0.001)	0.35 (-0.08–0.78: p=0.110)
T6	2.08 (1.43–2.74; p<0.001)	2.73 (2.05–3.42; p<0.001)	0.65 (0.07–1.23; p=0.029)
COPM-s			
T1	0.21 (-0.35–0.76; p=0.469)	0.18 (-0.41–0.77; p=0.553)	-0.03 (-0.51–0.46; p=0.915)
T3	1.16 (0.66–1.67; p<0.001)	1.43 (0.89–1.97; p<0.001)	0.27 (-0.10–0.64; p=0.155)
T6	1.80 (1.24–2.35; p<0.001)	2.26 (1.68–2.85; p<0.001)	0.46 (-0.024–0.95; p=0.062)

Model included treatment (2 dummies, reference is CAU), time (continuous), treatment by time interaction, center (5 dummies), baseline values of the dependent variable. Models were run on 47 multiply imputed datasets and the results combined using Rubin's rules.

eTable 10. Mean values at follow-up for all outcomes, based on mixed linear models

COPM-p[a] (N=183)		**Treatment groups**	
Means (SE)	CAU	OT Coach	OT Coach and Sensor
T1	4.90 (0.19)	5.10 (0.18)	5.39 (0.19)
T3	6.54 (0.21)	6.74 (0.21)	7.03 (0.22)
T6	6.71 (0.22)	6.91 (0.21)	7.20 (0.23)
Longitudinal effect (95%CI)	reference	0.20 (-0.28 – 0.67; 0.413)	0.49 (-0.02 – 1.00; 0.057)
COPM-s[b] (N=179)	CAU	OT Coach	OT Coach and Sensor
T1	5.55 (0.17)	5.66 (0.16)	5.98 (0.17)
T3	6.94 (0.18)	7.05 (0.18)	7.37 (0.19)
T6	6.98 (0.18)	7.09 (0.18)	7.41 (0.20)
Longitudinal effect (95%CI)	reference	0.11 (-0.31 – 0.53; 0.607)	0.43 (-0.02 – 0.87; 0.062)
POMA[c] (N=78)			
Means (SE)	CAU	OT Coach	OT Coach and Sensor
T1	17.99 (0.58)	18.36 (0.61)	18.40 (0.64)
T3	20.10 (0.64)	20.47 (0.69)	20.51 (0.71)
T6	21.29 (0.75)	21.66 (0.78)	21.70 (0.81)
Longitudinal effect (95%CI)	reference	0.37 (-1.26 – 2.00; 0.656)	0.41 (-1.28 – 2.11; 0.634)
TUGd (N=71)			
Means (SE)	CAU	OT Coach	OT Coach and Sensor
T1	24.29 (1.86)	24.01 (1.71)	25.77 (1.89)
T3	20.53 (1.89)	20.24 (1.81)	22.00 (1.96)
T6	18.66 (1.96)	18.38 (1.87)	20.14 (2.02)
Longitudinal effect (95%CI)	reference	-0.29 (-5.07 – 4.50; 0.907)	1.48 (-3.55 – -6.50; 0.565)
Katz ADL[e] (N=182)			
Means (SE)	CAU	OT Coach	OT Coach and Sensor
T1	8.10 (0.29)	7.52 (0.28)	7.11 (0.31)
T3	6.39 (0.32)	5.80 (0.31)	5.39 (0.34)
T6	6.32 (0.36)	5.73 (0.35)	5.33 (0.37)
Longitudinal effect (95%CI)	reference	-0.58 (-1.38 – 0.21; 0.148)	-0.99 (-1.85 – 0.13; 0.024)
SOS[f] (N=178)			
Means (SE)	CAU	OT Coach	OT Coach and Sensor
T1	2.82 (0.21)	2.47 (0.20)	2.64 (0.21)
T3	2.69 (0.22)	2.34 (0.23)	2.51 (0.23)
T6	2.58 (0.22)	2.23 (0.22)	2.40 (0.24)

eTable 10. Continued

Longitudinal effect (95%CI)	reference	-0.35 (-0.85 – 1.45; 0.165)	-0.18 (-0.71 – 0.35; 0.502)
FOF[g] (N=190)			
Means (SE)	CAU	OT Coach	OT Coach and Sensor
T1	5.36 (0.26)	4.21 (0.25)	4.69 (0.28)
T3	5.13 (0.28)	3.97 (0.28)	4.45 (0.30)
T6	5.27 (0.29)	4.12 (0.28)	4.59 (0.31)
Longitudinal effect (95%CI)	reference	-1.15 (-1.83 – -0.48; 0.001)	-0.68 (-1.41 – 0.06; 0.072)
FES[h] (97)			
Means (SE)	CAU	OT Coach	OT Coach and Sensor
T1	27.11 (1.32)	25.80 (1.18)	24.78 (1.04)
T3	24.08 (1.39)	22.77 (1.26)	21.75 (1.17)
T6	25.16 (1.38)	23.85 (1.28)	22.83 (1.17)
Longitudinal effect (95%CI)	reference	-1.31 (-4.56- 1.93;0.428)	-2.33 (-5.62- 0.95; 0.164)
Eq5D[i] (N=191)			
Means (SE)	CAU	OT Coach	OT Coach and Sensor
T1	0.57 (0.03)	0.60 (0.03)	0.63 (0.03)
T3	0.66 (0.03)	0.68 (0.03)	0.71 (0.03)
T6	0.66 (0.03)	0.69 (0.03)	0.72 (0.03)
Longitudinal effect (95%CI)	reference	0.03 (-0.04-0.10; 0.439)	0.06 (-0.02-0.13; 0.151)

COPM-p[a] = Canadian Occupational Performance Measure-performance scale (range 1-10), where higher values indicate better performance);
COPM-s[b] = Canadian Occupational Performance Measure-satisfaction (range: 1-10), where higher values indicate better performance)
POMA[c] = Performance-Oriented Mobility Assessment: ≤ 18 indicates high risk of falls; 19-23 moderate risk of falls; ≥24 low risk of falls
TUG[d] = Timed Up and Go (in seconds); a lower score indicates better functional mobility and balance
Katz-ADL index[e] (range 0-15); a higher score indicates higher dependence in ADL and IADL
SOS[f] = Sense of Safety. VAS-score from 1-10; a higher score indicates feeling safer
FOF[g] = Fear of falling. VAS-score from 1-10; a higher score indicates more fear of falling
FES-I[h]= Falls Efficacy Scale international. Score 16-19: little fear of falling; 20-27 moderate fear of falling; 28-64 much fear of falling
EQ5D[i] = Self-reported health related quality of life (range 0-1); a higher score indicates better health related quality of life
T0=baseline; T1=at discharge, 1 month after start rehabilitation; T3=after the intervention stopped, at approximately 4 months after the start rehabilitation; T6=six months after the start of rehabilitation.
Longitudinal effects are based on mixed linear models (treatment group, time, nursing home, baseline value of outcome variable and random intercept and slope for patients) and indicate the differences with care as usual

eTable 11. Longitudinal treatment effects on all secondary outcomes (n=240)

	OT Coach	OT Coach and Sensor
	Mean difference (95% CI; p value)	**Mean difference (95% CI; p value**
POMA[a]	0.90 (-0.22 –2.01; 0.113)	1.00 (-0.28 – 0.29; 0.127)
TUG[b]	1.65 (-1.96 – 5.27; 0.370)	1.06 (-2.81 – 4.94; 0.590)
KATZ ADL[c]	-0.71(-1.47 – 0.04; 0.064)	-0.70 (-1.52 – 0.12; 0.096)
SOS[d]	-0.20 (-0.65 – 0.26; 0.398)	-0.06 (-0.58 – 0.46; 0.814)
FOF[e]	-1.15 (-1.80 – -0.50; 0.001)	-0.51 (-1.24 – 0.23; 0.177)
EQ5D[f]	0.29 (-0.04 – 0.10; 0.397)	0.06 (-0.16 – 0.13; 0.125)

Treatment effects are expressed as mean differences with scores in the care as usual (control) group.
POMA[a] Performance-Oriented Mobility Assessment: ≤ 18 indicates high risk of falls; 19-23 moderate risk of falls; ≥24 low risk of falls
TUG[b] Timed Up and Go (in seconds); a lower score indicates better functional mobility and balance
Katz-ADL index[c] (range 0-15); a higher score indicates a higher dependence in ADL and IADL
SOS[d] Sense of Safety. VAS-score from 1-10; a higher score indicates feeling safer
FOF[e] Fear of falling. VAS-score from 1-10; a higher score indicates more fear of falling
EQ5D[f] Scale 0-1; a higher score indicates better health related quality of life

Chapter

7

Everyday life after a hip fracture: what community-living older adults perceive as most beneficial for their recovery

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Abstract

Background: The transition from inpatient rehabilitation to the home environment is a vulnerable period for older adults after hip fracture; during this transition, they must cope with physical and psychological restrictions that influence their everyday functioning. However, studies describing older adults' experiences of this transition to home are lacking.

Objective: To gain insight into what older adults perceive as most beneficial to their recovery to everyday life.

Design and Methods: Semi-structured interviews were conducted with 19 older adults after hip fracture. The adults were aged 65-94 and participated in the SO-HIP study in the Netherlands. Grounded theory coding techniques were applied.

Results: Four categories were derived from the data: 'restrictions for everyday life', 'recovery process', 'resources for recovery' and 'performing everyday activities'. Physical and psychological restrictions are consequences of hip fracture that older adults have struggled to address during recovery. Three different resources were found 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 in the same manner as before or differently; unsuccessful experiences led to ceasing certain activities altogether.

Discussion and Implications: The findings suggest 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. We propose that interventions must contain components that support self-management and adaptation so that participants are better able to cope with their restrictions.

A conceptual model is presented and provides 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 surgery.

Background

Hip fracture is a common injury among older adults after a fall, resulting in mortality, morbidity and loss of functional independence.[1-4] Worldwide, a substantial increase in the number of hip fractures is expected mainly because of the growth of the older population.[5-7] In the Netherlands, approximately 15.000 older adults are admitted to a hospital each year after hip fracture. After hospitalization for a hip fracture, approximately 40 percent of the older adults receive short-term geriatric rehabilitation.[8] Many of these older adults live alone, have multiple comorbidities and do not regain their premorbid functional abilities after the hip fracture, and they experience functional decline and restriction in everyday life.[2,9-11]

Fear of falling (FOF) is an important factor that has been associated with functional decline after hip fracture. Many older individuals experience FOF directly related to the fall, and it is a major constraint for successful rehabilitation.[9,12,13] As a consequence of FOF, older adults move less and minimize their participation in activities such as walking and performing activities in the house; they are also at risk of not experiencing a full recovery.[3,13] FOF is therefore an important theme that therapists need to focus on during rehabilitation.

