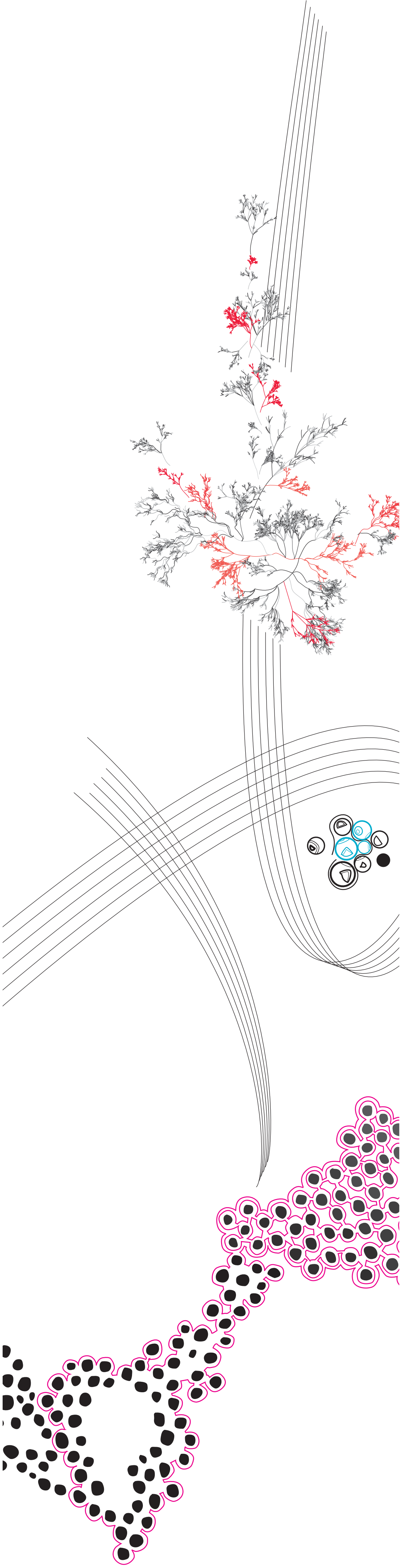

REHABILITATION AFTER CARDIAC SURGERY: USING OBJECTIVE MEASUREMENTS TOWARDS PATIENT SPECIFIC IN-HOSPITAL MOBILISATION

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Preface

Het afgelopen jaar heb ik in het Thorax Centrum Twente mogen werken aan de thesis die hier nu voor u ligt. In deze periode heb ik mezelf kunnen ontwikkelen als Technisch Geneeskundige, zowel op klinisch, persoonlijk en professioneel vlak met deze thesis als eindresultaat. Hiermee sluit ik ook mijn studententijd af en kijk ik uit naar een toekomst als Technisch Geneeskundige. Het afgelopen jaar heb ik met verschillende mensen mogen samen werken en zijn er mensen om mij heen geweest die ervoor hebben gezorgd dat ik nu deze thesis in kan leveren. Deze mensen ben ik dan ook erg dankbaar.

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Ying wil ik bedanken voor de technische begeleiding. Van jou heb ik geleerd om goed na te denken over mijn resultaten en wat voor implicaties dit heeft. Ook heb ik geleerd om een betere structuur in mijn verslag aan te houden. Randy en Robby wil ik bedanken voor jullie hulp bij het kwalitatieve onderzoek. Voor mij was dit helemaal nieuw en door mijn gesprekken met jullie heb ik geleerd hoe ik een interview kan opzetten en hoe ik de vragen zo goed open en objectief mogelijk kan stellen. Peter wil ik bedanken voor het voorzitten van de commissie en het toezien op het zo goed mogelijk verlopen van mijn afstudeertraject.

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In mijn tijd bij het TCT zijn er ook veel medestudenten gepasseerd. Hen wil ik bedanken voor de gezellige momenten tussendoor, het meedenken als ik even vastliep en het motiveren als het even een dag tegen zat. Met name Jacomine, Karin en Dave wil ik bedanken voor deze bijzondere tijd.
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Dan rest mij alleen nog om jullie veel leesplezier te wensen!

Marianne Reintjes

Abstract

Introduction Early mobilisation has been shown to have a positive impact on patients after cardiac surgery. However, patients spent most of their time in bed or sedentary. In order to improve mobilisation in these patients, interventions should move towards more patient-specific strategies. Current activity levels should be measured objectively to gain insight in the mobilisation status of a patient. This information can be used to implement a physical activity intervention method. However, extensive literature on physical activity interventions has shown that the effectiveness of an intervention is dependent on choosing the correct strategies that match the needs of a specific patient population. Understanding the barriers of mobilisation or working with a new intervention is important for development of a successful intervention
Objective To optimise and validate an algorithm to objectively measure mobilisation in patients after cardiac surgery and to investigate the current barriers to mobilisation during hospitalisation and the requirements of an accelerometer-based feedback system according to healthcare professionals.
Methods Using two accelerometers, one placed on the upper arm and one on the upper leg, movements of patients after cardiac surgery during the practice moments with a physiotherapist were measured. This data was used to validate and optimise a neural network that can classify activities in six categories: lying, sitting, standing, cycling, walking, and walking stairs. A qualitative interview study was conducted to investigate the current problems around mobilisation, how patients are motivated to mobilise and how an accelerometer-based feedback system can be incorporated to better guide the mobilisation process. Participants were healthcare professionals at Thorax Centrum Twente. Interviews were transcribed, coded and different themes were analysed.
Results Mobilisation data from 14 patients postoperatively and 31 patients preoperatively was labeled and used to train a neural network. This resulted in a trained algorithm with an overall classification accuracy of 93%. Using only the upper leg sensor an overall accuracy of 89% was reached, however, the algorithm using one sensor could not adequately differentiate between lying and sitting. Barriers to mobilisation are patient characteristics and health status, the hospital environment and expectations of hospital stay. Using a positive approach is of great influence on peoples behaviour. Furthermore, there should be a balance between stimulating patients but also guarding their boundaries. When incorporation an accelerometer-based feedback data should be presented as simple as possible, using graphs and colours.
Conclusion Activities of patients after cardiac surgery can objectively be measured using two accelerometers. When implementing an accelerometer-based feedback system this objective information can help patients gain more insight in their own recovery process, which can motivate them to take more responsibility over their own health. Healthcare professionals can intervene earlier when having insight in the current mobilisation status of a patient, and the mobilisation protocol can be adapted to the patients specific needs.

Keywords cardiac surgery; in-hospital mobilisation; neural network; activity recognition; physical activity; qualitative research; barriers; accelerometer-based feedback

Contents

Acronyms

CABG coronary artery bypass graft

CVA cerebrovascular accident

ICU intensive care unit

IQR interquartile range

KATZ-ADL Katz Index of Independence in Activities of Daily Living Functioning

LOSO leave one subject out

METC Twente Medical Ethics Committee Twente

MOV$_E$M$_E$NTT Mobilisatie Objectiveren op de Verpleegafdeling middels Metingen Na Thorax chirurgie in Thoraxcentrum Twente

TAVI transcatheter aortic valve implantation

TCT Thorax Centrum Twente

Chapter 1

General introduction

Approximately 1.5 million people in the Netherlands suffer from a chronic heart- or vascular disease. Accounting for 22% of all deaths, it is the second largest cause of death in the Netherlands [1]. Annually, 15.000 open heart surgeries are performed [2]. These surgeries consist mostly of a coronary artery bypass graft (CABG), which can either be on- or off-pump, valve replacement or repair, or a transcatheter aortic valve implantation (TAVI). Furthermore, it is common for CABG and valve surgery to be combined [3]. Although an improvement of surgical and anaesthesia techniques has resulted in a reduction in mortality rates, postoperative complications are still frequent and have a major effect on hospital length of stay and quality of life [4]. Early mobilisation is thought to reduce postoperative complications, such as pneumonia, deep venous thromboembolisms and arrhythmias [5–7]. Furthermore, early mobilisation might lead to reduced hospital length of stay, increased functional capacity and a more effective functional recovery [7–12]. Besides physical advantages, early mobilisation can also positively impact mental status. It reduces delirium [13], anxiety and depressive moods, and the ability to perform physical activity gives people the feeling of freedom and autonomy [6, 14].

Despite the known advantages of early mobilisation, patients often exhibit inactive behaviour after surgery, which can lead to reduced cardiac output, deep venous thromboembolism, loss of muscle mass and strength, and a decrease in the ability to live independently [6]. Patients spent most of their time in the hospital lying in bed or sedentary, even though most patients have the ability to walk independently upon hospital discharge [15–17]. Studies investigating barriers to mobilisation have found that patients often do not understand the importance of mobilisation [18]. The hospital environment is considered to discourage physical activity, since patients feel that the hospital bed implicates that they are ill and need to lay down, patients do not associate hospital stay with being physically active, the environment is boring, and because of the included routines and roles, patients feel dependent on health care providers for instructions and support. Furthermore, health care professionals report they do not have time to assist patients with physical activities or to motivate them [14, 18, 19].

1.1 Improving mobilisation after cardiac surgery at Thorax Centrum Twente

At Thorax Centrum Twente (TCT), patients receive physiotherapy on a daily basis. Figure 1.1 shows the activities patients practice with the physiotherapist on each postoperative day, for patients that have an uncomplicated recovery. In addition to these training moments with the physiotherapist, patients are encouraged to mobilise on their own by walking on the ward and, if their condition is sufficient, patients can use the ergometer on their own, with a maximum of ten minutes each time and up to three times per day.

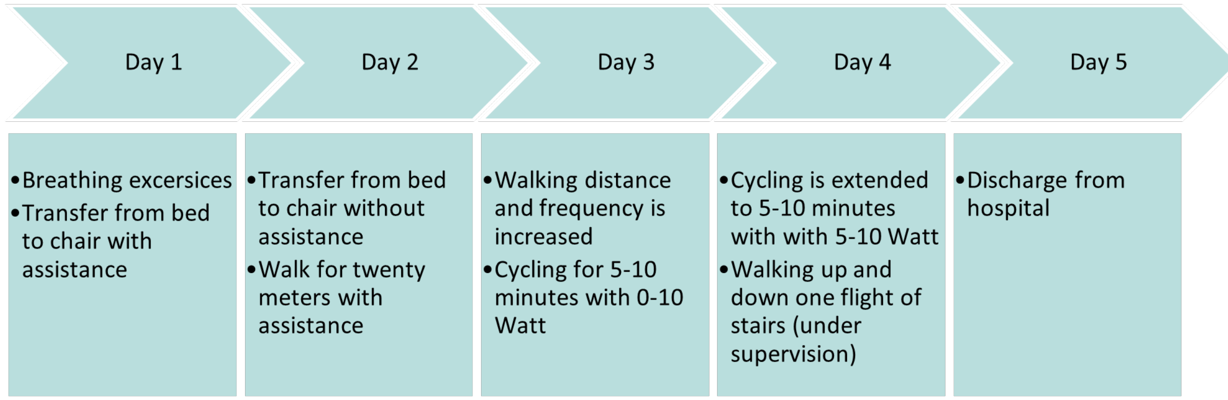


Figure 1.1: Activities patients perform with the physiotherapist for each postoperative day, in case of an uncomplicated recovery.

