Sensor monitoring to measure and support activities of daily living for independently living older persons
Pol, M.C.

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General introduction
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).\textsuperscript{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.\textsuperscript{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.\textsuperscript{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).\textsuperscript{1} Multiple chronic conditions are presumed to have greater health needs and a high healthcare utilization.\textsuperscript{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.\textsuperscript{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.\textsuperscript{20} Many factors, such as age, pre-fracture functionality, comorbidity and fear of falling, influence functional outcome of after a hip fracture.\textsuperscript{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.\textsuperscript{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.\textsuperscript{25-27} Consequences of fear of falling are decreased functional performance, loss of independence, lower participation and lower quality of life.\textsuperscript{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).\textsuperscript{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.\textsuperscript{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.\textsuperscript{29}

In this proposed alternative ICF scheme, the environmental factors encompass functional and personal factors.\textsuperscript{29} Functioning is the central component in this scheme and can be conceptualized from different perspectives: activities,
participation and body functions/structures.\textsuperscript{29} To indicate the importance of participation, participation is positioned in the middle of the scheme.\textsuperscript{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.\textsuperscript{29} Comorbidities are added to the personal factors. The scheme as a whole, 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 et al.\textsuperscript{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.\textsuperscript{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

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\textsuperscript{29}Huber, et al.

\textsuperscript{7}Id.

\textsuperscript{30-33}Id.
Modified Katz ADL index\(^3^{4}\) 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.\(^3^{5}\) 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.\(^3^{6-41}\)

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.\(^4^{1}\) 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.\(^4^{2-45}\) 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.\(^1^{0,46,47}\) 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.\(^4^{1}\) 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.\(^4^{8}\)
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. 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. 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.

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. 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). It is not possible to measure other IADL, such as handling money, shopping and traveling. 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.

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. 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.

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. Self-efficacy beliefs determine how people feel, think, motivate themselves and behave. Bandura states that anyone, regardless of their past or current environment, has the ability to exercise and strengthen their self-efficacy.

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”.

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

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. 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). 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. 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. 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. In this phase, we tested and evaluated our intervention, the SO-HIP trial. The fourth stage is the phase of implementation. This phase we will be working on after finishing this PhD-study.

![Figure 4. Key elements of the development and evaluation process](image-url)
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 and 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.
Chapter 1  |  General introduction

References

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