In the Netherlands and in most other countries, there is a trend towards a shorter inpatient rehabilitation period. The mean duration is approximately four weeks; however, the duration of functional recovery varies from 6 months to 1 year following hip fracture.[14]

We know little about how older adults experience the transition from inpatient rehabilitation to their home and what supports their continued recovery to everyday life. Much of the research on hip fracture recovery has focused on risk factors that explain functional recovery or functional decline after hip fracture or has focused on intervention strategies related to improving mobility and functional recovery.[2,15-18] Some qualitative studies provide understanding of older adults' perspectives on recovery after hip fracture. These studies have concentrated on functional limitations and how the impact of hip fracture varies depending on individual circumstances, particularly pre-existing health conditions.[19-21] However currently missing are studies related to older adults' experiences and perspectives that focus on the transition from inpatient rehabilitation to further recovery to everyday life at home.

Our study focuses on the impact of hip fracture on everyday life and the recovery from inpatient rehabilitation to further recovery at home. This study addresses the following research question: What aspects of the recovery process after hip fracture do community-dwelling older adults perceive as the most beneficial for their return to everyday life?

Methods

A qualitative research approach was needed to provide a rich understanding of participants' experiences and perspectives concerning their recovery after hip fracture for their return to everyday life. We conducted qualitative interviews with older adults and used coding techniques based on constructivist grounded theory as interpreted by Charmaz.[22] This method consists of systematic, flexible guidelines for collecting and analyzing qualitative data to construct theories 'grounded' in the data themselves.[10]

Study Setting and Sample

The study was conducted between April 2016 and December 2017 in the Netherlands. We purposefully sampled participants out of the SO-HIP study (www.sohipstudie.nl).

The SO-HIP study

The participants of the SO-HIP study were older adults who recovered after a hip fracture. The study, a three-arm stepped wedge cluster randomized trial, aimed to compare the effects a transitional care rehabilitation program in which sensor monitoring was used in coaching on patient perceived performance of daily functioning of older adults after hip fracture to occupational therapy without sensor monitoring and to usual care.

The SO-HIP intervention consists of a coaching component and the use of sensor technology to support older adults in their recovery after hip fracture. The coaching is based on the principles of a cognitive behavioral therapy (CBT) program concerning falls and focuses on setting realistic goals for increasing performance in meaningful daily functioning at home. The sensor technology consists of a wearable sensor worn on the hip and a few ambient sensors at home that are used to assist the older adults in obtaining feedback on their physical activities and as a tool to assist therapists in CBT-based coaching. We compared three groups in the SO-HIP study: 1) participants who received care as usual; 2) participants who received occupational therapy based on coaching; and 3) participants who received occupational therapy based on coaching and the use of sensor technology.

The rationale and details of this intervention have been described previously.[23]

Participants

We purposefully sampled participants out of the three groups of the SO-HIP study (n=240) who were discharged to go home and finished the rehabilitation approximately six to eight months after hip fracture. Initially, a sampling frame was developed to include the following: 1) participants out of the three groups of the SO-HIP study; 2) participants who represented a range in age; and 3) participants who were diverse in gender.

Table 1 presents the characteristics of the participants, who included twelve women and seven men. The age of the participants ranged from 65 to 94 years.

Ethical Considerations

The present study has been approved by the Medical Ethics Committee of the Academic Medical Centre, University of Amsterdam in the Netherlands (protocol ID AMC 2015_169). Participants were given a full written and oral explanation of the purpose of the study, confidentiality and anonymity were assured, and written informed consent was obtained before inclusion.

Table 1. Characteristics of the Interviewed Participants

Partici-pant	Gender	Age	Living arrange-ment	Cog-nition MMSE	Katz ADL	Fear of Falling	POMA-Ti-netti	Mobility aid
A	Female	93	S	23	10	5	21	walker
B	Male	65	S	28	4	1	26	none
C	Female	72	C	26	1	4	16	walker
D	Female	79	C	25	2	2	26	none
E	Female	90	C	22	7	1	19	walker
F	Male	78	C	28	1	3	26	none
G	Female	94	C	27	6	1	19	walker
H	Male	79	C	29	0	1	28	none
I	Male	89	C	27	5	6	14	none
J	Female	85	C	26	4	1	22	stick
K	Female	69	C	28	1	2	27	none
L	Male	82	C	21	4	4	24	none
M	Female	84	C	27	5	1	18	walker
N	Female	89	C	24	3	4	19	walker
O	Female	76	C	30	5	1	23	walker
P	Female	84	C	27	3	7	18	walker
R	Male	89	C	24	8	7	-	walker
S	Male	91	S	25	8	6	20	walker
T	Female	66	C	30	1	5	28	none

Notes: C= living alone in a home in the community; S= living alone in a senior residence
MMSE= Mini Mental State Examination. score median (range of 0 to 30); a higher score indicates better cognitive functioning
Katz ADL= modified Katz ADL 15 score, range 0-15; a higher score indicates more (I)ADL (Instrumental) activities of daily living) dependence.
Fear of falling. VAS- score 1-10; a higher score indicates more fear of falling
POMA = Performance Oriented Mobility Assessment. ≤ 18 indicates high risk of falls; 19-23 moderate risk of falls; ≥24 low risk of falls
(I)ADL=Instrumental and activities of daily living. IADL=Instrumental activities of daily living
Note that the scores are at 6 months after the start of the rehabilitation.

Data Collection

We conducted semi-structured interviews at the participants' homes for approximately one hour. These interviews were conducted by the first author (MP) and a research assistant (MT). We used an interview guide containing several topics that aimed to reconstruct participants' experiences with their recovery and their return to everyday life. The interview guide was adapted as the data analysis progressed. The interview guide consisted of open-ended questions followed by probing questions and was used flexibly. During the interview, the participants were encouraged to reflect and to clarify details.[22] Initial questions were broad, e.g., "Since you have been back home, how have you been doing?"

More focused questions were asked regarding specific topics, e.g., “What has changed in your daily living since you had a hip fracture?”, “Which aspects of the rehabilitation, or what recently, was most helpful for you in your ability to function at home again?” and “Do you think the sensor data could support or motivate you in optimizing your daily functioning?” An example of an ending question was “Of all that we discussed, what recently do you perceive as most beneficial in optimizing your daily functioning?”

Interviews were recorded digitally and transcribed verbatim. Memos made during and after the conversations were included in the analysis and provided additional information.

Data Analysis

As we aimed to identify older adults’ experiences regarding their recovery, we applied open coding techniques derived from grounded theory, as interpreted by Charmaz.[22] Grounded theory coding consists of at least two main phases: an initial coding phase and a focused selective coding phase that uses the most significant or frequent initial codes to sort, synthesize and integrate large amounts of data.[22] In the process of initial coding, a line-by-line analysis of the transcripts was performed by the first and second authors, MP and SP, while constantly comparing the data of each interview and between the interviews and comparing the data with codes (constant comparison). We described emerging thoughts about possible categories in memos. In the subsequent focused coding activities, we distributed the most useful initial codes into categories related to a core category, linking codes and specifying relationships between categories. These focused codes were more directed, selective and conceptual than the first initial codes. We performed this entire coding process first for the ‘care as usual’ group, followed by the ‘occupational therapy with coaching’ group and the ‘occupational therapy with coaching and sensor monitoring’ group. Data were managed and organized using MAXQDA version 12.

Discrepancies between MP and SP during coding activities were resolved through discussion and consensus with the research team. The final set of four major categories and subcategories was agreed upon by all authors. In the last phase of the analysis, a first conceptual model was developed, indicating the links between the categories by analyzing how the process of recovery was related to resources for recovery.

Results

The conceptual model (Figure 1) provides 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 surgery. Participants described the remaining physical restrictions (being less mobile, dependence on mobility aids) and psychological restrictions (being tired and careful and concerned about falling again) after their hip fracture that had implications for everyday life (Category 1). The recovery process (Category 2), which started directly after hip fracture, was described by participants as trying and requiring practice, eventually leading to successful and unsuccessful experiences. Additionally, participants mentioned different resources that helped

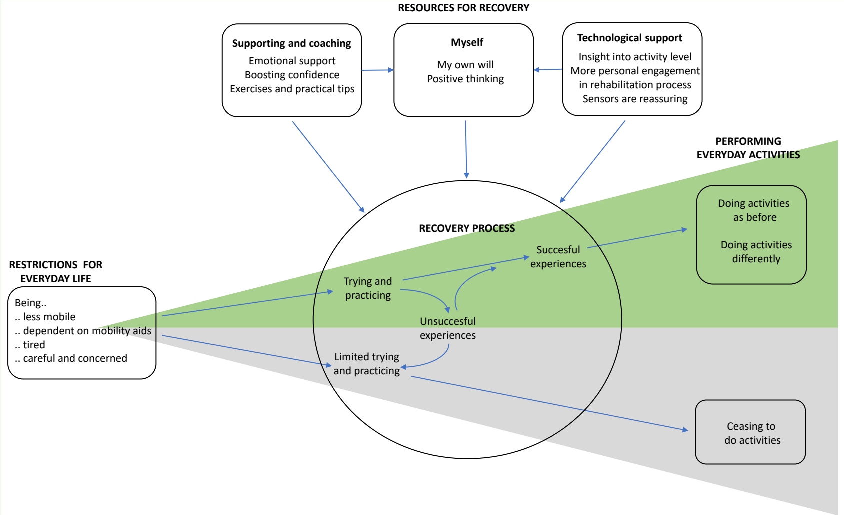

Figure 1. Conceptual model of participants' experiences concerning their recovery to everyday life

them in the recovery process (Category 3): supporting and coaching, 'myself' and technological support. These resources resulted in performing everyday activities (Category 4) in two distinct ways: (1) engaging in the activities in the same manner as before or differently and (2) ceasing to engage in the activities. These related categories are depicted in a conceptual model (Figure 1) and are detailed below.

Category 1-Restrictions for everyday life

All participants expressed remaining physical restrictions and psychological reactions after being discharged from inpatient rehabilitation to their home. These reactions had implications for their everyday life.

Being less mobile

All of the participants expressed that their mobility had become limited. They expressed having difficulties in standing up from a chair, in keeping balance, in walking long distances or in cycling. For example, Mrs. E told the interviewer the following: *"I walk a little bit in the neighborhood, but I don't go any further."* Mrs. D's comments were as follows: *"Cycling is the thing I miss most; I always took the bike for shopping"*.

Being dependent on mobility aids

A majority of the participants had to use mobility aids, such as a walker, which they had not used or had not been using on a regular basis before the hip fracture. Some participants perceived the need for mobility aids as a lack of improvement and as representing the consequences of aging, thus making them feel old. Although the use of mobility aids provided greater safety when walking, they generally expressed that it also limited them in their mobility and restricted them in doing everyday activities. Mrs. A expressed this experience as follows: *"I have to do everything with the help of the walker, even the housekeeping; it limits me quite a bit"*. Mr. O said, *"Before this, I could walk normally, but now I have to walk with the help of a walker. I'm chained to the walker"*.