In order to improve mobilisation and raise awareness on the importance of mobilisation, a poster was designed by a study called 'Moving is improving!' [20]. This poster, displayed in Figure 1.2, can currently be found in every room on the ward and it displays exercises that patients can perform on their own, and provides information on the importance of mobilisation and how patients can contribute to their own recovery. Visitors and health care professionals can use this poster to further motivate patients to exercise. However, a poster is static and does not adapt to a patient specific situation throughout hospital stay.

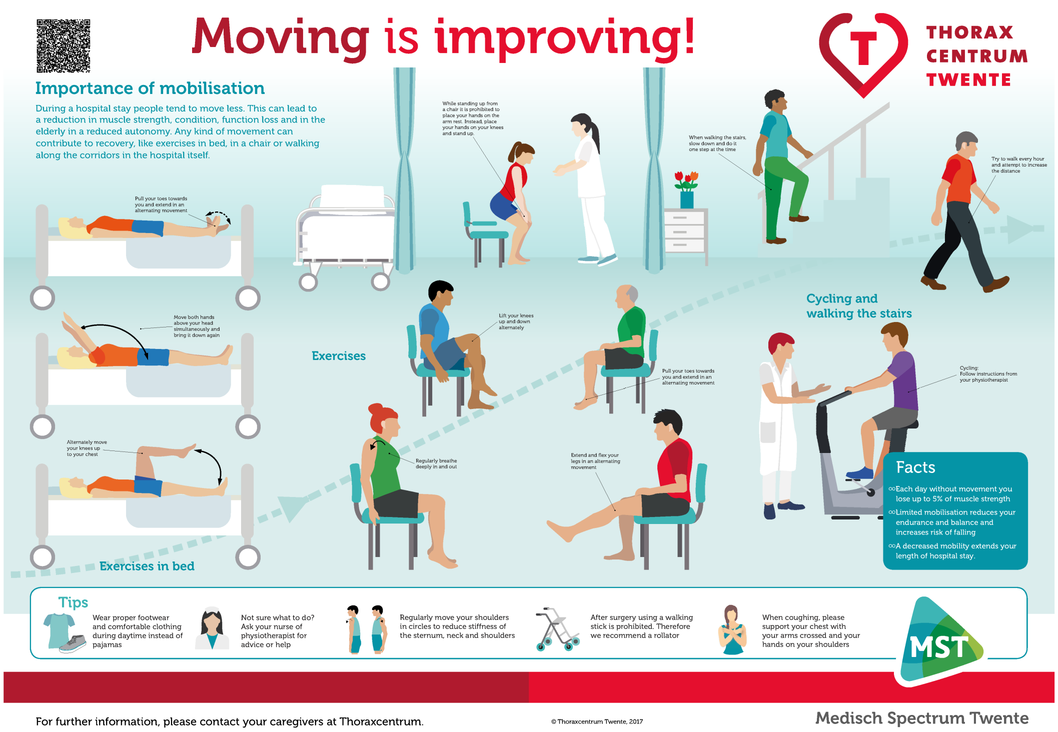


Figure 1.2: Mobilisation poster that can be found in every room on the ward at TCT. It informs patients on the importance of mobilisation and explains what exercises patients can perform. Poster obtained from [21].

To further improve mobilisation in these patients, interventions should move towards more patient-specific strategies. Provided information and exercises should match the patients current functional level. To achieve this, information about the mobilisation status of the patient should be objectively quantified. In this way, it can be detected earlier if the mobilisation progress stagnates or if patients are overestimating themselves. Insight in this information can help healthcare professionals and patients to better guide each individual recovery. Currently, levels of mobilisation are often monitored by self-reporting of patients and observations by nurses and physiotherapists. Self-reporting is subjective and shows low validity and reliability [22]. Direct observations by nurses or physiotherapists, such as behavioural mapping, are labor-intensive and have a considerable impact on the patients privacy. With behavioural mapping, patients are observed during chosen moments of time, for example one minute every ten minutes [23]. This protocol has a good to excellent inter-rater reliability [24], and can also be used to map the physical and social environment in which activity takes place. The combination of objective data with contextual data can help in the understanding of the outcomes of certain interventions [23]. However, this method has several limitations. It can over- or underestimate amounts of physical activity, since dynamic activities such as walking are often less than a few minutes, so they might be missed if only one minute every ten minutes is observed. Furthermore, most studies using direct observation asses physical activity only during working hours and monitoring patients with this method has a very high workload for the hospital staff. This makes behavioral mapping not feasible for continuous monitoring of physical activity.

In the past decades multiple devices and wearables have been developed, which can be suitable to monitor mobilisation objectively. Examples of these devices are pedometers, accelerometers, heart rate monitors, wristbands or smartwatches [25]. Especially tri-axial accelerometers have gained popularity, due to their accuracy and ability to capture large amounts of data [25]. Examples of most commonly used accelerometers are the ActiGraph, GENEActiv, Actical, ActivPAL, Actiheart and Fitbit [26, 27]. These accelerometers all have different attachment places, such as the waist, wrist or chest, and produce different outcome measures. These outcome measures include step count, identification of body position or postural transition, physical activity energy expenditure, and various measures of physical activity intensity [26–29]. The disadvantage of most commercially available accelerometers is that they are not transparent in their raw data processing, making it difficult to assess their validity or to change the outcome measures based on the activities of interest or different body placement. Studies investigating the validity and reliability of accelerometers and algorithms to detect activities make use of different outcome measures and use different ways of reporting [30]. Furthermore, the study populations are very heterogeneous and not all algorithms that are tested in a certain population can be generalised to other populations, due to differences in moving patterns and walking speeds. Therefore, there is a need for a validated accelerometer and algorithm to detect relevant mobilisation parameters and activities in patients after cardiac surgery.

1.1.1 Objective analysis of mobilisation at TCT: the MOV$_E$M$_E$NTT study

In order to assess mobilisation more accurately and objectively, a study called the Mobilisatie Objectiveren op de Verpleegafdeling middels Metingen Na Thorax chirurgie in Thoraxcentrum Twente (MOV$_E$M$_E$NTT) study was carried out at TCT [31]. In this study, two accelerometers (AX3, Axivity) were used to measure the movements of patients after cardiac surgery. An artificial neural network was developed for classification of the six most frequently performed activities by patients on the ward. These movements can be divided into static activities, which include lying in bed, sitting and standing, and dynamic movements, which include walking, cycling and walking stairs. Before surgery, patients completed a measurement protocol, in which they performed the six activities mentioned. The measured data was labelled with the corresponding activity classes and this data was used to train and test the algorithm. Using this data the algorithm reached an accuracy of 98% using two sensors. When using only the upper arm or upper leg sensor the accuracy was 80% and 95% respectively. However, the algorithm is not yet validated on patients after surgery. Especially in the first few days after surgery, patients are expected to move slower and differently than before surgery, which can influence the ability of the algorithm to correctly classify these movements. High accuracy in classification of activities from a predefined protocol or laboratory setting might not translate into high accuracy in free-living situations [32, 33]. In Chapter 2 the algorithm of the MOV$_E$M$_E$NTT study will be explained in more detail. Furthermore, the unresolved problems arising from the MOV$_E$M$_E$NTT study will be discussed, and a validation and optimisation of the algorithm will be presented.

1.2 Translation of measurements to clinical practice and coaching

Recently, studies have been investigating the use of persuasive technology to motivate people to be more physically active. These studies have been carried out in healthy persons as well as in different patient populations, such as patients with obesity, depression, cardiac rehabilitation programs, hospitalised patients and children. These interventions can range from only giving patients insight in their behaviour, to including all kinds of behavior change techniques, such as goal setting, self-monitoring, feedback, social support, instructions, prompts/cues, information, social reward, and action planning [34]. The past years, virtual reality or serious gaming is also becoming more popular in both clinical and at home setting. Using accelerometers, continuous data can be measured from patients at the ward. However, not all information is useful and it should be investigated what healthcare professionals need in order to better guide the mobilisation process. With the current technological advances it can be temping to try and measure and objectify everything that is possible, but too much information can also be overwhelming, for both patients and hospital staff. Therefore, choices need to be made in what information is relevant and what contributes to the recovery of patients after cardiac surgery. In Chapter 3 expert interviews are conducted to explore the needs and wishes of healthcare professionals on how such a measurement system should work and look, and their view of what is best for patients at the ward of TCT.

Chapter 2

Validation and optimisation of a neural network to objectively quantify in-hospital mobilisation after cardiac surgery

2.1 Introduction

After cardiac surgery, early mobilisation has been shown to have a lot of benefits in the recovery of patients. It reduces postoperative complications, reduces hospital length of stay, increases functional capacity and is also believed to positively impact mental status [5–14, 16]. In order to improve mobilisation in patients after cardiac surgery, it is necessary to raise awareness on the importance of mobilisation and interventions should move towards more patient-specific strategies that match the patients current functional level. To achieve this goal, objective information about the activity levels of patients should be obtained. Accelerometers are widely used to measure activity levels in various healthy and patient populations. The disadvantage of most commercially available accelerometers, such as the Fitbit, ActiGraph and ActivPAL, is that they are not transparent in their raw data processing, making it difficult to assess their validity or make changes in the outcome measures based on activities of interest or to make changes in sensor placement. At TCT activities of interest are lying in bed, sitting in a chair, standing, walking, cycling and walking stairs, since these are the activities patients perform on the ward. Most studies using accelerometers to classify activity of hospitalised patients use only step count, or classify lying and sitting together as sedentary behaviour [26, 35, 36]. Therefore, a new algorithm needs to be developed that can distinguish between the activities of interest and this algorithm needs to be validated on the desired patient population.

