General introduction

The title of this thesis contains the three key elements: **measuring**, **physical behavior**, and **stroke**. This chapter introduces these elements in the reversed order, leading to the aims and the outline of this thesis.

STROKE

Neurological dysfunction caused by an infarction or a bleeding of the brain circulation is called a stroke. In the Netherlands, about 39,000 people suffer from a stroke each year and about 9,200 people die each year as the result of a stroke [1]. After surviving the acute phase of a stroke, more than half of these people are more or less dependent on others for daily-life functioning [2, 3], making stroke the leading cause of adult disability [4]. From the perspective of the International Classification of Functioning, Disability and Health (ICF) (Figure 1.1) [5], a stroke can disturb several *Body Functions and Structures* such as psychological, emotional, social, sensor, and motor. Disturbed motor body functions can range from minor coordination deficits to complete paralysis. These disturbed motor functions lead to constraints in the *Activities* domain, which is divided into *Capacity* and *Performance,* and can, for example, be defined as the use of an assistive device, the ability to self-care, or a person's physical behavior. In turn, disorders in the *Activities* domain might affect the *Body Functions and Structures* domain, and have an effect on the *Participation* domain. Since, until now, there is no cure for a stroke, stroke rehabilitation aims to improve the domains *Body Functions and Structures*, *Activities*, and *Participation* while coping with the remaining disabilities [6].

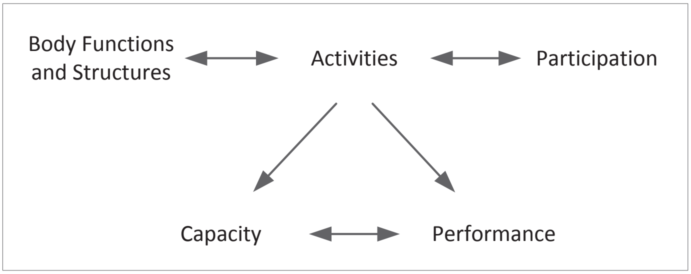

Figure 1.1 Three domains and two qualifiers of the ICF model.

PHYSICAL BEHAVIOR

In this thesis, the *Performance* qualifier of the *Activities* domain is defined as a person's physical behavior. This is what a person actually performs, not his/her capacity to do this. Physical behavior is an umbrella term for all behaviors of a person related to body postures, movements, and physical activities in daily life [7]. Components of physical behavior include, for example, physical activity, body postures & movements, transitions between body postures & movements, quality of movements, sedentary behavior, and arm use. In this thesis, three components of physical behavior are studied: i) sedentary behavior, ii) body postures & movements, and iii) arm use.

Sedentary behavior

Sedentary behavior is defined as *'any waking behavior characterized by an energy expenditure ≤1.5 metabolic equivalents (METs) while in a sitting, reclining, or lying posture'* [8] and is negatively related to morbidity and mortality, irrespective of physical activity [9, 10]. Both sedentary behavior and moderate-vigorous physical activity can be accumulated in large amounts in the course of one day. Thus, besides being sufficiently physically active, reducing sedentary behavior should be a goal to attain a healthy lifestyle. In both preventing and recovering from a stroke, sedentary behavior plays an important role. First, sedentary behavior is a risk factor for the occurrence and recurrence of a stroke [11]. Second, sedentary behavior has a deconditioning effect on the locomotion system and hinders motor function recovery [12]. Therefore, after a stroke, it is even more important for people to reduce sedentary behavior than for the general population.

Body postures & movements

Body postures & movements are literally the postures and movements a person performs, like sitting, standing, walking, etc. After surviving a stroke, it can be a considerable challenge to perform more active body postures & movements (such as standing and walking) due to disturbed motor functions [13]. From the perspective of motor recovery, it is important to study body postures & movements, rather than the levels of physical activity. This is because, from the perspective of energy expenditure, sitting and standing are almost similar [14-16], whereas they are not similar from the perspective of motor recovery [12]. Therefore, it is more relevant to avoid too much time lying or sitting and promote upright activities (e.g. standing, walking) to stimulate motor recovery, than to reach a certain level of energy expenditure. Thus, body postures & movements are an important aspect of stroke rehabilitation. Moreover, information on body postures & movements is needed to measure sedentary behavior according to its two-component definition. The information on body postures & movements is also useful when measuring arm use, to distinguish arm movements during walking from those during sitting or standing.

Arm use

The arms are important in the performance of many daily-life activities. However, after a stroke, these activities can be difficult to perform due to a paretic arm. About 75% of stroke survivors initially have problems using their paretic arm in daily life and about 65% of them still have this problem after six months [17, 18]. Limited arm function may cause problems in using the arm to perform daily-life activities and, as a consequence, in participating in social activities and at work; therefore, it is also associated with a poorer quality of life [19]. A limited arm function is not the only cause of these problems. A discrepancy between capacity and performance, *what a person can do (arm function)* versus *what he/she actually does (arm use),* can play a role as well. This discrepancy (also known as 'non-use') is a major issue after a stroke [20]. Therefore, it is important to integrate both *arm function* and *arm use* as outcome measures in stroke rehabilitation.