Being tired

Some of the participants indicated that they were tired much sooner than before and that they had less energy. This tiredness limited their mobility and restricted their activities. Others expressed that activities were taking up much more time, and because of their lower energy levels, they had to balance their activities. As expressed by F, *"Activities take up much more time; I did the gardening in a single day, and now I need three or four days because I get tired a lot sooner, and therefore, I divide up the activities"*.

Being careful and concerned about falling again

Almost all of the participants expressed concerns about falling again, which influenced their activities. Mrs. D expressed this sentiment as follows: *"I'm worried to fall again; I have to have something to hold on to everywhere I walk"*. As a result of these worries about falling, a majority of them were very careful and focused on planning their activities. Mrs. J noted the following: *"I am more focused on things, and I evaluate how I walk and hold on to something, for example, the stairs. Before this, I never used to hold on to the railing. Currently, I have to. It is just taking care not to fall again"*.

Category 2-Recovery process

Although all of the participants experienced physical and psychological restrictions, they showed different ways of coping with these restrictions. When the participants talked about the period of inpatient rehabilitation, most of them expressed satisfaction with the care and therapy they received. They realized their dependency on care and the impossibility of living independently at home at that moment. Participants mentioned that trying and practicing exercises was the central element in the recovery process and in gaining successful and sometimes unsuccessful experiences.

Trying and practicing and successful experiences

According to Mr. I, *"Look, what they used to do is ok: 'What you can do yourself, you should do; it was 'trying and practicing'"*. Mrs. T added, *"Each day I had therapy, everyone encouraged me to practice by doing the exercises to recover"*.

Some of the participants mentioned the practical things they had to practice before discharge that worked in comforting most of them. As Mrs. D expressed, *"We did some cooking in the kitchen of the ward, and we practiced how you could use the walker at the kitchen sink to determine if we were able to succeed at home. For a moment, you feel you make progress and can do it"*.

Limited trying and practicing and unsuccessful experiences

Some participants expressed disappointment and frustration that they could no longer perform their activities as they used to. Mrs. A stated, *"I hardly walk* *outside because I'm scared to fall; I feel more isolated because I can't go to the gym or go to the shopping center anymore".*

Category 3-Resources for recovery

Participants talked about different ways to adapt or find alternative ways of doing their everyday activities.

Almost all of the participants experienced the transition to their home as very difficult. They felt insecure in doing things by themselves and in seeking their independence again, as expressed by Mr. I: *"The change of going home was disappointing at first. All of a sudden, you have to do it all by yourself, and there is no protection around you".* However, participants also talked about different resources that helped them in the recovery process.

'Myself'

A majority of the participants mentioned their own will and a positive attitude as important resources for recovery and in changing their everyday activities.

My own will

Mrs. M explained, *"My own will helped me most to do activities again; I think it is my own motivation. Because I can't accept help that is not necessary; what I can do myself I want to do myself".* Mrs. J stated, *"I think it is my mind; stop moaning and groaning and keep on going".*

Positive thinking

Some participants expressed that their way of positive thinking influenced their recovery. Mrs. A said,

"Think positively and keep on moving". Mr. I said, *"Don't give up. The most helpful thing was my own positive approach and me, who truly wanted to go for it. Keep on going with what you still can do".*

Supporting and Coaching

Participants mentioned different forms of support and coaching that they found helpful in their return to everyday life. A majority of the participants appreciated the talks with and the support of other rehabilitants and found these contacts helpful in their recovery, as expressed by Mr. I: *"These people truly helped me to get through with this, we truly had a good time and lots of fun, and I still have contact with them".*

Family support was also an important recourse, as expressed by Mrs. D: *"If your mind boggles at something when you don't dare do anything, well, you need people in your surroundings, your children or whoever".*

Half of the interviewed participants received a follow-up rehabilitation at home consisting of a few home visits and some telephone consultations, which influenced the way they performed their everyday activities.

Analysis provided insight into the different mechanisms by which this coaching changed the everyday activities of the participants by influencing the recovery process.

Emotional support

Participants experienced the support of the therapist as truly helpful in their recovery to everyday life. Some participants experienced the support of the therapist as emotional support. They could talk about difficult activities, as expressed by Mrs. M: *"I truly appreciated that there was a follow-up because you suddenly go from being at the nursing home to being at home all on your own, and so it was very nice that there was somebody I could talk to about what was disappointing or what was going well"*.

Boosting confidence

Others expressed the support of the therapist as rebuilding or boosting self-confidence, as Mrs. N expressed: *"The aftercare has been important; we discussed what I had done, and I felt more confident in doing difficult activities"*. Some participants had experienced the fall at home as traumatic, and it still had a great impact on their everyday life. When they came home again, they had to face the place where the fall had occurred. One participant, Mrs. J, expressed the support she felt from the therapist who helped her by going back to the place where she had her fall: *"She observed that I was dreading to go to the bathroom where I had my fall and where I had been lying on the floor for a long time. Therefore, she said to me: 'Shall we go to the bathroom?', and that was very important to me."*

Exercises and practical tips

Other participants mentioned the practical tips and the practice of difficult activities at home with the therapist as very helpful. Mrs. J stated, *"She was interested in the activities I wanted to do; she gave me tips and stimulated me to do these things again. It truly helped me. Also, it helps that you can ask questions about things you come upon when you have to do it yourself again"*.

Technological support

A third of the respondents had received the same follow-up rehabilitation with coaching, as mentioned above, with the addition of sensor technology as a coaching tool. These participants experienced this technology as an extra support in their recovery to everyday life and described this support in different ways.

Insight in activity level

The feedback of the sensor data helped some participants to become aware of the amount of movement or the activities they had performed. Some participants were extra motivated to move more and to do more everyday physical activities because of the use of the sensors, as expressed by Mrs. M: *"It motivated me to move more, for example, in the evening when I didn't want to go on my home trainer, I thought by myself, I want to do it anyway because it is good to move. And when you had a look at the sensor data, it gave you such a good feeling, I've done so much"*.

More personal engagement in the rehabilitation process

Some of the participants were more engaged in their rehabilitation because they could see their results on the tablet and could make their own follow-up actions to reach their goals.

Mrs. O said, *"When you looked back on the first month on the tablet and a few months later, I clearly observed the progress I made. I thought to myself, I did a good job. By means of the graphs, I realized that I truly did it all myself"*.

Sensors are reassuring

Some of the participants stated that having sensors at home made them feel safe because they experienced a kind of control and therefore were daring to do more. Mrs. T said, *"It made me feel happy because something is keeping an eye on me, and that is reassuring to me. I thought when something is going wrong, they will keep an eye on me"*.

Category 4-Performing everyday activities

Participants expressed how they were performing their everyday activities at the end of their recovery process. Most of them had found their daily routines in everyday activities; for a few of them, these routines were nearly the same as prior to the hip fracture. Most of the participants made some changes or looked for alternatives to manage their everyday activities.

Doing activities in the same manner as before or differently

Some of the participants were still doing the same activities as before the hip fracture and believed that they have to go on as before.

Mrs. K. explained, *"Look, if you want to walk to the shopping center because you always walked that distance, you have to try and do that again. The first time you can plan your route to the shopping center so that you can stop and rest for a while sitting on a bench, and after a few times, you become better and better at it, and you can do it in the same way as you did before"*.

Most of the participants mentioned that they performed their everyday activities in a different way than before the hip fracture and in a way to cope with the implications of the hip fracture. Some of them performed their activities in a safer way. For example, according to Mrs. A, *"Yes, you find out all kinds of ways to do things safely, for example, watering flowers. You become truly good at it. I put the watering can on the walker and then I hold onto my walker"*.

Some of the participants make use of appliances so that they can do the activities themselves. Mr. I explained, *"I moved to a senior apartment, so everything is on the ground level, and to take a shower, I make use of a stool and a handgrip"*.

Ceasing to do activities

Participants within this category stopped doing some of the social and physical activities that they did before their hip fracture. Mrs. A explained this change as follows: *"I cancelled my travel insurance because I don't want to go on holiday anymore, and I therefore can't go to my children who are living abroad. I can't stand the long wait at the airport Schiphol anymore"*. Mr. F said, *"Before the fall, I was busy, I was always on the road. Now I stay at home more"*.

Some participants rationalized this stopping of activities as a natural consequence of aging, as expressed by Mrs. G: *"So yes, you become older, and old age comes with restrictions, so I have to accept that I can't do some things anymore"*.

Discussion and Implications

This study explored the experiences and perspectives of older adults after a hip fracture regarding the aspects of the recovery process they perceive as most beneficial to their return to their everyday life.

Four major categories were identified: 'restrictions for everyday life', 'recovery process', 'resources for recovery' and 'performing everyday activities'. The findings show that physical and psychological restrictions are an inevitable consequence of hip fractures that older individuals must address during their recovery process and return to everyday life. The results show three different resources that are beneficial for recovery: 'supporting and coaching', 'myself' and 'technological support'. These three resources influenced the recovery process, in which it is important to have successful experiences while trying out and practicing activities. A successful process can lead to older adults doing everyday activities in the same manner as before or differently. On the other hand, if activities are not tried out and practiced or lead to unsuccessful experiences, older individuals are inclined to cease certain everyday activities altogether.

In accordance with previous research, this study highlights the participants' struggles to cope with the restrictions they experience after their hip fracture.[24-26] Our findings show the difficulties participants experience in the transition from inpatient rehabilitation to everyday life at home and how they view support and coaching from therapists, family and co-rehabilitants as very helpful. This finding is in line with that of Magaziner[11], who reported that the period of greatest change in the ability to perform activities of daily living after hip fracture are the first four to six months after discharge. However, most traditional rehabilitation programs mainly focus on the first period of rehabilitation, the inpatient rehabilitation, and do not have a follow-up at home.

The present study shows that the resources for recovery, as described by the participants, activate facilitating mechanisms that help them with recovery. Coaching with the elements of education, goal-setting and practice provides emotional support, which boosts self-confidence for practicing everyday activities, after which participants feel more secure in performing these everyday activities. 'Myself' highlights the mechanisms of positive thinking or individuals' own motivation that influence their recovery. Technology encourages people to become more active in developing motivation for or engaging more fully in their recovery process.

Whereas most current rehabilitation programs after hip fracture tend to solely focus on improving mobility and basic activities of daily living, the current study's findings regarding the resources and mechanisms for recovery highlight the need for a more comprehensive approach in rehabilitation programs for independently living older adults who have experienced a hip fracture.