The MOV$_E$M$_E$NTT study has made a first step towards achieving such an algorithm [31]. This algorithm uses a feed forward artificial neural network to classify the previously mentioned six activities. Neural networks try to mimic the function of the human brain, by replicating the structure and behaviour of the neuron. They consist of an input layer, one or more hidden layers with nodes and an output layer. The amount of inputs, hidden layers and outputs depends on the classification problem [37]. The the neural network developed by the MOV$_E$M$_E$NTT study has 160 inputs, in the form of calculated features, one hidden layer with 18 nodes and six outputs, which correspond to the six activities that can be classified.

In the MOV$_E$M$_E$NTT study the network was trained based on data gathered from cardiac patients prior to their surgery. They performed a predefined protocol, in which they performed the six activities of interest. The static activities were performed for a minimum of thirty seconds, and the dynamic activities for at least sixty seconds. For the static activity 'lying', patients laid on their back and on both sides. Time was captured using a stopwatch. Using a leave one subject out (LOSO) validation, an overall accuracy of 96% was reached. However, when training a neural network, it is important that the training data is representative of the real situation. Since a neural network is trained to recognise patterns, movement patterns of the training data should be similar to movement patterns in real life. It has been shown in previous studies, that a trained algorithm on a specific patient or healthy population does not translate well to other patient populations, if there are differences in movement patterns. For example, slow walking in elderly patients, patients with stroke and patients with hip fractures is not detected well [35, 36]. Since patients tend to walk slower and differently after surgery, it can be expected that training the algorithm with accelerometer data obtained prior to surgery is not representative of the real situation. Furthermore, studies have found that high accuracy in classification of activities in a predefined protocols do not always lead to high accuracy in free-living situations [32, 33]. Since the algorithm in the MOV$_E$M$_E$NTT study did use a predefined protocol, it can not be assumed that the algorithm works equally well in free-living situations. Therefore, the algorithm should be tested on patients postoperatively, moving in a non-predefined manner. If needed the algorithm should be trained with additional data collected from patients postoperatively.

Another question raised by the MOV$_E$M$_E$NTT study is if it is feasible to classify the six activities based on the data of one sensor. In other studies often one sensor is used, commonly placed at the waist, sternum or lower back, since those places make it possible to measure whole-body movement [38]. However, these places are not suitable for this patient group, since placing of sensors at the sternum would interfere with the wound area. Placement of the sensors at the waist or lower back would be uncomfortable, since patients lay in bed most of the time, especially in the first days. Therefore, using one sensor placed at the upper leg would be more suitable in this patient population. Using one sensor would reduce calculation time, is more comfortable for patients, and would reduce costs since less sensors are needed. A first analysis made by the MOV$_E$M$_E$NTT study showed an accuracy of 74% using only the upper arm sensor, and an accuracy of 92% using only the upper leg sensor. Even though the overall accuracy suggest that using only the upper leg sensor is sufficient, this should be investigated in more detail and with accelerometer data from patients postoperatively. Especially the difference between lying and sitting is expected to be difficult to detect, since the upper leg is in the same position during these static activities.

2.1.1 Study objective

Early mobilisation can be beneficial in the functional recovery of patients, can reduce hospital length of stay and reduce postoperative complications. In order to move towards more patient-specific mobilisation strategies, it is important to be able to quantify in-hospital mobilisation objectively. To achieve this goal, the developed network from the MOV$_E$M$_E$NTT study is tested on patients postoperatively. If needed, the algorithm will be optimised by additional training of the algorithm using data collected postoperatively. Furthermore, it will be investigated if the use of only the upper leg sensor is feasible.

2.2 Materials and methods

2.2.1 Study design and population

In this validation study, measurements were performed on patients after cardiac surgery at TCT. Patients were recruited between November and December 2021. Measurements took place each day during practice moments with the physiotherapist, starting when patients returned from the intensive care unit (ICU) at the ward, until patients where either discharged to home or transferred to the referring hospital. Patients were eligible if they are above eighteen years old, received elective or urgent cardiac surgery, and have a Katz Index of Independence in Activities of Daily Living Functioning (KATZ-ADL) score above two before surgery. KATZ-ADL is a widely used instrument to assess the ability to perform basic activities of daily living independently. These activities include bathing, dressing, toileting, transferring, continence and feeding. A score of six indicates full function, four indicates moderate impairment, and two or less indicates severe functional impairment [39]. Patients with an ICU stay longer than 72 hours, patients with post-operative cerebrovascular accident (CVA) and patients who are mentally incompetent were excluded from this study. Patients were approached prior to their surgery to provide information about the research and to obtain written informed consent. Ethical approval was obtained by the Medical Ethics Committee Twente (METC Twente) and received number K21-13.

2.2.2 Measurements

To measure the activity of patients after cardiac surgery, two AX3 accelerometers (Axivity ltd, Newcastle, UK) were placed on the right upper arm and the right upper leg, since the MOV$_E$M$_E$NTT study found these locations to be most optimal for measurements [31]. Sensor locations are visualised in Figure 2.1.

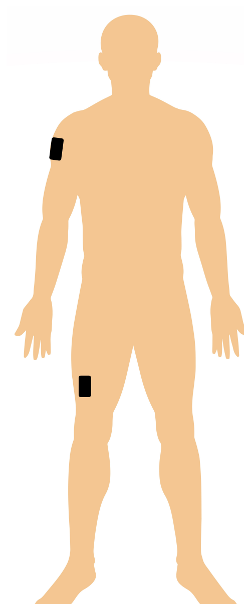


Figure 2.1: Sensor locations: anterodistal on the right upper leg and lateroproximal on the right upper arm.

To attach the sensors, Tegaderm^{TM} patches were used. The sensors were attached a few minutes prior to the practice moments with the physiotherapist and removed a few minutes afterwards. Physiotherapists provided usual care and followed the general mobilisation protocol. No adjustments to the mobilisation protocol were made for this research. This is to ensure that collected data represents the normal situation. In Figure 2.2 the typical route of a patient can be seen, from the moment they are accepted for surgery to discharge or transfer to the referring hospital. The differences between measurement moments of the MOV$_E$M$_E$NTT study and the MOV$_E$M$_E$NTT validation study can also be seen in this time path.

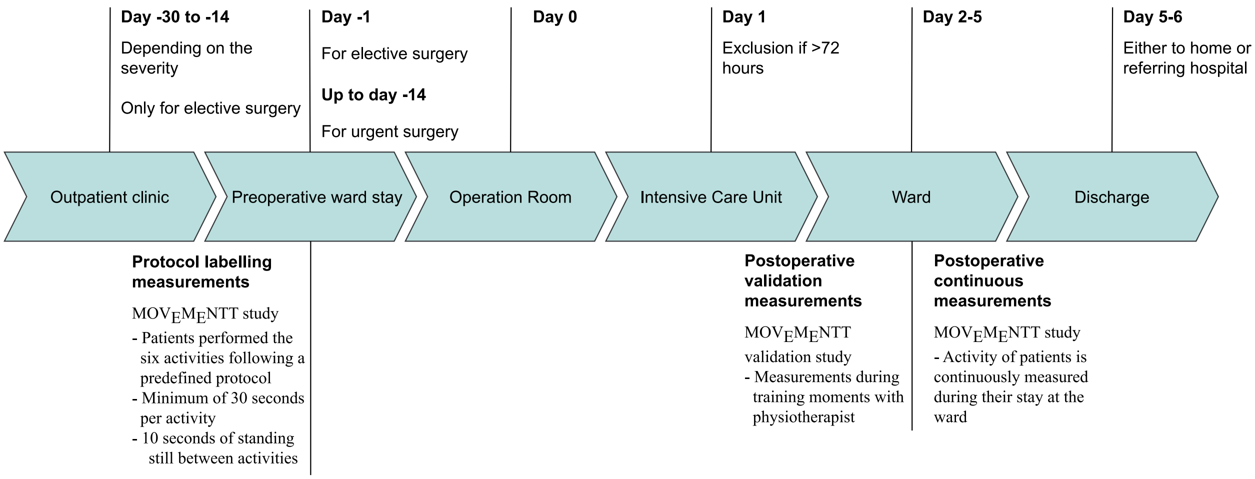


Figure 2.2: Typical route of a patient from the moment they are accepted for surgery to discharge, and inclusion and measurement moments of the MOV$_E$M$_E$NTT and MOV$_E$M$_E$NTT validation study.

The time the measurement was started was noted on an activity form. Each time a new activity (lying, sitting, standing, walking, cycling or walking stairs) was performed, the time interval was determined using a stopwatch. If there was a moment of transfer between activities or no clear activity was performed, this was also noted on the activity form. These moments of transfer included getting in and out of bed, getting in and out of the chair, climbing on and off the ergometer, and putting on clothes or shoes. These time intervals and corresponding activities were used to label the data.

2.2.3 Signal processing

Measured data was downloaded as a .cwa file from the sensors using OmGui software (1.0.0.43, Open Movement GUI Application, Newcastle University, UK). This software was also used to start and stop measurements. Data was further analysed in MATLAB (2020b, the MathWorks Inc, Natick, MA). After reading the .cwa file into MATLAB, the correct time frame was manually selected. Preprocessing steps include a noise reduction, using a third order median filter and a third order low-pass Butterworth filter with a cutoff frequency of 20 Hz [40]. Class labels were added according to the activity form. Raw accelerometer data can not be directly used as an input for neural networks. First, the data needs to be divided into windows [41]. From these time windows, features can be calculated which can be used as the input for the neural network. Acceleration data and corresponding labels were buffered into segments of 256 samples with an overlap of 128 samples. The neural network makes a classification based on these 256 samples, which corresponds to 2.56 seconds. This time frame is based on the work of Anguita et al. [40]. In order to capture walking movements, the time frame should include at least a full walking cycle, which means two steps. The average person walks with a minimum of 1.5 steps/sec, which means two steps in 1.3 seconds. To be able to capture slower walking the time frame should be larger than 1.3 seconds. Since signals are also mapped in the frequency domain, 2.56 seconds was chosen, which indicates 256 samples, so the Fast Fourier Transform is optimised for power of two vectors [40]. Data segments that included labels from more than one activity class were excluded from analysis. Furthermore, data segments that were labeled as transfer moments were excluded from analysis. In this way, only clearly performed activity segments were included in the analysis.