MEASURING PHYSICAL BEHAVIOR

Physical behavior can be measured using several methods. Simple, inexpensive and widely applicable methods include self-reports, proxy-reports, and questionnaires. However, important disadvantages of these methods are recall bias, social desirability, and subjectivity [21, 22]. Especially for people after stroke, using reports and questionnaires can be difficult due to cognitive and/or communicative impairments. In order to gain valid data on the physical behavior of people after stroke, ambulatory measurements are needed. This means continuously measuring a free moving person in his/her own environment in everyday life, i.e. ambulatory monitoring [23]. A preferred technique for this is accelerometry because it is relatively inexpensive, easy-to-use, and widely applicable. Accelerometry measures accelerations, which are the result of gravity and movements of the human body. Data on these accelerations can provide detailed information about different components of physical behavior [24]. Based on accelerations, movement counts can be calculated to determine a person's energy expenditure and arm movement intensity, which can be translated into arm use. In addition, accelerations can be used to determine the performed body postures & movements by determining the orientation of the sensor relative to gravity.

Until recently, accelerometer-based activity monitors were often multi-sensor systems which involved low levels of wearing comfort and required complex data processing software. Due to various technological developments, nowadays, the devices are smaller, wireless and generally one-sensor systems, with user-friendly software. Despite the enormous supply of new devices, not all of them are clinically applicable, mainly due to the lack of validation. Worldwide, people after stroke represent a large group with a high economic burden; therefore, it is important to be able to measure their physical behavior in a valid way. A population-specific validation study is needed, because movement patterns can change after a stroke [25]. Although the Activ8 Physical Activity Monitor (the Activ8) [26] is a promising device to measure body postures & movements and their intensities in stroke rehabilitation, it has not yet been validated for use in people after stroke. This activity monitor can also be the basis of an arm use monitor. However, before this arm use monitor can be used in stroke rehabilitation, it needs to be further developed and validated.

To measure physical behavior, the component of interest has to be translated into a measurable variable, this is called 'operationalization'. Even when the outcome measure has been operationalized, different ways of calculating the measure might still exist. In literature, many different types of operationalization and ways of calculation have been used for the components of physical behavior. This makes it difficult to compare studies and hinders progress in developing knowledge on physical behavior and health. For example, sedentary behavior is often operationalized as 'the amount of time someone sits' [27, 28], or 'the amount of time with low energy expenditure' [29, 30]. Although both are operationalizations of sedentary behavior, two different things are measured. The effect of those different operationalizations of sedentary behavior on the outcomes describing sedentary behavior has not yet been examined.

In the end, the aim is to measure physical behavior in stroke rehabilitation. Measuring energy expenditure and body postures & movements can provide information about a person's sedentary behavior and motor recovery during stroke rehabilitation. Moreover, measuring arm use together with the arm function can provide important information about non-use. Nevertheless, since it remains unclear how arm use recovers and how it is related to arm function, measuring these two aspects can contribute to knowledge elucidating the issue of non-use. Also, the information on other components of physical behavior can expand our knowledge on recovery after a stroke. All that information can also be used in clinical practice to personalize stroke rehabilitation, e.g. to provide a person with feedback about his/her arm use and to stimulate him/her to increase this arm use by using his/her arm capacity to its full ability.

OBJECTIVES AND OUTLINE OF THIS THESIS

As described above, measuring physical behavior involves important methodological aspects to be considered before using ambulatory monitoring to measure physical behavior in daily life. The primary aim of this thesis was to investigate two methodological aspects from the perspective of stroke rehabilitation. Another aim was to describe daily-life arm use in people in the subacute phase after a stroke. Figure 1.2 presents an outline of the chapters of this thesis and their relation with the methodological aspects and the components of physical behavior.

First, the effect of different operationalizations is studied in the component 'sedentary behavior'. In ***Chapter 2***, this effect is assessed in healthy people. ***Chapter 3*** describes data of people after stroke, because different movement patterns could influence the effect studied. Second, the validity of two specific devices is assessed. In ***Chapter 4***, the validity of the Activ8 is evaluated to measure body postures & movements in people after stroke, and ***Chapter 5*** describes the development and validation of the Activ8 arm use monitor (the Activ8-AUM) in this population. In addition to the chapters addressing the methodological aspects of measuring physical behavior, in ***Chapter 6*** the validated Activ8-AUM is used to measure arm use during stroke rehabilitation. The recovery of arm use is described in a longitudinal study during the first six months after a stroke, and it is related to the recovery of arm function during the same period.

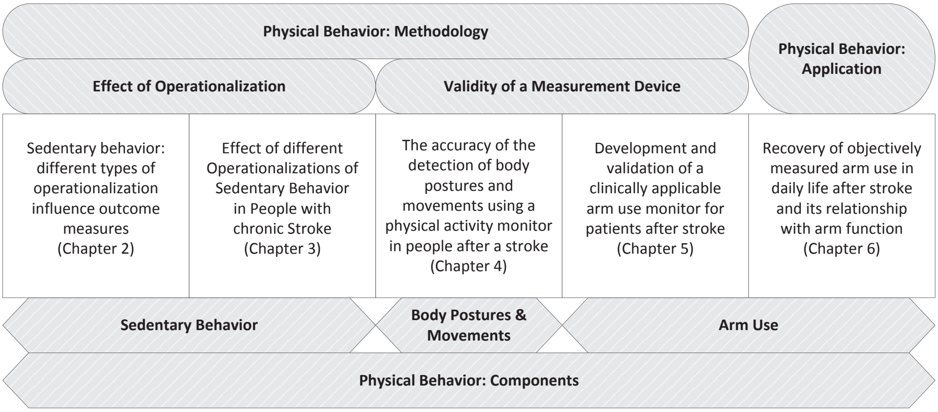

Figure 1.2 Overview of the content of this thesis.

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