This study shows that participants use different methods of adaptation to cope with the physical and emotional limitations they experience. Trying and practicing are central elements in the recovery process, together with successful and unsuccessful experiences. These results are in line with the elements of the Selection, Optimization and Compensation model (SOC model of successful aging), a model that focuses on the processes individuals engage in to maximize gains and minimize losses in response to everyday demands and functional decline.[27] In this model, selection focuses on the selection of goals or everyday activities that are most important for a person's everyday life.[28] Most participants in our study chose to select everyday activities that they truly want to do or made a choice to cease doing certain activities. Optimization refers to the skills or strategies used to achieve goals in performing everyday activities, and Compensation focuses on the use of alternative ways to reach a goal or to maintain a desired level of everyday functioning.[28,29]

Our findings suggest that participants choose strategies or ways of adaptation that they are better able to incorporate into their routines or methods of everyday functioning despite their physical or psychological restrictions. This finding fits with the new concept of health in which health is considered the dynamic ability to adapt and to manage one's own well-being[30] and is in line with the results of earlier research.[29]

The findings highlight the added value of a follow-up rehabilitation after discharge to support older individuals in their return to their everyday functioning. This study adds to the current understanding that a personalized approach in rehabilitation that is focused on everyday functioning is important for participants to regain more confidence during the recovery process in doing the activities that are important for them. These findings are in line with the recommendations of a longitudinal study of older adults' experiences after hip fracture.[31]

Finally, this research provides the new insight that the combination of coaching and technology supports older individuals in adapting their activities to retain their functioning in everyday life. The present study shows that participants experience the use of sensor technology as part of the coaching and as an extra source of support to move more and do their everyday activities. Some of the participants indicated that they are more engaged in their rehabilitation by using this technology because they can see and follow their own level of activity on a computer tablet. As such, the technology supports the participant with objective feedback about their real-time movement, and this feedback acts as a source of self-management support. Participants indicated that in addition to the feedback of the sensor data, their talks about these data with the therapists are helpful in enabling them to change some activities and improve everyday functioning. This finding is in line with the findings of recent research that show improvement in physical functioning through the combination of a monitoring and feedback tool embedded in a counseling program.[32] To our knowledge, there has been no research on experiences with the use of this technology for individuals after hip fracture. In accordance with previous research, privacy is not seen as an issue in the use of sensor technology.[33-35]

Implication for daily practice

The findings of the current study have implications for interventions that guide the transition from inpatient rehabilitation to recovery to everyday life at home. The current study highlights the strong need for a follow-up rehabilitation at home to support participants in their search for finding new routines in performing their everyday activities. Traditionally, hip rehabilitation focuses on clinical rehabilitation, so more attention should be paid to follow-up interventions at home. The present study suggests that the focus of these follow-up interventions must be personalized with special attention to the everyday activities that are meaningful for individuals. Interventions must focus on the new perspectives on health as 'the ability to adapt and to self-manage[30] so that participants are more able to cope with their physical or psychological restrictions. Intervention components such as goal-setting, education, practice, and evaluation could be helpful for this process. Additionally, the combination of coaching and technology can be used to empower older adults to self-manage and adapt their activities for their return to everyday life.

Strengths and limitations

As with all aspects of qualitative research, the generalization of the results to other contexts is limited because of the small sample of 19 participants, however saturation of the data was emerged.

A strength of the study is that we had interviews with 19 participants who were diverse in gender, age, physical and cognitive functioning and living conditions, which represents the Dutch general population of older adults who undergo geriatric rehabilitation after a hip fracture. Although we sampled this wide diversity of participants, we interviewed participants who had the ability to reflect on and articulate their experience. Therefore, it is possible that we did not interview participants with more severe (cognitive) limitations that might have influenced their experiences and perspectives concerning their recovery. A limitation of our study is that we only asked participants what helped them in their recovery and not specifically what barriers they experienced.

Because our sample came from the SO-HIP trial, we interviewed participants who have had different rehabilitation interventions. This circumstance was, in one way, a strength of the study because we had a greater diversity of experiences in our sample. A limitation is that the experiences of the participants were influenced by the specific interventions they had received and therefore cannot be generalized. However, the study is giving interesting insight into the older adults' perspective of the recovery process from inpatient rehabilitation to home and might help to improve the rehabilitation of community-living older adults who undergo geriatric rehabilitation after hip fracture.

Conclusion

We identified older adults' experiences and perspectives regarding the recovery process after hip fracture and the aspects they perceived as most beneficial for their return to everyday life. The findings provided us with a deeper understanding of how different resources for recovery could influence the recovery process and facilitate coping, despite physical and psychological restrictions. Participants highlight their own role ('myself') as essential for recovery. Additionally, coaching provides emotional support, which boosts self-confidence in performing everyday activities. Furthermore, technology can encourage older adults to become more active and being engaged in the recovery process. As such, interventions that make use of both coaching and technology support the participants' own roles in their recovery, thereby empowering them. The way people adapted led to two ways of performing everyday activities at the end of recovery: ceasing to do activities and doing activities in the same manner as before or in a different manner. These findings can facilitate the development of interventions adapted to the needs of older adults after hip fracture that guide their transition from inpatient rehabilitation to recovery to everyday life at home.

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General discussion

Chapter

8

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.[1] Among this group, many will become dependent on care and support, and as a result, the burden and cost of health care will increase.[2] Most older individuals prefer to live independently at home as long as possible[3], and the Dutch health care policy is supporting this.[4] 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[5] (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.[5] 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.[6] 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.[7] 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[8] 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

Robben.[9]

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[10] and in a review by Ambient Assistive Technologies (AAL)[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.[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.[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 data).

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.[14] 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.[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-deviating 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.[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.[22,23,24]

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.[25,26] 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[27] (**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.[28] 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**).[29,30] 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.[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.[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.[14]

For our trial we used a stepped wedge design, which is used with increasing frequency in the evaluation of service delivery interventions.[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.[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.[33] 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**).[34]

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.[16] 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.[35,36] 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.[37,38]

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.[5,39,40] 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[41] and the new Dutch policy on health[4], 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 goalsetting; iii) the intervention takes place at home, and iv) the intervention is based on technology that enables people to their daily functioning.[42-44]

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 goalsetting 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.

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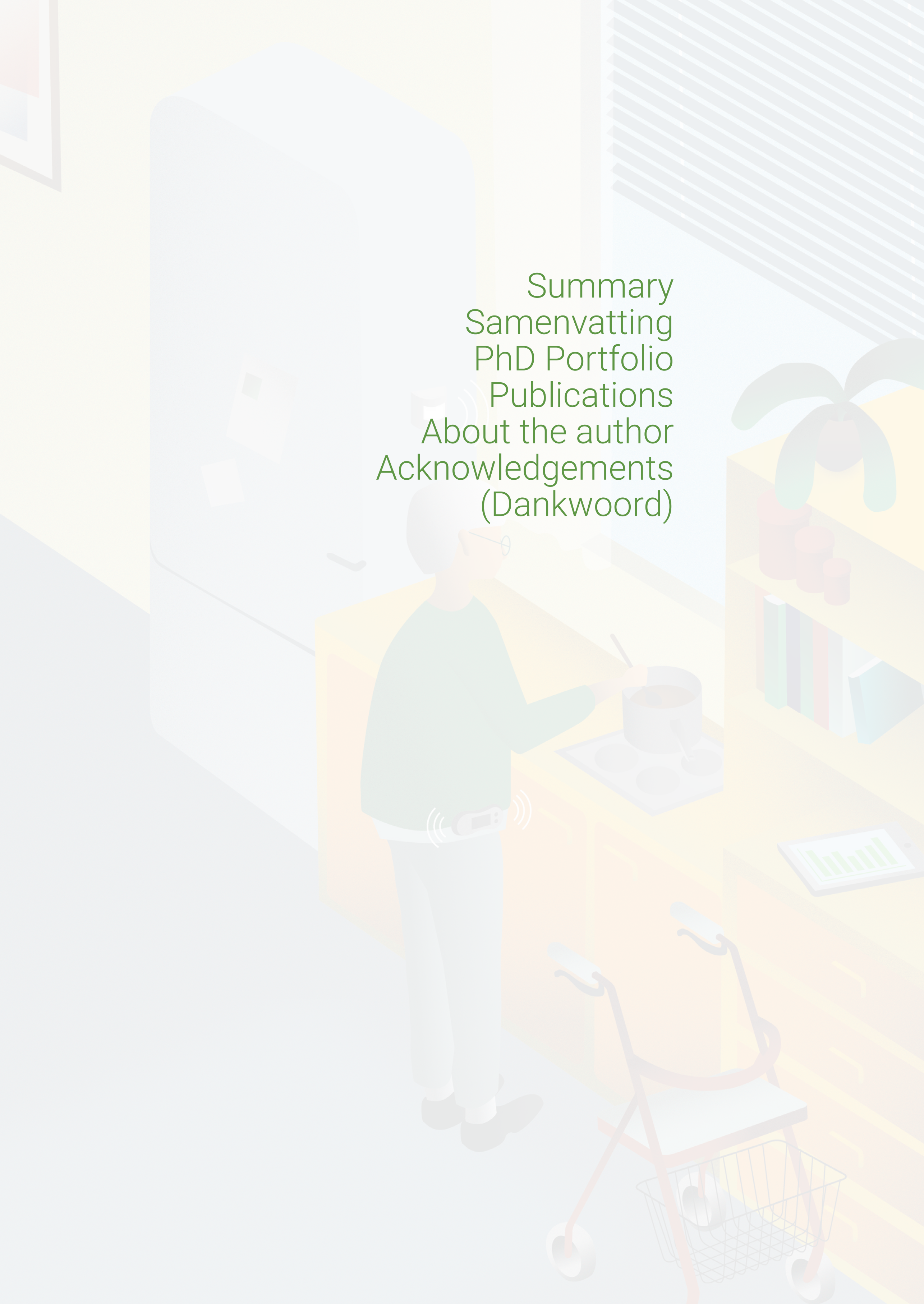

Summary
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Summary

Chapter 1 is the general introduction to this thesis. In the coming years, the number of older persons 65 years and older is expected to grow enormously. The proportion of single-living people aged 80+ will also increase. Most people prefer to live independently at home for as long as possible, which is also the policy of the Dutch government. A growing group of these very old persons have to deal with health decline and often have more than one chronic condition that influences their everyday functioning. Among these older persons, many will become dependent on care and support. As a result, the burden and cost of healthcare is expected to grow. These developments provide opportunities for developing interventions that enable older persons to perform everyday activities and to remain healthy and live independently at home. In this thesis, we investigated if sensor monitoring can be used by health care professionals in their daily practice to support the everyday functioning of older persons at home.

Sensor technologies are developed as (health-)monitoring systems to easily provide an observation of the daily functioning. These observations of everyday functioning can provide important information that health care professionals are able to use in their daily practice to support the patient's everyday functioning. However, the application of these sensor technologies in everyday life and clinical practice by health care professionals is rare.