From these windows, features can be calculated. In the field of activity recognition, both time- and frequency-domain features are used. Frequency-domain features can be used to distinguish dynamic from static activities. High-frequency components are related to dynamic motion, whereas the low-frequency, also called the zero-frequency, is related to the influence of gravity, which can be used to identify static postures [42]. The algorithm in the MOV$_E$M$_E$NTT study is based on an open source Matlab script by Bunkheila

[43]. The original algorithm by Bunkheila is written for the use of one sensor, and it is trained using a public domain data set for human activity recognition, which contains acceleration data from 30 healthy subjects wearing a smartphone at the waist [40]. In order to make the algorithm suitable for the purpose of measuring activity after cardiac surgery the algorithm was adapted to be able to make classifications based on data from two sensors instead of one. The original classes of 'walking upstairs' and 'walking downstairs' were combined to 'walking stairs', and the class 'cycling' wad added. Furthermore, in addition to the features calculated by the original algorithm, some additional features were added based on an article written by Janidarmian et al. [41]. For each segment, time-domain and frequency-domain features were calculated for both sensors in the x- y- and z-direction leading to a total of 160 features. Time-domain features include mean and median of total acceleration, the root mean square and standard deviation of body acceleration, and the median absolute deviation and signal magnitude area of both total and body acceleration. Frequency-domain features include auto-correlation, spectral peaks and spectral power [43].

2.2.4 Performance of the neural network

The calculated features were given as an input to the neural network developed in the MOV$_E$M$_E$NTT study. This neural network uses 59 features of the original 160, based on a neighborhood component analysis [31], and was trained using the data collected from patients preoperatively. Performance of the algorithm was investigated by calculating accuracy, recall and precision. Accuracy is the total number of correct predictions divided by the total number of predictions. Recall is the fraction of correctly classified samples divided by the number of samples that should have been in identified in that class. This is also known as the true positive rate. Precision is the number of correctly classified samples in a class divided by the number of samples that are classified in that class. This is also known as the positive predictive value [44]. The formulas for accuracy, recall and precision can be seen in Equation 2.2.4, 2.2.4 and 2.2.4 respectively. Furthermore, confusion matrices were made to investigate in more detail where classification errors occur. In Fig. 2.3 a workflow can be seen that describes all the steps from data collection to performance output.

$$\text{Accuracy} = \frac{\text{Number of correct classifications}}{\text{Total classifications}} \tag{2.1}$$

$$\text{Recall} = \frac{\text{True positives}}{\text{True positives + False negatives}} \tag{2.2}$$

$$\text{Precision} = \frac{\text{True positives}}{\text{True positives + False positives}} \tag{2.3}$$

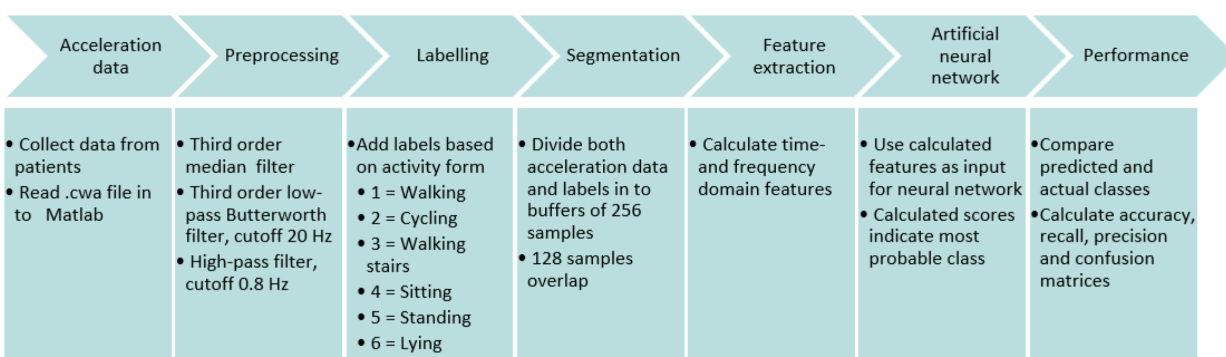


Figure 2.3: Workflow that describes all the steps from data collection to performance output.

2.2.5 Optimisation of neural network

After performance of the neural network developed by the MOV$_E$M$_E$NTT study was assessed, it was investigated if performance could be improved by additional training of the neural network. Training was done using both the data collected from patients preoperatively by the MOV$_E$M$_E$NTT study, and the data collected postoperatively as described in section 2.2.2. Performance of the newly trained neural network was investigated using a leave one subject out (LOSO) analysis, since the neural network is thought to have a different performance for each subject. This is due to the fact that each person moves differently, which can cause a change in performance of the algorithm if a person moves significantly different than other individuals. This could be because of the use of walking aids or different posture. Every iteration, the algorithm leaves one subject out and the neural network is trained based on the remaining subjects. Then the neural network is tested based on the classification of the data of the left out subject. Accuracy, recall and precision were calculated and confusion matrices were made.

2.2.6 Use of only upper leg sensor

Finally, it was analysed whether using only the upper leg sensor can generate similar results compared to using both the upper leg and arm sensors. To investigate the use of only one sensor, the algorithm was adapted to calculate only the eighty features of the leg sensor. The neural network was adjusted, so it has eighty inputs. The new network was trained using only the acceleration data from the upper leg sensor, and tested using the LOSO validation method as described in 2.2.5. Performance was again assessed by calculating accuracy, recall and precision, and by inspecting the confusion matrices.

2.2.7 Statistical analysis

In order to assess if the patient groups from the MOV$_E$M$_E$NTT and MOV$_E$M$_E$NTT validation study are comparable, statistical analysis on patient characteristics was performed using IBM SPSS Statistics for Windows, version 28 (IBM Corp., Armonk, N.Y., USA). Continuous variables are presented as median with interquartile range (IQR), and nominal variables are presented as numbers and percentages. Continuous variables were tested for normality using the Shapiro-Wilk test and by visually inspecting the histograms and skewness and kurtosis. Based on the distribution, the continuous variables were compared using the unpaired t-test or Mann-Whitney U test. Nominal variables were compared using the Fishers exact test.

2.3 Results

2.3.1 Patient demographics

After including 18 patients in the validation study, measurements were performed on 14 patients. One patient was excluded due to a postoperative CVA. One patient was excluded due to surgery unsuitability. Another patient was excluded due to an ICU stay longer than 72 hours. Finally, one patient could not be measured due to stay at the coronary care unit. Baseline, perioperative and postoperative patient characteristics from both the MOV$_E$M$_E$NTT and the MOV$_E$M$_E$NTT validation study can be found in Table 2.1, Table 2.2 and Table 2.3 respectively. Patients from the MOV$_E$M$_E$NTT validation study had significantly more recent myocardial infarctions than patients from the MOV$_E$M$_E$NTT study. Furthermore, patients from the MOV$_E$M$_E$NTT validation study had significantly more urgent surgery instead of elective surgery than patients from the MOV$_E$M$_E$NTT study. Other baseline characteristics were not significantly different between the two groups.

Table 2.1: Baseline patient characteristics; data are medians [IQR] or numbers (percentage).

	MOV$_E$M$_E$NTT (n=29)	**MOV$_E$M$_E$NTT validation (n=14)**	**P-value**
Age (years)	70 [64-74]	71 [66-75]	0.84
Sex			
Male	22 (76%)	11 (79%)	1.00
Female	7 (24%)	3 (21%)	
Body Mass Index (kg/m^2)	27 [25-29]	27 [26-29]	0.52
Body Surface Area (m^2)	2.0 [1.9-2.1]	2.0 [1.8-2.2]	0.62
Diabetes	6 (21%)	3 (21%)	1.00
Multivessel disease	12 (41%)	8 (57%)	0.52
Recent myocardial infarction	2 (7%)	6 (43%)	**0.01**
Left Ventricular Ejection Fraction			
Poor, <30%	4 (14%)	0 (0%)	
Moderate, 30-50%	12 (41%)	4 (29%)	0.22
Good, >50%	13 (45%)	10 (71%)	
COPD	1 (3%)	0 (0%)	1.00
Extracardiac arteriopathy	3 (10%)	0 (0%)	0.23
Neurological dysfunction	3 (10%)	1 (7%)	1.00
Previous cardiac surgery	0 (0%)	0 (0%)	1.00
NYHA class			
I	12 (41%)	7 (50%)	
II	7 (24%)	6 (43%)	0.12
III	10 (34%)	1 (7%)	
IV	0 (0%)	0 (0%)	
Urgency			
Elective	23 (79%)	3 (21%)	**<0.001**
Urgent	6 (21%)	11 (79%)	
Euroscore I	3.5 [1.5-6.0]	3.3 [2.1-5.5]	0.85
Euroscore II	1.3 [0.9-2.2]	1.3 [0.9-1.4]	0.74

COPD = Chronic obstructive pulmonary disease. NYHA = New York Health Association. EuroSCORE = European system for cardiac operative risk evaluation.

Table 2.2: Periprocedural patient characteristics; Data are medians [IQR] or numbers (percentage).

	$\mathbf{MOV_EM_ENTT}$ (n=29)	$\mathbf{MOV_EM_ENTT}$ validation (n=14)	P value
Type of surgery			
TAVI	0 (0%)	1 (7%)	0.08
CABG	15 (52%)	11 (79%)	
Valve surgery	9 (31%)	2 (14%)	
CABG + valve surgery	5 (17%)	0 (0%)	
Surgical approach			
Mini sternotomy	4 (14%)	2 (14%)	1.00
Median sternotomy	25 (86%)	12 (86%)	
Cardiopulmonary bypass	22 (76%)	10 (71%)	1.00
Cardiopulmonary bypass time (min)	100 [87-143]	80 [65-101]	0.13

TAVI = Transcatheter Aortic Valve Implantation. CABG = Coronary artery bypass graft.

Table 2.3: Postoperative patient characteristics; data are medians [IQR] or numbers (percentage).

	$\mathbf{MOV_EM_ENTT}$ (n=29)	$\mathbf{MOV_EM_ENTT}$ validation (n=14)	P value
ICU stay (days)	1 [1-2]	1 [1-1]	0.05
Surgical ward stay (days)	5 [3-6]	5 [4-5]	0.59
Discharge to			
Home	23 (79%)	11 (79%)	1.00
Referring hospital	6 (21%)	3 (21%)	

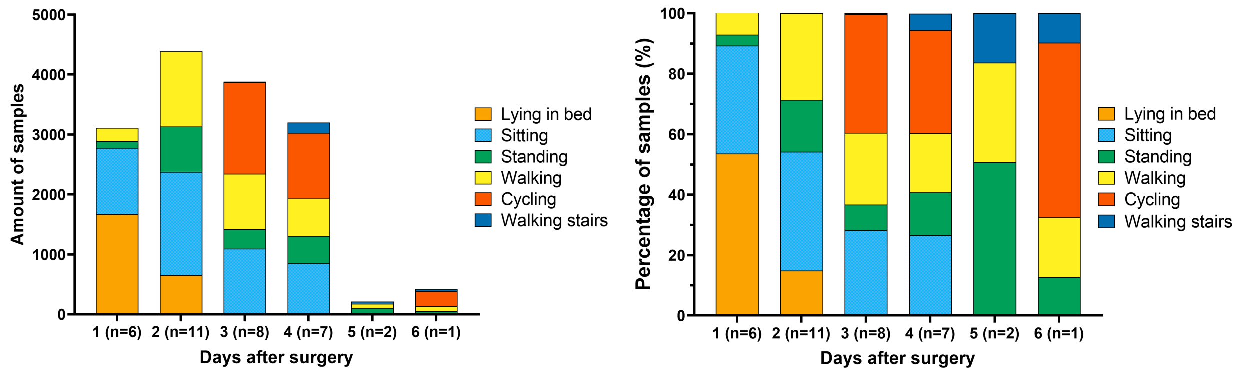
2.3.2 Data set

In total, 15195 samples of 2.56 seconds were collected. This corresponds to a total of 648.3 minutes. Table 2.4 shows how these samples are divided over each activity. It can be seen that not all classes are equally divided. Especially walking stairs does not have much samples compared to the other classes.

Table 2.4: Amount of data samples per activity class. Each sample is 2.56 seconds.

Activity	Amount of samples (n=14)
Lying	2229
Sitting	4852
Standing	1809
Walking	3181
Cycling	2860
Walking stairs	264
Total	15195

Fig. 2.4 displays the distribution of samples per postoperative day. On the first day mostly lying and sitting is measured, on the second day standing and walking increases. On day three to six, no lying is measured. Cycling and walking stairs start at day three. This corresponds to the protocol described in Chapter 1. The amount of participants that is measured per day is also displayed in Fig. 2.4.



(a) Absolute amount **(b)** Relative amount

Figure 2.4: Amount of samples per activity class per postoperative day, including the number of patients measured during each postoperative day.

2.3.3 Performance of original and optimised neural network

The left side of Table 2.5 shows the performance of the neural network developed by the MOV$_E$M$_E$NTT study, tested with the validation data measured during the practice moments with a physiotherapist. An overall accuracy of 87% was found. Notable are the low recall for walking (67%), and the low precision for standing (67%) and walking stairs (49%). Fig. 2.5 shows the confusion matrix. The confusion matrix shows that walking is often misclassified as standing or walking stairs.

Table 2.5: Performance of the neural network developed in the MOV$_E$M$_E$NTT study, tested with the data measured postoperatively (left) and performance of the neural network with additional training using both preoperative and postoperative data (right). Data are in percentages; mean [min max]

	Algorithm MOV$_E$M$_E$NTT			**Algorithm MOV$_E$M$_E$NTT validation**		
	Recall	**Precision**	**Accuracy**	**Recall**	**Precision**	**Accuracy**
Lying	100 [96 100]	77 [0 100]	77 [0 97]	97 [74 100]	86 [0 100]	84 [0 100]
Sitting	84 [8 100]	98 [50 100]	83 [3 100]	90 [52 100]	97 [78 100]	88 [52 100]
Standing	95 [59 100]	67 [4 100]	65 [3 99]	92 [38 100]	85 [61 100]	79 [38 100]
Walking	67 [42 99]	97 [0 100]	66 [0 99]	91 [77 100]	95 [88 100]	87 [76 100]
Cycling	99 [97 100]	96 [0 100]	95 [0 100]	99 [98 100]	99 [0 100]	98 [0 100]
Walking stairs	88 [67 100]	49 [0 100]	46 [0 93]	86 [71 100]	75 [0 100]	67 [0 96]
Overall	89 [67 94]	81 [41 86]	87 [73 96]	93 [73 100]	90 [56 100]	93 [77 100]

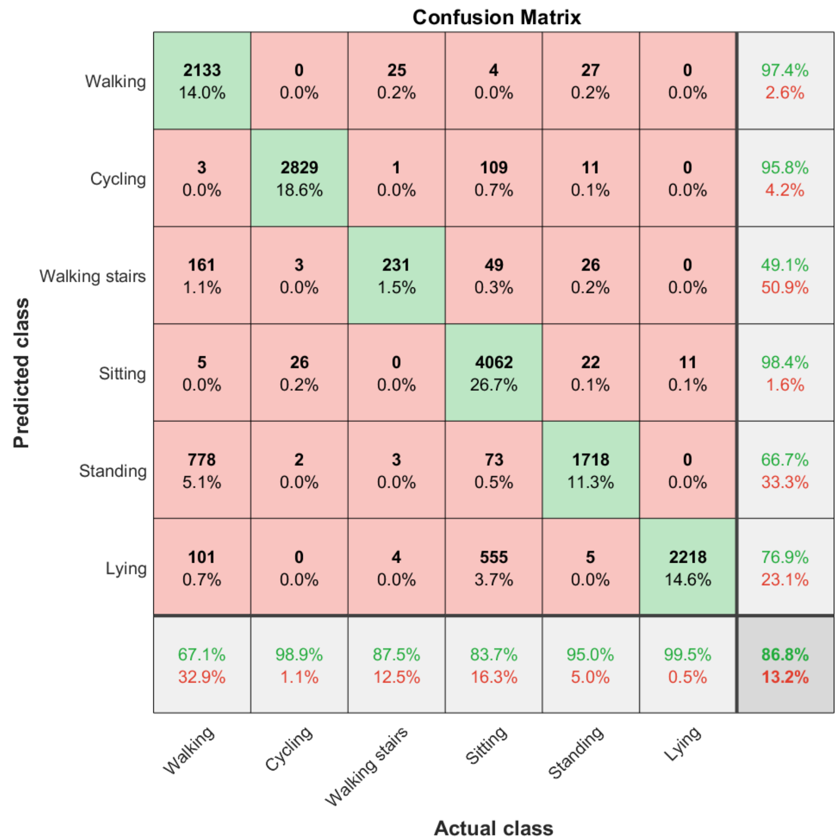


Figure 2.5: Confusion matrix for the performance of the algorithm developed by the MOV$_E$M$_E$NTT study, trained with the data collected preoperatively and tested with the data collected postoperatively. The outer column on the right displays the precision in green, and the false discovery rate in red. The bottom row displays the recall in green, and the false negative rate in red. The cell in the bottom right of the matrix shows the overall accuracy.

The right side of table 2.5 shows the performance of the neural network, after training the network using both the data collected preoperatively by the MOV$_E$M$_E$NTT study and the data collected postoperatively by the validation study. The neural network now reaches an overall accuracy of 93%. Furthermore, the recall for walking increased to 91%. The precision for standing and walking stairs increased to 84% and 75% respectively. Fig. 2.6 shows the confusion matrix. This confusion matrix shows that walking is still misclassified as standing sometimes, but less often than in the original neural network. Furthermore it can be seen that walking is also less frequently misclassified as walking stairs.

Fig. 2.7 displays an example of P09 on postoperative day two. This is the first time the patient starts walking after surgery, meaning they are likely to walk slower than prior to their surgery. The figure shows the algorithm developed by the MOV$_E$M$_E$NTT study on the left, and the newly trained algorithm on the right. It can be noted that the original algorithm often switches between standing and walking, whereas the new algorithm correctly classifies the activity as walking.

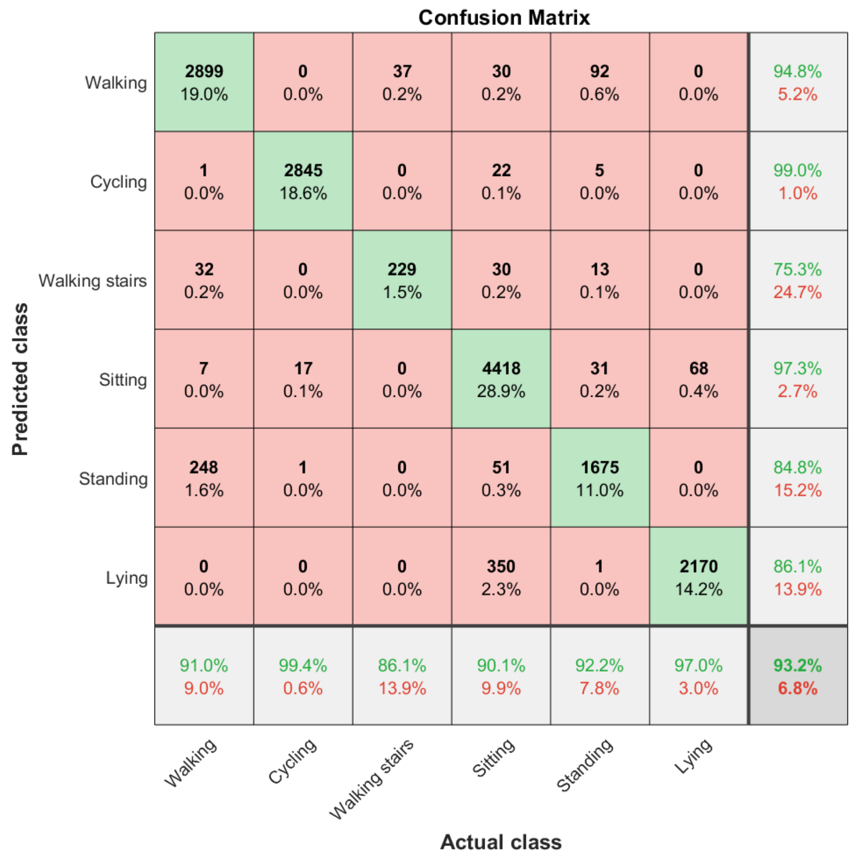


Figure 2.6: Confusion matrix for the performance of neural network trained with data from patients pre- and postoperatively, and tested using the LOSO validation. The column outer column on the right displays the precision in green, and the false discovery rate in red. The bottom row displays the recall in green, and the false negative rate in red. The cell in the bottom right of the matrix shows the overall accuracy.