The aim of this thesis is to evaluate the applicability and effectiveness of sensor monitoring for measuring and supporting the everyday functioning of older persons (65 years and older) who live independently at home. In this thesis, we use sensor monitoring into two ways. In the first way, we focus on the assessment of a person's level of daily functioning by sensor monitoring to detect deviations in the ADL patterns and to warn caregivers or health care professionals of such deviations. This could reflect changes in health care status and lead to interventions that support the independence of the older individual. A second way sensor monitoring is used is as a feedback and coaching tool in rehabilitation to support the rehabilitation process and, in this way, to increase everyday functioning. In this thesis, we developed an intervention on the rehabilitation of community-living older individuals after hip fracture.

Hip fracture is a common injury among older persons. Fear of falling is an important factor that keeps persons from moving and performing everyday activities needed for good recovery. Increasing self-efficacy beliefs can reduce this fear of falling and can help increase physical daily activity needed to recover. We developed an intervention based on cognitive behavioral therapy, (CBT) in which sensor monitoring was integrated, to increase self-efficacy and by doing this support the recovery of everyday functioning. The thesis follows a phased process for developing and evaluating the intervention according to the new Medical Research Council (MRC) guideline for developing and evaluating complex interventions. The chapter concludes with an outline of the thesis.

Chapter 2 reports a prospective cohort study that investigated the level of agreement between patient-proxy ratings concerning the (Instrumental) Activities of Daily Living ((I)ADL of hospitalized older patients and investigated whether cognitive impairment or other factors are associated with any disagreements

in these ratings. At the time of hospital admission, the functional status of older people is frequently measured by healthcare professionals assess the patient's ability to perform (I)ADL). This assessment focuses on the patient's recent or premorbid functional status and is often obtained by asking the patient to provide a self-report of his or her (I)ADL functioning. This knowledge of functioning is important for short-term care planning and is predictive of the post-discharge functional status. One of the main problems during interviewing acutely hospitalized older people is that they may have pre-existing or acute cognitive impairments, which is expected to affect the accuracy and validity of the self-reported data. Therefore, proxy reports are often used to provide substitute data.

The study used data of the DEFENCE- I (Develop strategies Enabling Frail Elderly New Complications to Evade) study, conducted at the Academic Medical Center (AMC), Amsterdam. A total of 460 acutely admitted older patients (mean age= 78 years) and their proxies were included in the study and were interviewed using the modified Katz ADL index. The patients and proxies exhibited moderate to good levels of agreement in (I)ADL (70- 90%, $p< 0.001$). The differences in the patient-proxy reporting for the (I)ADL were greater ($p< 0.001$) for the patients with severe cognitive impairments than for the patients with mild to no cognitive impairment. A lower MMSE score (OR= 0.95; 95% CI 0.91 to 0.99) and the presence of delirium (OR=2.56; 95% CI 1.38 to 4.75) were associated with a greater level of disagreement between the patients' and proxies' ratings regarding (I)ADL.

The results suggested that for patients with mild cognitive impairment at the time of hospital admission, their self-report of (I)ADL is accurate and can be used for assessing (I)ADL functioning. For patients with a severe cognitive impairment (MMSE score of less than 15 points) or prevalent delirium, the nearest proxy may provide valid information about the patient's (I)ADL functioning.

Chapter 3 presents the results of a systematic review to study the application and effectiveness of sensor monitoring as a method to measure and support daily functioning in older people living independently at home. Studies that described the use of sensor monitoring to measure daily functioning or to support older people with daily functioning, studies that included community-dwelling individuals aged 65 years and over and studies that focused on daily functioning as a primary outcome measure were identified through Pubmed, Embase, PsychINFO, INSPEC and the Cochrane Library between 2000 and October 2012. Data were collected on type of sensor monitoring technology, number and types of sensors used, the aim of sensor monitoring and participant characteristics.

Seventeen studies were finally included. Because of the variety of non-randomized studies included in this systematic review, the Newcastle Ottawa scale was used for quality assessment of the included case-controlled studies, the pre-post design study and the mixed method study; three studies were considered low quality, and two studies were considered moderate quality. Half of the included studies used sensor monitoring solely as a method for measuring ADLs and IADLs and to detect changes in daily living. The focus of these studies was on the technological development of sensor monitoring. The other half of the studies aimed to support people in their daily living. There was limited evidence of the effect of the interventions because of a lack of high methodological quality.

The results of our study suggested that health care professionals could take advantage of sensor monitoring in their clinical practice to detect early periods of decline more quickly than compared with the use of traditional measures of functional status. This might enable them to provide early interventions to prevent decline, although clear evidence is still lacking. We proposed a roadmap for further development and improvement of sensor monitoring to measure and support daily functioning in independently living older people and to collect evidence about the use of sensor monitoring for clinical practice. The recommended steps of this roadmap are 1) determining the target population that can benefit from sensor monitoring, 2) investigating the use of sensor monitoring in community-dwelling older persons, 3) developing guidelines for health care professionals regarding the use of sensor monitoring, 4) involving participants, caregivers and health care professionals in the development and implementation of sensor monitoring, 5) conducting large-scale trials, and 6) studying the cost-effectiveness of sensor monitoring.

Chapter 4 describes a qualitative study on older people's perspectives regarding the use of sensor monitoring in their daily lives. The 11 participants were between 68 and 93 years old and were purposefully sampled from a pilot study (n=23) in which the sensor monitoring method was tested for one and a half years. Seven of them were living independently in the community, and four were living in a senior residence. Interpretative phenomenological analysis (IPA) was used as a guiding framework for the analysis because of the interest in older persons' experiences regarding the use of sensor monitoring in their daily lives as well as their meaning of these experiences.

This study showed that the interviewed older people were positive about sensor monitoring in their daily lives. The participants indicated that the technology helped them to live independently at home, especially because they were all living alone. They experienced the sensors as important in two ways: for detecting emergencies, such as a fall, and for detecting declines in daily functioning. They experienced that the sensor monitoring contributed 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. Some participants experienced the sensors as a motivator that helped them to remain active. Privacy was not an issue for the participants. The increased sense of safety outweighed the privacy issues, mainly because the sensor only registers movement in the home, rather than the participants' actions, as would be done with a camera. Participants considered that health care professionals' continuous access to their sensor data and the use of the data for their safety were far more important than their privacy.

The findings in this study show that sensor monitoring could enable older people, who are living alone in the community and experience some age- and health-related limitations, to maintain their daily functioning and safety at home.

Chapter 5 presents the study protocol of a trial investigating the effect of sensor monitoring embedded in an OT rehabilitation program on the recovery of ADL among older individuals after hip fracture. The design was a three-arm, stepped-wedge, cluster-randomized trial. We planned to randomize six nursing homes and to include a total of 288 older individuals, previously living alone in the community, who after a hip fracture were admitted to a geriatric rehabilitation ward for a short-term rehabilitation. Patients in the care-as-usual group received care as usual. Patients in the first intervention group received an OT rehabilitation program with coaching based on cognitive behavioral therapy principles. Patients in the second intervention group received sensor monitoring added to the OT rehabilitation program.

The intervention was delivered by occupational therapists starting at the beginning of the rehabilitation at the nursing home, with a follow-up after discharge consisting of four home visits and continuing with four telephone consultations. The sensor monitoring consisted of a wearable activity monitor, worn on the hip at the nursing home and after discharge at home, and the sensor monitoring system consisted of a number of sensors placed in the home and a web-based feedback application at home.

The primary outcome was patient-perceived performance of daily functioning at six months, assessed using the COPM. Secondary outcomes were 1) physical functioning, measured by the Tinetti Performance Oriented Mobility Assessment, Timed up and Go and the Independence in (Instrumental) Activities of Daily Living assessed using the Modified Katz ADL 2) sense of safety, measured with a visual-analog scale of safety; 3) fear of falling, measured with the visual-analog scale for fear of falling and the Falls Efficacy Scale International; and 4) health-related quality of life measured with the EQ 5D.

Effects were estimated with mixed linear models by using baseline values of all outcomes as covariables. Two-sided 95% confidence intervals were calculated. Alongside the trial, a descriptive qualitative and quantitative analysis was planned to be used on the data from the evaluation forms of the patients and the therapists and a process evaluation.

Chapter 6 reports the effects of the SO-HIP trial. From April 1, 2016 to December 1, 2017, we conducted the SO-HIP three-arm, stepped-wedge, cluster-randomized trial in six SNFs (12 wards) according to the planned study protocol described in chapter 5. Three pairs of SNFs were randomized to one of three fixed sequences. Each sequence started with providing care as usual (CAU) (the control condition) followed by cognitive behavioral therapy (CBT)-based occupational therapy (OTc) and ending with CBT-based occupational therapy with sensor monitoring (OTcsm). The primary outcome was patient-reported daily functioning at 6 months, assessed with the Canadian Occupational Performance Measure (COPM).

In total, 240 patients with a mean age of 84 years were enrolled in the study (77 CAU, 87 OTc and 76 OTcsm). 129 patients completed the 6-month follow-up. At baseline, the mean COPM performance scores (range 1-10) were 2.92 (SE 0.20) and 3.09 (SE 0.21) for the CAU and OTcsm groups, respectively. At six months, these values were 6.42 (SE 0.47) and 7.59 (SE 0.50), respectively. The mean patient-reported daily functioning in the OTcsm group was larger than in the CAU group (difference 1.17 [95% CI (0.47-1.87) *P*=0.001]. We found no significant differences in daily functioning between OT without sensor monitoring and CAU.

There were no significant differences in secondary outcomes, besides Katz ADL (difference -0.99 [95% CI -1.85—0.13] *P*= 0.024).

We concluded that among older patients after hip fracture, a rehabilitation intervention with coaching and sensor monitoring 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. Future research examining the long-term effect and cost-effectiveness of the intervention is recommended.

Chapter 7 describes the results of a qualitative study that we conducted alongside the SO-HIP trial to gain insight into what older adults after hip fracture perceive as most beneficial to their recovery, from inpatient rehabilitation to further recovery at home. Semi structured interviews were conducted with 19 older adults (65-94 years) who, after their hip fracture, participated in one of the three arms of the SO-HIP trial. We used coding techniques based on constructivist grounded theory.

This study showed that older adults struggled with physical and psychological restrictions after hip fracture during recovery. Three resources were found 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 in the same manner as before or differently from before; unsuccessful experiences led to ceasing certain activities altogether.

The results suggest 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 older adults' own roles in their recovery, thereby empowering them so that they are better able to cope with their restrictions.

A conceptual model was presented, which provided an understanding of the participants' experiences and perspectives concerning their process of recovery to everyday life in the six months after hip fracture surgery.

Chapter 8 presents the general discussion of the main findings of this thesis. The general discussion includes a reflection on a few issues that may have had impact on the effectiveness of the SO-HIP intervention.