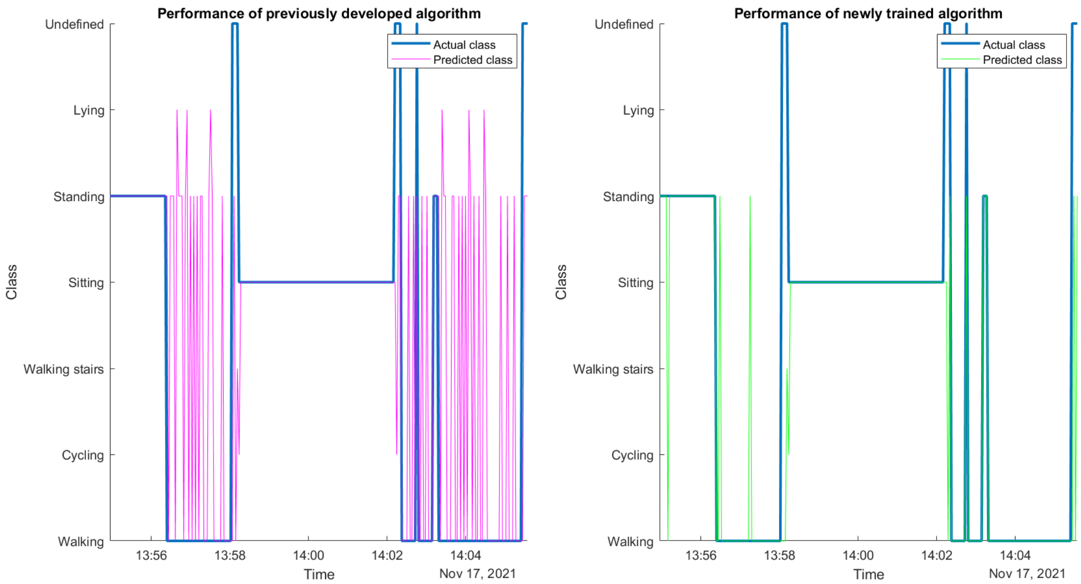


Figure 2.7: Comparison of the previously developed algorithm on the left vs. the newly trained algorithm on the right.

2.3.4 Performance of neural network using only the upper leg sensor

Table 2.6 shows the performance of the algorithm when using only the upper leg sensor. Using only the upper leg sensor an overall accuracy of 89% is reached. However, the recall and precision for lying, decrease from 97% to 79% and from 86% to 75% respectively. The recall and precision for sitting decrease from 90% to 84% and from 97% to 90%. The recall and precision for walking stairs decrease from 86% to 69% and from 75% to 69%. The recall and precision for standing, walking and cycling using one sensor are comparable to using two sensors. In Fig. 2.8 the confusion matrix for the performance of using only the upper leg sensor is shown. The confusion matrix shows that especially lying is misclassified as sitting, and sitting is misclassified as lying more frequently than when using two sensors. Furthermore, walking stairs is misclassified as walking more often then when using two sensors.

Table 2.6: Performance of the neural network with additional training using only the upper leg sensor. Data are in percentages; mean [min max].

	Recall	**Precision**	**Accuracy**
Lying	79 [31 100]	75 [0 100]	63 [0 100]
Sitting	84 [31 100]	89 [51 100]	76 [31 100]
Standing	92 [48 100]	88 [56 100]	82 [50 100]
Walking	93 [76 100]	93 [0 100]	89 [0 99]
Cycling	99 [95 100]	98 [0 100]	98 [0 100]
Walking stairs	69 [17 100]	69 [0 100]	52 [0 96]
Overall	86 [72 100]	85 [57 97]	89 [74 100]

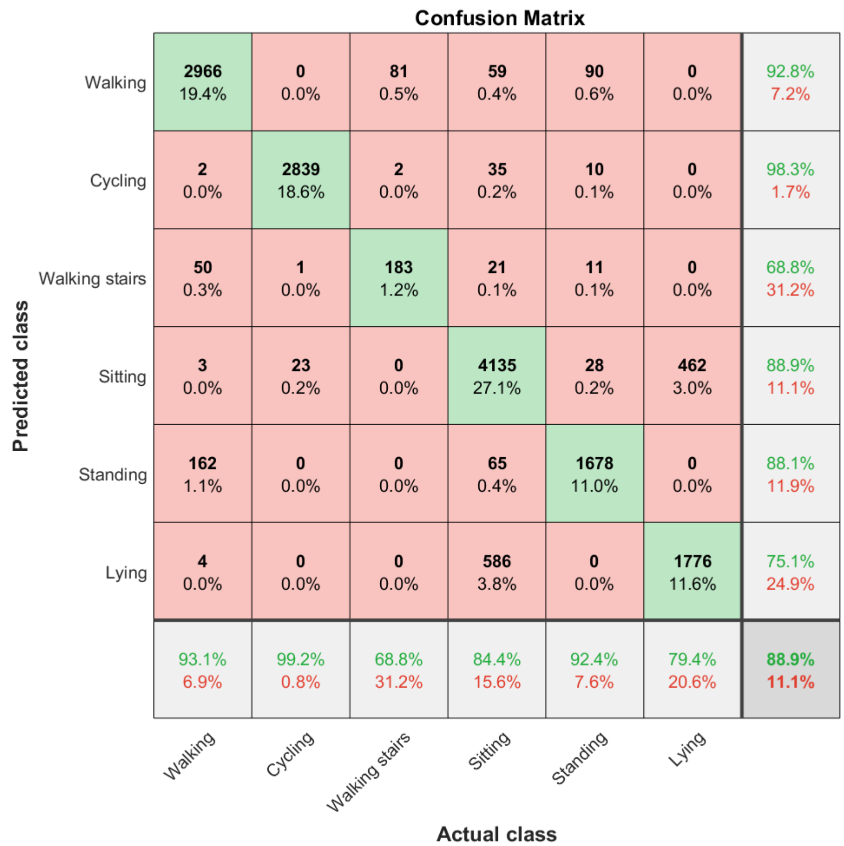


Figure 2.8: Confusion matrix for the performance of the algorithm developed by the MOV$_E$M$_E$NTT study, trained with the data collected preoperatively and tested with the data collected postoperatively, based on only the upper leg sensor. The column outer column on the right displays the precision in green, and the false discovery rate in red. The bottom row displays the recall in green, and the false negative rate in red. The cell in the bottom right of the matrix shows the overall accuracy.

2.4 Discussion

This study aimed to test and optimise an artificial neural network to objectively measure mobilisation during hospital stay of patients after cardiac surgery. This was done by collecting data from patients postoperatively and investigate the performance of a neural network trained with data collected preoperatively. This led to an overall accuracy of 87%, with problems in correctly differentiating between walking and standing. Optimisation of the neural network was achieved by additional training, using data from patients collected postoperatively in addition to the data collected preoperatively. This led to an overall accuracy of 93%, with improvements in classification of walking, standing and walking stairs. Another aim of this study was to investigate the feasibility of using only one sensor, in order to reduce costs and calculation time, and to increase patient comfort. Adaptions to the neural network to function using one sensor, led to an overall accuracy of 89%. However, recall and precision for classifying lying, sitting and walking stairs decreased considerably.

2.4.1 Baseline characteristics MOV$_E$M$_E$NTT and MOV$_E$M$_E$NTT validation study

From the statistical analysis it can be concluded that the patient groups of the MOV$_E$M$_E$NTT and the MOV$_E$M$_E$NTT study validation are mostly comparable. There was, however, a significant difference in the amount of recent myocardial infarction and urgency of the surgery, with the validation group having more recent myocardial infarction and more urgent surgeries. There is a simple explanation for this finding. The validation study was carried out during the COVID-19 pandemic, in the period that hospitals were down scaling their elective care. Instead of the normal capacity of approximately four surgeries each day, there were only one or two. Due to this limited capacity, most surgeries were performed on patients that were hospitalised due to a myocardial infarction and had to stay in the hospital until their surgery. These patients often had complaints of angina pectoris or dyspnea during their admission to the hospital, but some were symptom free during the time they were waiting for surgery. It is not expected that this difference between the two groups leads to differences in movement patterns, and therefore it is not expected that this difference will have an influence on the validity of this study.

2.4.2 Performance of the neural network

When testing the neural network developed by the MOV$_E$M$_E$NTT study, it was noted that especially in the first two days after surgery walking was often misclassified as standing. This can be seen in the confusion matrix in Fig. 2.5 and in the example in Fig. 2.7. It is also reflected by the low recall of walking and the low precision of standing. After surgery, patients walk considerably slower, often due to pain and fatigue. Later in their hospital stay these misclassifications decrease, as walking is more similar to the preoperative situation. Another problem that was noted was that when patients were starting to walk more normally, walking was sometimes misclassified as walking stairs. This can also be seen in the confusion matrix in Fig. 2.5, and is reflected by the low precision of walking stairs. This can be explained by the fact that patients start to lift their feet more, which the network recognises as walking stairs. When using both the preoperative and postoperative data for training of the network, these misclassifications decrease. Since the data collected postoperatively includes samples of patients that walk slowly, the network learns to recognise that slow walking also belongs to walking and not to standing.

It is notable in Table 2.5 and 2.6 that the range of the precision sometimes ranges from zero to hundred. This happens because not all patients have performed all activities during their stay. For example, if a patient is only measured at day three and four, lying is not measured in that particular patient. If then one sample is misclassified as lying, precision will be zero. This needs to be taken into account when interpreting the ranges for precision and recall.

In this study it was tested whether using only the upper leg sensor would provide similar results to using two sensors. Using only one sensor would reduce calculation time and is more comfortable for the patients. Using only the upper leg sensor an accuracy of 89% was reached compared to an accuracy of 93% using two sensors. Although overall accuracy still seems good, looking further into the performance of the algorithm shows that especially the performance of classifying lying and sitting decreases when using only one sensor. Using only the upper leg sensor the recall and precision for lying are 79% and 75% respectively, compared to 97% and 86% when using both sensors. For sitting the recall and precision are 84% and 89% using only the upper leg sensor, compared to 90% and 97% when using two sensors. These results are as was expected, since the upper leg is in the same position during sitting and lying. A review investigating the validity and reliability of accelerometry to identify lying, sitting, standing and purposeful activity in adult hospital inpatients has also found that accelerometers placed in isolation on the thigh could not differentiate between lying and sitting positions [29]. Other studies have used different placements when measuring whole-body movement, such as the waist, sternum and lower back [38]. However, these placements are not suitable in the hospital setting since patients lie in bed often. When placing sensors on the lower back or waist, this could lead to discomfort for the patients. Placement of the sensors on the sternum is not desirable, because of interference with the wound area. Another strategy would be to place the sensor at the ankle, since the ankle is in different positions during sitting and lying. However, the ability to differentiate between standing and sitting would then decrease, since the ankle is in the same position during these activities. Furthermore, the ankle is expected to generate more irrelevant movement, which could negatively influence the classification of movements and postures. Since on the first day mobilisation consist of sitting on the edge of the bed or sitting in the chair it is important to be able to correctly distinguish between sitting and lying [8]. Furthermore, patients are encouraged to spent less time in bed during the course of their hospital stay and spent more time in an upright position. Since this is such an important part of the mobilisation process, it is recommended that both sensors are used to be able to correctly identify whether patients are lying in bed or sitting in a chair.

2.4.3 Comparison to relevant literature

Comparing the results of this study to the results of other validation studies is quite challenging, since there is no consensus in literature on measurement protocols and performance metrics. There is a lot of variety in patient populations, types of accelerometers used and placement of the accelerometers. In addition, the activities that are classified differ per study. Most studies classify lying and sitting together as sedentary behaviour and other activities are classified as dynamic activity, rather than specifying which activity is being performed. While in this study accuracy, recall and precision are used to describe the performance of the algorithm, other studies use metrics such as sensitivity, specificity, percentage error, mean difference or the F1-score, which is a measure that combines precision and recall. Finally, not all studies transparently describe how their algorithms work, which makes it difficult to compare results and explain possible differences.

Valkenet et al. investigated the validity of three accelerometers (ActiGraph GT9X Link, Activ8 professional, Dynaport MoveMonitor), each with a different wear location (hip, upper thigh, and lower back) to detect lying, sitting, standing and walking [23]. They included twelve patients, of which only two inpatient subjects, which performed a predefined protocol. Patients were only included if they could perform all activities included in the protocol. Video recordings were used for reference. They showed good to excellent validity of all three sensors to detect walking (81% to 99%). However, the positive predictive values for standing, sitting and lying were lower, ranging from 19% to 74%, 28% to 57%, and 0% to 100% respectively. These ranges can be explained by the different wear locations. For example, during standing the DynaPort MoveMonitor registered sitting in 84% of the samples, due to placement at the lower back, which is in the same position during standing and sitting. By combining two sensors, as is the case in the MOV$_E$M$_E$NTT validation study, the positive prediction values (precision) become higher overall, meaning static positions are better distinguishable. The ability to detect walking in the study of Valkenet et al. is comparable to this study, with outcome measures above 90%.

In a study performed by van Dijk-Huisman et al., an classification algorithm for assessment of physical activity in hospitalized patients was optimised and validated [35]. They used an adjustable activity classification algorithm previously developed by Bijnens et al., which has been shown to be able to discriminate between dynamic, standing, and sedentary (lying/sitting) behavior in elderly persons using a decision tree [45]. The algorithm can be optimised by for other target populations and locations where the sensor is worn by adjusting algorithm parameters, such as data segmentation window, amount of physical activity threshold, ans sensor orientation threshold. Van Dijk-Huisman et al., measured patients that were admitted for elective total knee or hip arthroplasty, or were aged seventy or older and acutely hospitalized. They measured acceleration on the upper leg during physical therapy sessions using a MOX Activity logger and used recordings with a held hand camera for reference. Total sensitivity, specificity and accuracy were 89%, 95%, and 93% respectively. Total accuracy is comparable to the accuracy found in this study. However, sensitivity (which equals recall) for standing was 65% (34% to 77%), which is comparable to the recall found in this study before additional training of the network. When looking at only the acutely hospitalized elderly patients, sensitivity drops to 35%. They suggested that the difficulty with correctly classifying standing could be due to the patients' slow gait, which makes it more difficult to select an appropriate threshold to distinguish between standing and walking. This found difficulty of detecting slow gate is comparable to the finding in this study, when performance of the algorithm was assessed before optimisation. The advantage of using a neural network instead of the decision tree used by van Dijk-Huisman et al., is that the network can be trained to recognise patterns, omitting the need to choose one threshold for all different patients. The improvement in recall of walking with additional training of the network shows this advantage. Furthermore, for the particular patient group of patients after cardiac surgery, the first one or two days after surgery, mobilisation consists mostly of getting out of bed and sitting in a chair. Therefore, classifying sitting and lying together is not desirable.

Fridriksdottir and Bonomi developed an algorithm for recognizing activities typical for hospitalized patients using a deep neural network. The advantage of using a deep neural network over an artificial neural network is that it can automatically extract features from raw input instead of using predefined features. Twenty healthy subjects completed a protocol that consisted of activities typical for hospitalized patients, wearing a accelerometer attached to the left side of the trunk. All activities of the protocol were classified in to six activity classes; lying, upright (sitting/standing), walking, stair ascent, stair descent and wheelchair transport. They reached an overall accuracy of 95%, which is comparable to the result in this study. Furthermore, they also found that slow walking and walking up/down the stairs are the most challenging activities to classify, which is in line with the findings of this study.

2.4.4 Limitations

One of the limitations of this study is that testing of the neural network is done based on practice moments with a physiotherapist. Even though patients move in a natural manner, meaning they can stop walking if they want to or are not told to sit perfectly still for example, the activities they perform are based on the mobilisation protocol that physiotherapists follow for patients after cardiac surgery. This explains why no lying is measured on postoperative day three to six. On these days, patients are often already sitting in a chair when they are visited by the physiotherapist. Transfer moments between activities were excluded from analysis and data was only labeled when patients were clearly performing a certain activity. This was done because it is unclear under what class these transfer moments belong. During free-living, these moments of transfer between activities or when patients walk for a second and then stop for example will be classified as well. This could have an influence on the performance of the neural network. To be certain about the performance of the network during free-living, a patient should be recorded the entire day and data should be labeled according to what is seen. This was not done in this study, because this takes a lot of time and video recording a patient the entire day would be a serious invasion of their privacy. To be able to correctly label all the activities, it should be determined to what class these transfer moments belong, or an additional class 'transfer' should be added. These transfer moments, however, are expected to occupy only a small part of all the activities that are classified, meaning that they are not likely to have a significant impact on the global mobilisation status of the patient.

Another limitation was that in this study time intervals to label the accelerometer data were measured with a stopwatch and the corresponding activities were noted on a form. Each time a patient switches between activities the stopwatch is pressed to obtain a round, which gives the time interval an activity is performed. However, the reaction time needed to press the stopwatch after change of the activity could introduce small errors. Furthermore, patients sometimes move in unpredictable ways. For example when walking, some patients stop for a second and then start walking again. These small interruptions of certain activities are difficult to capture with the stopwatch. These errors were aimed to be diminished as much as possible, by excluding the intervals in which no clear activity was performed or during moments of transfer between activities, for example getting on the ergometer. To obtain more precise time intervals the gold standard, which is video recording, could be used. However, this is more invasive of the privacy of patients and is more time consuming. Since the algorithm makes a classification based on 2.56 seconds, the reaction time to press the stopwatch is not expected to have a significant influence, since this is only a fraction of the time window. Additionally, activities are often performed for a longer period of time, which means that all the other segments after the transfer will be correctly labeled.

In neural network training it is often recommended to include approximately the same amount of samples for every class. In this study, the amount of samples per class is not evenly distributed. Especially walking stairs has few samples in the validation study compared to the other classes. This is due to the fact that patients only walk stairs on day four or five. For some patients these days were missed, because of weekends or transfers to referring hospitals. However, since walking stairs is only performed once and under direct supervision of a physiotherapist, this is considered to be representative of the realistic situation. Walking stairs in never performed by patients themselves, and therefore it has more consequences for clinical practice if the algorithm has low precision than low recall. The optimised neural network, which has less training samples that include walking stairs, increases the precision for walking stairs, so it is expected that this is beneficial for clinical practice.

2.4.5 Clinical relevance and recommendations for future research

Based on the results of this study and in comparison to other literature, it is believed that the performance of the algorithm is sufficient for its intended use. A point of improvement could be to implement a smoothing step in the algorithm. Sometimes, the algorithm classifies a single segment as another activity than the surrounding segments. Especially when patients are not lying completely flat, the algorithm tends to switch between lying and sitting. Since it is likely that patients perform activities for a longer period of time, a majority voting algorithm could be implemented to reduce the errors produced by these misclassifications. Even without this adjustment, this validation study shows that mobilisation of patients after cardiac surgery can be objectified accurately.

The next step to implement this algorithm in the clinical setting and for the algorithm to have clinical relevance, would be to translate these measurements to useful information. Even though the measurements can already objectively measure the physical activity of patients after cardiac surgery, the way it is measured now is not of direct use to the patient or physiotherapist. Implementation of these measurements can take many forms, from just collecting data and showing this to patients and physiotherapist, to more complicated interventions such as serious gaming. For a system like this to be of added value in daily practice it is important to understand the needs and barriers of the hospital staff and patients to work with such sensors. In Chapter 3 expert interviews will be conducted to investigate these needs and barriers.

2.5 Conclusion

This study shows that mobilisation of patients after cardiac surgery can be objectively quantified with two accelerometers worn at the upper thigh and upper arm. Using data collected from patients preoperatively and postoperatively, a neural network is trained, leading to a total classification accuracy of 93%. The importance of using two sensors in order to correctly differentiate between static activities including lying, sitting and standing has been shown. Future research should focus on the translation of objective measurements to interventions that can be implemented in clinical care, leading to a more patient-specific mobilisation strategy. A first step would be to explore the wishes and needs of hospital staff working with patients after cardiac surgery.

Chapter 3

Translation from objective measurements to coaching and better guidance of the individual mobilisation process: Expert interviews

3.1 Introduction

The benefits of physical activity, both inside and outside of the hospital have been investigated on a large scale. Since the middle of the 20^{th} century it has been recognised that physical activity is a major determinant of health [46]. Studies focusing on early mobilisation protocols in hospitalised patients have found that physical activity can reduce postoperative complications, reduce hospital length of stay, can increase functional capacity, can lead to a more effective functional recovery, and has a positive impact on mental status [7–14]. However, in hospitals it has been shown that patients spent most of their time in bed or sedentary, especially in the afternoon [15–17, 31]. Even in the healthy population almost half of the population does not meet the recommended amount of physical activity [47]. Even though wearable technology is rapidly expanding, which makes it possible to objectively measure physical activity, there is no consensus on how to use these measurements in the guidance of increasing physical activity and reducing sedentary behavior.

In order to increase physical activity and reduce sedentary behaviour, it is necessary to change peoples behaviour, which can be quite challenging. Research on physical activity interventions is extensive and very broad, leading to the existence of umbrella reviews of reviews on the literature [48]. From all these interventions it is quite challenging to determine what predicts a successful outcome and why certain interventions work for some groups, but not for others [30, 48]. Interventions often incorporate multiple features, without looking at the effect of each individual component, which makes it difficult for clinical practitioners to choose the correct features for a specific group. For example, a review investigating which behaviour change techniques work in increasing older adults' physical activity found that many techniques that increase physical activity in younger adults, such as goal setting, providing feedback on performance, providing information about others, when and where to perform behaviour, and self-monitoring, may not be as effective in older adults [49]. Most of the interventions aiming to increase physical activity in patients are used in the outpatient setting for the management of chronic diseases, such as diabetes, since promoting physical activity is one of the fundamentals of treatment [50]. When looking more into the subgroup of cardiac patients, most studies have focused on rehabilitation, rather than the hospital setting [51–53].