A first issue we reflected on was the intervention fidelity, dose and context. One of the findings was that therapists experienced difficulties in applying the prescriptive dose of interventions at home. They were not used to implementing interventions at home for individuals after hip fracture. Findings from the perspectives of patients were that they appreciated the home visits because they felt insecure in their performance of daily activities even after a few weeks at home. We suggested more research is needed to determine the optimal intervention duration and intensity. Another finding was that therapists sometimes struggled with applying coaching techniques and the use of the sensors to patients with cognitive restrictions. We suggested more attention should be given to this in training.

A second issue we discussed was the theoretical concept of self-efficacy beliefs. A key element of the coaching was focusing on cognitive restructuring and the use of behavioral change techniques to address psychological, physical and functional factors related to concerns about falls and thereby to increase self-efficacy of patients. Some of the therapists expressed a lack of confidence in applying some of the behavioral change techniques and the motivational interviewing. We suggested extra training and guidance will be important for successful implementation of the intervention in the future.

A third issue we reflected on was the impact of the SO-HIP technology on the effectiveness of the intervention. We reflected on the choice of the wearable sensor, the measures of the type of sensor used and some technical restrictions that could have influenced the results.

The methodological considerations included the design, the study population, outcome measures and external validity. This chapter ends with some implications for clinical practice and education and suggestions for future research, as well as our final conclusions.

Samenvatting

Hoofdstuk 1 beschrijft de introductie van dit proefschrift. De komende jaren is er een toename van het aantal ouderen van 65 jaar en ouder. Ook de groep alleenwonende tachtigplussers zal toenemen. De meeste ouderen willen zo lang mogelijk thuis blijven wonen, iets dat aansluit bij het beleid van de Nederlandse overheid. Met het ouder worden van de bevolking zal een toenemend aantal ouderen te maken krijgen met achteruitgang in gezondheid en beperkingen ondervinden in het dagelijks functioneren. Velen van hen hebben meer dan één chronische aandoening, dat heeft een negatieve invloed op het dagelijks functioneren thuis, waardoor ouderen steeds meer afhankelijk worden van formele en informele zorg. Hierdoor komen de lasten en kosten van de gezondheidszorg onder druk te staan. Deze veranderingen vragen om het ontwikkelen van interventies die ouderen ondersteunen om zo lang mogelijk zelfstandig thuis te kunnen blijven functioneren en wonen. In dit proefschrift onderzoeken we of sensormonitoring gebruikt kan worden om het dagelijks functioneren van zelfstandig wonende ouderen te ondersteunen.

Met sensormonitoring kan met behulp van een draagbare sensor en met sensoren die in een woning geplaatst worden continu (24 uur per dag zeven dagen per week) informatie worden verzameld over het dagelijks functioneren in de thuissituatie. Deze informatie kunnen zorgprofessionals gebruiken bij het ondersteunen van het dagelijks functioneren van hun cliënt. De toepassing van deze technologie vindt echter nog sporadisch plaats. Het doel van deze PhD-studie is het onderzoeken van de toepasbaarheid en effectiviteit van sensormonitoring bij het inventariseren en ondersteunen van het dagelijks functioneren van zelfstandig wonende alleenstaande ouderen.

In ons onderzoek gebruiken we sensor monitoring op twee manieren. Als eerste wordt het ingezet als assessment van het dagelijks functioneren. Bij afwijkingen in de activiteitenpatronen van het dagelijks functioneren worden zorgprofessionals gewaarschuwd waardoor ze een interventie kunnen inzetten. Een tweede manier is de sensor monitoring te gebruiken als een feedback- en coachingshulpmiddel in de geriatrische revalidatie. Hierbij is het onderzoek gericht op de toepasbaarheid en effectiviteit van deze interventie, die onderdeel is van een transitie-revalidatieprogramma voor ouderen na een heupfractuur.

Een heupfractuur komt veel voor bij ouderen. Veel ouderen hebben daarbij last van valangst, die ouderen ervan weerhoudt te bewegen en hun fysieke dagelijkse activiteiten uit te voeren, terwijl dit juist belangrijk is voor een goed herstel. Het ervaren van valangst belemmert de geriatrische revalidatie in de thuissituatie. Het vergroten van de zelf-effectiviteit van ouderen kan valangst doen verminderen waardoor ouderen meer gaan bewegen en meer fysieke dagelijkse activiteiten uitvoeren.

We hebben een ergotherapeutische coachingsinterventie ontwikkeld, gebaseerd op cognitief gedragsmatige therapie en ondersteund door sensormonitoring, om de zelf-effectiviteit van ouderen te vergroten en daarmee hun dagelijks functioneren bij de geriatrische revalidatie te ondersteunen. In dit proefschrift volgen we in een gefaseerd proces de richtlijn volgens de 'Medical Research Council' (MRC-guidline) die gericht is op het ontwikkelen en evalueren van complexe interventies.

Hoofdstuk 2 beschrijft een cohortstudie waarin de overeenkomst in de scores betreffende de activiteiten van het dagelijks leven (ADL) en de instrumentele activiteiten van het dagelijks leven (IADL) tussen de patiënten en hun naasten is onderzocht. Ook is vastgesteld of cognitieve beperkingen en andere factoren geassocieerd zijn met overeenkomsten dan wel verschillen tussen deze scores.

Bij acute opname in het ziekenhuis wordt de functionele status van ouderen vaak gemeten door een vragenlijst af te nemen over het functioneren in ADL en IADL. Dit assessment richt zich op de informatie over het ADL- en IADL-functioneren en ook op de informatie over het functioneren in ADL en IADL voorafgaand aan de opname. Het onderzochte assessment is een zelf-rapportage door de patiënt over zijn of haar functioneren t.a.v. de ADL en IADL. Deze informatie is belangrijk voor het plannen van de zorg op de korte termijn en is ook voorspellend voor de functionele status na ontslag. Een van de problemen gedurende het interviewen van acuut opgenomen ouderen is de aanwezigheid van cognitieve problemen waarvan wordt verwacht dat deze invloed hebben op de accuraatheid en validiteit van de zelfgerapporteerde data over de ADL en IADL. Als er sprake is van cognitieve problemen worden vaak de naasten gevraagd om deze informatie te geven.

De studie is gebaseerd op data uit de DEFENCE-I-studie van het AMC Amsterdam Universitair medisch centrum. Totaal hebben 460 acuut opgenomen ouderen (gemiddelde leeftijd 78 jaar en ouder) en hun naasten meegedaan aan de studie en zij zijn geïnterviewd met behulp van de gemodificeerde Katz ADL. Patiënten en hun naasten hadden gemiddeld tot goede overeenstemming over de het functioneren van de patiënt in ADL en IADL (70- 90%, $p < 0.001$). De verschillen waren groter ($p < 0.001$) bij patiënten met ernstige cognitieve beperkingen dan bij patiënten met milde tot geen cognitieve beperkingen. Een lagere MMSE-score (OR= 0.95; 95% CI 0.91 to 0.99) en de aanwezigheid van een delier (OR=2.56; 95% CI 1.38 to 4.75) waren geassocieerd met minder overeenkomst tussen patiënten en hun naasten op het gebied van ADL en (IADL.

De aanbeveling is om bij patiënten met een milde cognitieve beperking gedurende acute opname in het ziekenhuis een zelfrapportage over ADL en IADL af te nemen. Bij patiënten met een ernstige cognitieve beperking (MMSE-score <15) of een delier kan de naaste valide informatie geven over de IADL van de patiënt.

Hoofdstuk 3 beschrijft de resultaten van een systematische literatuurstudie over de toepassing en effectiviteit van sensor monitoring voor het meten en ondersteunen van het dagelijks functioneren van zelfstandig alleenwonende ouderen. De volgende typen studies werden betrokken in de review: studies die het gebruik van sensor monitoring bij ouderen beschrijven voor het meten van het dagelijks functioneren, en studies die sensor monitoring beschrijven voor het ondersteunen van het dagelijks functioneren. De inclusiecriteria waren studies waarin zelfstandig alleenwonende ouderen van 65 jaar en ouder waren betrokken en studies die zich richten op het dagelijks functioneren als uitkomstmaat. Studies werden gezocht in de databases Pubmed, Embase, psychinfo, Inspec en de Cochrane Libary tussen 2000 en oktober 2012. De data werden verzameld op basis van 1) type van sensor monitoring, 2) het aantal en type sensoren, 3) het doel van de sensor monitoring en 4) patiënt-karakteristieken.

In de review zijn zeventien studies geïncludeerd. Vanwege de variëteit van niet-gerandomiseerde studies werd De Newcastle-Ottawa schaal gebruikt als kwaliteitsinstrument om de geïncludeerde case-control studies, de pre-post-designstudie en de mixed-method studie te beoordelen. Van deze vijf studies waren drie studies van lage kwaliteit en twee studies van gemiddelde kwaliteit. In de helft van de studies werd sensor monitoring alleen voor het meten van het dagelijks functioneren en voor het detecteren van veranderingen in het dagelijks functioneren gebruikt. De focus in deze helft van de gevonden studies lag op de technische ontwikkeling van sensor monitoring. In de andere helft van de studies werd sensor monitoring gebruikt om ouderen te ondersteunen bij het dagelijks functioneren. Er was beperkt bewijs voor het effect van de interventies omdat er weinig studies waren van hoge kwaliteit. De resultaten laten zien dat zorgprofessionals, door gebruik te maken van sensor monitoring, achteruitgang in dagelijks functioneren van ouderen eerder kunnen herkennen in vergelijking tot het gebruik van traditionele methoden. Hiermee kunnen zij sneller interventies inzetten die achteruitgang in het dagelijks functioneren mogelijk kan tegengaan. Hier is echter nog geen bewijs voor gevonden.

Op grond van de resultaten hebben we een 'roadmap' opgesteld voor de verdere ontwikkeling, verbetering en evaluatie van sensormonitoring die gebruikt wordt voor het meten en ondersteunen van het dagelijks functioneren van zelfstandig wonende ouderen. De stappen zijn: 1) bepalen van de doelgroep ouderen die profijt kan hebben van sensor monitoring, 2) onderzoeken van het gebruik van sensor monitoring bij zelfstandig wonende ouderen, 3) het ontwikkelen van richtlijnen voor zorgprofessionals over het gebruik van sensor monitoring in hun praktijk, 4) het betrekken van de doelgroep, informele zorgverleners en zorgprofessionals in de ontwikkeling en implementatie van sensormonitoring, 5) het uitvoeren van grootschalige trials en 6) onderzoeken van de kosten effectiviteit van het gebruik van sensor monitoring.

Hoofdstuk 4 beschrijft een kwalitatieve studie over de perspectieven van ouderen betreffende het gebruik van sensor monitoring in hun dagelijks leven thuis. Uit een pilotstudie van 23 ouderen die sensor monitoring gedurende anderhalf jaar hebben uitgeprobeerd werden 11 deelnemers gevraagd mee te doen aan deze studie. Vier deelnemers waren woonachtig in een seniorenwoning en 11 woonden zelfstandig in een huis in de wijk. Interpretatieve fenomenologische analyse (IPA) werd gebruikt als methode voor analyse van de ervaringen van ouderen over het gebruik van sensor monitoring in hun dagelijks leven en de betekenis die ze gaven aan deze ervaringen.

De deelnemers waren positief over het gebruik van sensor monitoring in de thuissituatie. Ze ervaarden de technologie als steun om zelfstandig thuis te blijven wonen vooral omdat ze alleenwonend waren. Ze vonden het gebruik van de sensoren belangrijk voor twee zaken: voor het detecteren van een ongeluk, zoals een val, en voor het detecteren van achteruitgang in hun dagelijks functioneren. Ze ervaarden de technologie als ondersteuning voor hun gevoel van veiligheid en dit was voor hen een belangrijke voorwaarde om zelfstandig thuis te kunnen blijven wonen. Dit gevoel van veiligheid droeg bij aan het accepteren van een sensor monitoringssysteem in de woning. Sommige deelnemers ervaarden de sensoren ook als motiverend om actief te blijven. Privacy was geen issue voor de deelnemers. Het toegenomen gevoel van veiligheid woog op tegen de privacy, vooral ook omdat de sensoren alleen beweging in huis registreren en geen beelden van hun activiteiten laten zien zoals bij het gebruik van een camera. Ze waardeerden dat zorgprofessionals continu toegang tot hun data hadden en dit gevoel van veiligheid vonden ze veel belangrijker dan de inbreuk op hun privacy.

De resultaten van deze studie laten zien dat sensor monitoring bij ouderen, die alleen wonen en die door leeftijd gezondheidsbeperkingen ervaren, kan ondersteunen bij het dagelijks functioneren en het vergroten van het gevoel van veiligheid thuis.

Hoofdstuk 5 presenteert het studieprotocol voor de geplande trial waarbij het effect wordt onderzocht van sensor monitoring als onderdeel van een ergotherapie-revalidatieprogramma gericht op herstel van het dagelijks functioneren bij ouderen die revalideren na een heupfractuur. Het design was een drie-arm stepwedge, cluster gerandomiseerde studie. De opzet was om zes verpleeghuizen te randomiseren, waarbij 288 alleenwonende ouderen die na een heupfractuur verbleven op een geriatrische revalidatieafdeling van een verpleeghuis konden deelnemen aan deze studie. Deelnemers in de controlegroep kregen de gebruikelijke revalidatiezorg aangeboden. Deelnemers in de eerste interventiegroep kregen een revalidatieprogramma met ergotherapie-coaching gebaseerd op elementen van cognitief gedragstherapie. Deelnemers in de tweede interventiegroep kregen daarbij ook nog sensormonitoring toegevoegd.

De interventie werd gegeven door ergotherapeuten, eerst in het verpleeghuis en aansluitend na ontslag een vervolgrevalidatieprogramma in de thuissituatie. De revalidatie thuis bestond uit vier huisbezoeken gevolgd door vier telefonische consulten door de ergotherapeut. De sensormonitoring bestond uit twee typen sensoren. Als eerste een draagbare sensor gedragen op de heup gedurende het verblijf in het verpleeghuis en na ontslag thuis. Als tweede werd er een sensormonitoringssysteem thuis geïnstalleerd. Dit sensormonitoringssysteem bestond uit een aantal sensoren die op verschillende plekken in de woning werden geplaatst en een datavisualisatie feedback-applicatie.

De primaire uitkomstmaat waar het effect op werd getoetst was de ervaren uitvoering van dagelijkse activiteiten bij zes maanden na start revalidatie, gemeten met de Canadian Occupational Performance Measure (COPM). Andere uitkomstmaten waren: 1) het fysiek functioneren, gemeten met de Tinetti Performance Oriented Mobility assessment, de Timed up en Go en de onafhankelijkheid in de Instrumentele en dagelijkse activiteiten, gemeten met de gemodificeerde KATZ-ADL score; 2) het gevoel van veiligheid, gemeten met een visuele analoge schaal (VAS); 3) valangst gemeten met een VAS voor valangst en de Falls Efficacy Scale International; en 4) gezondheid gerelateerde kwaliteit van leven, gemeten met de Euroquol EQ5D. Het effect van de interventies werd geanalyseerd met mixed lineair models waarbij de baseline-metingen als covariabelen werden genomen. Tweezijdige 95% confidencentervallen werden berekend. Naast de trial werd een procesevaluatie gepland.

Hoofdstuk 6 beschrijft de resultaten van de SO-HIP-effectstudie. De SO-HIP-studie vond plaats in de periode van 1 april 2016 tot 1 december 2017. Zes verpleeghuizen (totaal 12 afdelingen) hebben volgens de geplande studieopzet zoals beschreven in hoofdstuk 5 meegedaan. Paren van twee verpleeghuizen werden gerandomiseerd in drie clusters. Elk cluster voerde de interventies uit in volgorde van gebruikelijke revalidatiezorg en achtereenvolgens de twee interventies. In totaal hebben 240 deelnemers met een gemiddelde leeftijd van 84 jaar meegedaan aan de studie. 129 deelnemers hebben de zes maanden helemaal afgerond.

Bij de start van de studie was de gemiddelde COPM-uitvoerings-score (range 1-10) 2.92 (SE 0.20) voor de groep gebruikelijke revalidatiezorg en 3.09 (SE0.50) voor de groep ergotherapie met coaching en sensormonitoring. Bij zes maanden was dit 6.42 (SE 0.47) voor de gebruikelijke revalidatiezorg en 7.59 (SE 0.50) voor de groep ergotherapie met coaching en sensormonitoring. Het gemiddelde verschil in zelf gerapporteerde dagelijks functioneren in de groep ergotherapie met coaching en sensormonitoring was groter dan in de groep gebruikelijke revalidatiezorg (verschil 1.17 [95% CI (0.47-1.87) *P*=0.001]. We hebben geen significante verschillen gevonden in dagelijks functioneren tussen de groep ergotherapie met coaching zonder sensor monitoring en de groep gebruikelijke revalidatiezorg. Ook waren er geen significante verschillen in andere uitkomstmaten, behalve voor Katz ADL (verschil -0.99 [95% CI -1.85—0.13] *P*= 0.024).

De conclusie is dat bij de revalidatie van ouderen na een heupfractuur, een revalidatieprogramma ergotherapie met coaching en sensormonitoring meer effectief is in het verbeteren van zelf gerapporteerde uitvoering in dagelijks functioneren bij zes maanden dan een interventie ergotherapie met coaching zonder sensormonitoring en gebruikelijke revalidatiezorg. Aanbevelingen zijn om in de toekomst het lange termijneffect en de kosteneffectiviteit van deze interventie te onderzoeken.

Hoofdstuk 7 beschrijft de resultaten van een kwalitatieve studie die we naast de SO-HIP-trial hebben uitgevoerd. Het doel was om inzicht te krijgen in wat ouderen na een heupfractuur het meest belangrijk vonden en wat bijdroeg aan hun herstel bij de revalidatie in het verpleeghuis en bij het vervolg van het revalidatietraject thuis. Met 19 ouderen (65-94 jaar) die in één van de drie groepen van de SO-HIP-studie participeerden, werden semigestructureerde interviews gehouden. Bij het analyseren van de interviews hebben we gebruik gemaakt van codetechnieken gebaseerd op *constructivist grounded theory*.

Deze studie heeft laten zien dat ouderen gedurende hun herstel moeite hadden met de lichamelijke en psychologische beperkingen die zij ondervonden als gevolg van de heupfractuur. Drie typen van hulpbronnen vonden ze belangrijk bij hun herstel: 'ondersteuning en coaching', 'ikzelf' en 'technologische ondersteuning'. Deze drie hulpbronnen hadden invloed op het herstelproces. Wanneer deelnemers succesvolle ervaringen opdeden konden ze dezelfde activiteiten als van voor de heupfractuur weer oppakken, net zoals vroeger of op een aangepaste manier. Wanneer ze geen succesvolle ervaringen hadden stopten sommige ouderen met het uitvoeren van deze activiteiten.

De resultaten geven aan dat er na ontslag uit de geriatrische revalidatie meer aandacht moet zijn voor vervolg interventies in de thuissituatie om ouderen te ondersteunen bij het hervinden van nieuwe routines bij hun dagelijkse activiteiten. Hierbij gaat het om activiteiten die betekenisvol zijn voor de persoon en die indien nodig worden aangepast aan de persoon. Interventies die gebruik maken van de combinatie van ergotherapie met coaching en technologieondersteuning zijn het meest effectief bij ouderen bij het herstel van hun eigen rol en verantwoordelijkheid. Een conceptueel model werd ontwikkeld dat inzicht geeft in de ervaringen en perspectieven van ouderen over het proces van herstel in de eerste zes maanden na een heupfractuur.

In **Hoofdstuk 8** worden de belangrijkste resultaten van dit PhD-onderzoek besproken en dit hoofdstuk gaat in op een aantal topics die impact kunnen hebben gehad op de effectiviteit van de SO-HIP-interventie. Een eerste topic was de invloed van de intensiteit en de duur van de periode van oefenen en daarnaast de context waarin de interventie werd gegeven. Sommige ergotherapeuten gaven aan dat ze niet het volledig aantal voorgeschreven interventies nodig hadden. Dit kan komen omdat ze niet gewend waren om een vervolgbehandeling bij deze groep in de thuissituatie aan te bieden. Resultaten vanuit het perspectief van de ouderen liet juist zien dat zij de interventies thuis belangrijk vonden omdat ze zich vaak onzeker voelden bij het weer uitvoeren van dagelijkse activiteiten thuis. Verder onderzoek is nodig om te bepalen hoeveel huisbezoeken nodig zijn en wat de intensiteit van het oefenen moet zijn. Een tweede topic is het theoretische concept van 'zelf-effectiviteit'. Een element van de coaching was gericht op het herstructureren van gedachten en het gebruik maken van gedragsmatige verandertechnieken om te leren omgaan met factoren die te maken hebben met valangst. Op basis van de literatuur zou dit de 'zelf-effectiviteit' van deelnemers vergroten. Sommige therapeuten gaven aan dat ze zich nog te weinig competent voelden met het toepassen van deze coachingstechnieken en de motiverende gespreksvoering. Extra training en begeleiding is daarom belangrijk bij het succesvol implementeren van deze interventie in de toekomst. Een derde topic was de impact van de technologie op de mate van effectiviteit van de interventie. We bediscussieerden de keuze voor de draagbare sensor, de metingen die de verschillende sensoren opleverden en de technische beperkingen die soms optraden.

Het hoofdstuk sluit af met implicaties voor de praktijk en het onderwijs, enkele suggesties voor vervolgonderzoek worden gegeven en het hoofdstuk wordt afgesloten met een aantal conclusies.

PhD Portfolio

Name PhD student: Margriet Christine Pol
PhD period: Jan 2014- Dec 2018
Name PhD Supervisors: Prof. dr. Bianca Buurman and Prof. dr. ir. Ben Kröse
Name Co-supervisor: dr. Margo van Hartingsveldt

PhD training	Year	Workload ECTS
General courses		
Basic course Qualitative Health Research. Graduate School for medical Sciences, UvA, Amsterdam	2009	1.90
Module Qualitative research, European Master of Science in Occupational Therapy, www.ot- euro-master.nl	2012	12
Basic course Practical Biostatistic. Graduate School for medical Sciences, UvA, Amsterdam	2012	1.2
Clinical Data Management. Graduate School for medical Sciences, UvA, Amsterdam.	2013	0.32
Atlas.TI Evers Research and Training Rotterdam	2013	
Oral presentation in English. Graduate School for medical Sciences, UvA, Amsterdam	2013	0.90
Scientific Writing in English for publication. Graduate School for medical Sciences, UvA, Amsterdam	2014	1.50
Clinical Epidemiology. Graduate School for medical Sciences, UvA, Amsterdam	2014	0.60
Advanced topics in Biostatistics. Graduate School for medical Sciences, UvA, Amsterdam	2014	2.10
e-BROK. Graduate School for medical Sciences, UvA, Amsterdam (December 2018)	2018	1.00
Presentations		
Het verschil in perceptie van patiënt en mantelzorger over het functioneren van ouderen in ADL en IADL-activiteiten na acute opname in het ziekenhuis. Oral-presentation Jaarcongres Ergotherapie Nederland, Nov 24, 2010, Utrecht	2010	0.50

Sensor monitoring: A new method for observing ADL by independent living older persons? Oral-presentation Symposium Impaired mobility. April 24, 2012 Academic Medical Center Amsterdam	2012	0.50
Verschil in perceptie van de oudere en diens mantelzorger over zijn functioneren in ADL en IADL activiteiten. Oral-presentation Symposium Ergotherapie in de ouderenzorg April 26, 2012, Utrecht	2012	0.50
Activities of daily living and sensor activity monitoring of older people living independently; research and education. Poster-presentation 9th COTEC Congress of Occupational Therapy, May 24-27, 2012 in Stockholm, Sweden.	2012	0.50
Sensor monitoring to measure and support activities of daily living for independently living older people: A systematic review and roadmap for further development. Oral presentation Febr 6,2013 Geriatriedagen, Den Bosch	2013	0.50
Sensor monitoring to measure and support activities of daily living for independently living older people: a systematic review and roadmap for further development, Poster presentation 9th International Congress of the European Union Geriatric Medicine Society. September 2013 Venice - Italy	2013	0.50
Older People's Perspectives Regarding the Use of Sensor Monitoring in Their Home. Poster-presentation. European Union Geriatric Medicine Society September 2014 Rotterdam	2014	0.50
Older people's perspectives regarding the use of sensor monitoring in their home. Oral-presentation Minisymposium European Masters in Occupational Therapy HvA. Amsterdam, 20 April 2015	2015	0.50
Older people's perspectives regarding the use of sensor monitoring in their home. Oral-presentation 1e COTEC-ENOTHE Congress June 2016 Galway	2016	0.50
Effectiveness of sensor monitoring in an occupational therapy rehabilitation program for older persons after hip fracture, the SO-HIP trial: study protocol of a three- arm stepped wedge cluster randomized trial. Poster-presentation 1e COTEC-ENOTHE Congress June 2016 Galway	2016	0.50
Monitoren in de thuissituatie na een heupfractuur, ervaringen met de SO-HIP studie. Oral-presentation Congres Valpreventie Nijmegen Oktober 2016	2016	0.50

Sensor monitoring in an occupational program for older persons after hip fracture, the SO-HIP study. Oral-presentation Masters in Occupational Therapy Metropolitan University January 2017 Tokyo	2017	0.50
Sensormonitoring in an occupational program for older persons after hip fracture, the SO-HIP study Poster-presentation Jaarcongres Ergotherapie Nederland maart 2017	2017	0.50
The development of an activity application for mood self-management, the I-ACT' Oral-presentation Amsterdam Science and Innovation Award 2017 IXA June 2017	2017	0.50
De SOHIPstudie HvA Oral-presentation HvA Research Award 2017 Amsterdam December 2017	2017	0.50
Pol M. Older people's perspectives regarding the use of sensor monitoring in their home. Oral-presentation Minisymposium European Masters in Occupational Therapy HvA. Amsterdam, December 2017	2017	0.50
Hipper, Oral-presentation nominatie Zorginnovatie Noord Holland 23 januari Amsterdam	2018	0.50
Sensoren bij de revalidatie na een heupfractuur. Symposium op Geriatrie dagen. Oral-presentation 9 februari 2018 Den Bosch	2018	0.50
Effect of sensor monitoring in an occupational therapy program for older patients after hip fracture Oral-presentation WFOT congress Cape Town 24 mei 2018	2018	0.50

International conferences		
COTEC (Council of occupational Therapists for European Countries) conference Stockholm	2012	0.50
European Union Geriatric Medicine Society conference Venice	2013	0.50
COTEC-Enothe congress conference Galway	2016	0.50
Metropolitan University Tokyo conference Masters occupational Therapy Tokyo	2017	0.50
WFOT(World Federation Occupational Therapy) conference Cape Town	2018	0.50

Lecturing		
Minor degree program Health care technology. Amsterdam University of Applied Sciences	2014-present	1
Graduate Program bachelor Occupational Therapy. Amsterdam University of Applied Sciences	2014-present	1

Mentoring		
Internship SO-HIP study bachelor students Occupational Therapy K. Rous, L. Eichelberg, S. Rous	2016	1
Internship SO-HIP study bachelor students Occupational Therapy R. Stender and R. Overmeer	2017	1
Internship SO-HIP master student Information studies M. Bebnik	2017	1
Internship SO-HIP bachelor student Science Business and Innovation J. Graafland	2017	1
Internship SO-HIP study bachelor student Information Technology Y. Amarti	2017	1
Internship SO-HIP study bachelor student Health Care sciences D. Stekelenburg	2017	1
Internship SO-HIP study master student Psychology J. Tholel	2017-2018	1

Media	
Sensormonitoring. film Urban Vitality https://www.youtube.com/watch?v=NTNv-8H3HCY	2015
So-HIP studie; elearning opleiding Health Informatics Amsterdam UMC https://www.youtube.com/watch?v=PiCe7mkg0TE	July 2017
SOHIP promotiefilm. Research Award https://www.youtube.com/watch?list=PLqQz5Oy8HYpPVjrZbYOYD9pL2sTkJW0tW&time_continue=2&v=jR1h3-kr_As	Dec 2017
Website; www.sohipstudie.nl	2016

Grants	
Stichting de Blarickhof	2013 - 2014
Nuts Ohra- SO-HIP studie	2014 - 2016
SIA Raak Publiek - Hipper project	2014 - 2016

NWO-promotiebeurs jan	2014 - dec 2018
IXA APCA Hipper	2017 - 2018
SIA TOP-UP Hipper2Implementation	2017 - 2018
Awards	
HvA Research Award 2017 SO-HIP studie	2017
Nomination Amsterdam Science and Innovation Award 2017 IXA 'The development of an activity application for mood self-management, the I-ACT'	2017
Nominatie zorginnovatieprijs 2018 Noord-Holland Hipper sensoren en revalidatie	2018

Publications

Pol MC, Ter Riet G, van Hartingsveldt M, Kröse B, Buurman BM. Effectiveness of Sensor Monitoring in a Rehabilitation Program for Older Patients after Hip Fracture: the SO-HIP three-arm stepped wedge randomized trial. (Submitted)

Pol MC, Peek S, Nes F, van Hartingsveldt M, Buurman BM, Kröse B. Everyday Life After a Hip Fracture: What Community-Living Older Adults Perceive as Most Beneficial for Their Recovery. (Submitted)

Pol MC, Ter Riet G, van Hartingsveldt M, Kröse B, de Rooij SE, Buurman BM. Effectiveness of Sensor Monitoring in an Occupational Therapy Rehabilitation Program for Older Individuals after Hip Fracture, the SO-HIP trial: study protocol of a three-arm stepped wedge cluster randomized trial. *BMC Health Serv Res*. 2017 Jan 3; doi: 10.1186/s12913-016-1934-0.

Robben S, **Pol MC**, Buurman BM, Kröse B. Expert Knowledge for Modeling Functional Health from Sensor Data. *Methods Inf Med*. 2016 Dec 7;55(6):516-524. Epub 2016 Jun 20 DOI:10.3414/ME15-01-0072.

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About the author

Margriet Pol was born on January 26 1961 in Wageningen, the Netherlands. After graduating secondary school at the Dr Nassau College in Assen, she started her bachelor study on occupational therapy at the School of Occupational Therapy at the Faculty of Health, Amsterdam University of Applied Sciences (Hogeschool van Amsterdam, HVA) in the Netherlands. After graduating as an occupational therapist in 1984, Margriet worked as an occupational therapist in different health care centers in Amsterdam, Amstelveen and Laren in the Netherlands. She followed her master on Social Gerontology at the VU University Amsterdam of which she graduated in 2005.

In 2006, she started work as a lecturer at the School of Occupational Therapy, Amsterdam University of Applied Sciences. Since 2010 she has also become a member of the research group Occupational Therapy of ACHIEVE, Centre of Applied Research, Faculty of Health, Amsterdam University of Applied Sciences.

Margriet is lecturer and coordinator of the graduate program occupational therapy and also of the minor degree program in health care technology. Her expertise is in the area of geriatric rehabilitation, self-care, housing, environment, cognitive functioning, primary health care and health care-technology. She is especially interested in the numerous opportunities for the ageing population to stay active and participate in society.

At the end of 2013, she started her PhD-project on sensor monitoring to support everyday functioning of older adults living independently at home, for which she received a NWO-grant (Netherlands Organization for Scientific Research). The following years, she combined her PhD research with giving lectures and participating in other research projects and committees. Since 2017, she has become member of the committee of health care technology Ergotherapie Nederland (Dutch Association of Occupational Therapy).

In 2017, Margriet received the research award 'HvA research of the year' from the Amsterdam University of Applied Sciences for the 'SO-HIP study'. She is co-founder of 'Hipperacademy', a start-up which took place at the end of 2017. Next to this she started follow-up research projects on the implementation of health care technology in geriatric rehabilitation.

Margriet lives with her partner Geert Jan and together they are parents of Lars and Rosanne.

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