Studies investigating interventions to increase physical activity of hospitalised patients are less common. A recent meta-analysis by Taylor et al. aimed to determine if and what behaviour changing interventions are effective in hospitalised patients [54]. They found that goal setting and providing feedback on performance were independently associated with an increase in physical activity [54]. The effect of providing accelerometer-based feedback on physical activity in hospitalised patients has been investigated in different patient groups. A study by Peel et al. found that providing daily feedback, in addition to goal setting, to patients and therapists using an accelerometer in geriatric rehabilitation increased walking time compared to only goal setting [55]. Kanai et al. found an increase in physical activity, exercise expenditure and duration of activity time in hospitalised patients with ischemic stroke using accelerometer-based feedback [56]. On the contrary, Mansfield et al. found no difference in walking time, number of steps, longest bout duration, or number of long walking bouts for inpatient stroke rehabilitation using accelerometer-based feedback as part of a goal-setting process compared to patients that received no feedback [57]. An augmented feedback intervention was also not associated with an increase in time spent walking [58]. These differences might be explained by the way that the feedback is delivered. While Mansfield et al. and Dorsch et al. used a more passive approach, Kanai et al. asked the participants to actively note their accelerometer data on an activity calendar. There were also different methods of goal-setting, where the study of Kanai et al. used initially low targets that were easily accomplished. This explanation is supported by a review of Gormley et al., which found that goal-setting is effective, but having too many or unrealistic goals can be demotivating and stressful. Furthermore, they state that the timing of feedback and how feedback is delivered has impact on the effectiveness of the intervention [48]. A review by Baldwin et al. found that it is not clear wearable devices can impact physical activity or sedentary behaviour change across a range of inpatient settings. Studies that did report a positive effect on physical activity and sedentary behaviour included principles of thorough assessment and goal setting [30]. These discrepancies between studies underline the importance of understanding the needs, capacities and environment of the patient population that the intervention is applied to.

In order to correctly implement an intervention it is important to understand barriers and needs of healthcare professionals. Since they are the ones that see the patients daily, they can provide a lot of insight in the current problems regarding mobilisation of patients and how to overcome these problems. Earlier studies investigating the barriers and solutions for improving physical activity in hospitalised patients have found that key barriers are: differences in how physical activity is defined by healthcare professionals, the extend of freedom of choice and autonomy of patients, lack of time and knowledge from both patients and healthcare professionals, role expectations, expectations and characteristics of patients, physical status of patients, and the hospital environment [14, 18, 59]. These findings are supported by a review by Lee et al. investigating factors that influence physical activity after cardiac surgery. They found that patients with higher self-efficacy and positive attitudes or feelings about exercise were more physically active. Furthermore, support from family and peers, and incorporation of monitoring and personal recommendations for behavioral changes instead of general recommendations lead to more participation in rehabilitation [60]. Identified barriers were: uncertainty about the benefits of physical activity, and health related factors such as pain, injury, illness, comorbidities or depressive symptoms. However, the studies investigated in this review were focused on the participation in rehabilitation, rather then physical activity in the hospitalised setting.

3.1.1 Study goal

The effectiveness of interventions aiming to increase physical activity is dependent on different factors, including the setting and patient population. In order to set up a successful intervention it is important to understand the needs, barriers and wishes of the patient population and the situation that they find themselves in. Therefore, this study aims to answer the following research questions: What are the current problems around mobilisation of patients after cardiac surgery at TCT, how can patients be motivated to mobilise, and how can accelerometer-based feedback be incorporated to better guide the mobilisation process of patients according to healthcare professionals at the surgical ward?

3.2 Materials and methods

3.2.1 Study setting and design

This qualitative study was conducted at TCT, which is one of the top five thoracic centers of the Netherlands. The nurse to patient ratio at the cardio-thoracic surgery ward is 1:4 during daytime and 1:8 at night. The ward has one physiotherapist per day that sees every patient at a daily basis, until they have completed the entire mobilisation protocol. Completion of the mobilisation protocol is a prerequisite for discharge to home. Furthermore, there are two nurse practitioners per day that take care of the patients. One-on-one semi-structured interviews with healthcare professionals were held, aiming to investigate their views on the current daily practice and problems regarding mobilisation of patients after cardiac surgery and gain insight in how they believe physical activity can be promoted in this patient group. It was specifically of interest how they thought an accelerometer-based feedback system could be implemented, what the requirements for such a system would be, and how mobilisation data should be visualised. Ethical approval was obtained by the Ethics Committee Computer & Information Science of the University of Twente (number RP 2022-36). Written informed consent was obtained from each participant, prior to the start of the interview. Each participant was given a subject number. Audio recordings and transcripts of the interviews are anonymised using this subject number and saved on a secured disk.

3.2.2 Participant selection and recruitment

Healthcare professionals were selected to ensure heterogeneity in professions, age, sex and work experience. A physiotherapist with previous experience in conducting research in mobilisation of patients after cardiac surgery was asked for input on which healthcare professionals would be fit to participate in this study. Participants were required to be a surgeon, physiotherapist, nurse or nurse practitioner at TCT. Participants were invited for the interview by an email, including the participant information letter and a brief explanation of the objective of the study. This explanation was held short, in order to minimise the influence of this information on their answers in the interview. Inclusion of participants ended when no new answers were given to the asked questions and no new information was obtained.

3.2.3 Data collection and processing

The interviews were conducted between April and May of 2022 at the thoracic ward of TCT. In depth face-to-face interviews were conducted either in an empty patient room at the cardio-thoracic ward or in the office of the participant. During the interviews, only the researcher and the participant were present so the participants were encouraged to speak freely. The interviews were aimed to last for approximately 30 to 45 minutes. Interviews were conducted in Dutch, since this is the native language of all participants, and we believe that participants can speak more freely and authentically in their own language. Questions and quotes presented in this report are translated to English for readability. To be able to get answers to the research questions stated in 3.1.1, a semi-structured interview guide was used, which can be found in Table 3.1.

Table 3.1: Interview guide

Topics	Questions
Current mobilisation practice	How standardised is the mobilisation protocol? How is the patient involved in this process? What are problems that you currently experience regarding the mobilisation process? What is the best way to motivate patients to mobilise, how do you do this? What are differences between colleagues in this process? Would it be valuable to give patients insight in their own mobilisation process using objective data?
Previously set requirements for objective measurement system	What activities do you want to be able to measure? What would be a hindrance for patients to use such a system? What would be a hindrance for healthcare professionals to use such a system?
Feedback system	How accurate should this system be? During what time would you want to measure? What information is important to improve patient mobilisation? How should this information be visualised?

These questions were discussed with one of the supervisors of this study prior to the start of the first interview to ensure correct formulation of questions and adjustments were made accordingly. Questions were formulated as open as possible to encourage participants to talk openly and go in the direction they want to. Based on the answers of the participants follow-up questions were asked to increase understanding and explore different topics more in-depth. All interviews were recorded using a mobile phone, and these audio fragments were later saved on a secured disk using the subject number given to the participant after obtaining informed consent. Data was transcribed using the Listen N Write software (Version 1.30.0.10, Softonic, Barcelona, Spain). Listen n Write is a tool which includes a media player and text editor, so the user does not need to switch between two separate programs. It also has the ability to automatically pause the audio fragment when the user starts typing, and starts playing when the user stops typing.

3.2.4 Data analysis

Transcribed interviews were analysed using ATLAS.ti Windows (Version 22.0.6.0). Atlas is a qualitative research tool that can be used for coding and analysing transcript data. Initially, interviews were read thoroughly to get familiar with the data and get a first impression of preliminary characteristics and patterns. After that, data was read again, and relevant phrases and sections were labelled with codes. When finished with initial coding, it was investigated if codes were overlapping and if multiple codes could be grouped together to form categories and subcategories. From these categories the main reoccurring themes were identified, which will be described in the result section.

3.3 Results

3.3.1 Participants' characteristics

A total of eight healthcare professionals were included in the study. The participants consisted of physiotherapists (n=3), nurses (n=2), nurse practitioners (n=2), and a surgeon (n=1). The duration of interviews ranged from 30 to 48 minutes, leading to a total of 4.5 hours of interview data. Details can be found in Table 3.2.

Table 3.2: Participant characteristics

Participant code	Sex	Profession	Interview duration (minutes)
S1	Female	Physical therapist	46
S2	Male	Physical therapist	46
S3	Male	Physical therapist	30
S4	Female	Nurse	34
S5	Female	Nurse practitioner	38
S6	Female	Nurse	48
S7	Male	Surgeon	33
S8	Male	Nurse practitioner	30

When analyzing the data from the interviews, a few themes related to physical activity in patients after cardiac surgery stood out. These themes included patient characteristics and health status, environment and expectations, own responsibility of patients, the use of a positive approach and way of communication, and stimulating patients versus guarding their boundaries. These themes will be explained in more detail in sections 3.3.2 to 3.3.6. Furthermore, the outcomes of the more specific questions regarding the requirements of an accelerometer-based feedback intervention will be presented in section 3.3.7.

3.3.2 Patient characteristics and health status

One of the main things participants pointed out as being either a facilitator or barrier to mobilisation was the patient characteristics. The patient population at the thoracic ward is very heterogeneous, ranging from fifty year old patients with a blank history that are very physically active in their daily lives, to eighty year old patients with multiple comorbidities that already have a walking aid and home care before their admission to the hospital. Not only age is a limiting factor in mobilisation after surgery, there are also younger adults that are not physically active or have a bad lifestyle prior to their surgery. Participants described that they notice a great diversity in attitudes from patients towards their own health. Some patients are very motivated to do everything in their power to be as healthy as possible, whereas other patients just simply do not seem to care, with the latter group being hard to convince to change their attitudes and behaviour. Participants described patients with positives attitudes towards physical activity and their health prior to surgery as being more motivated to be physically active after surgery. The IQ of a patient plays a role in understanding the importance of mobilisation, with people that have a better understanding being easier to motivate.

Some patients are very involved with their health, they are concerned about how their health will be after the procedure, but other patients just do not care, they will say things like: "You know what, it does not matter. It is my disease, but you have to fix it." Those patients often fall back into bad habits. (S7)

The nature of a person also plays a role, one is more motivated while the other thinks: "I'm just operated, not now." (S5)

It is very strange to say, but it sometimes depends on the IQ of a patient as well. If someone just knows that health is important, then they know that they must mobilise immediately after the operation. (S6)

Participants mentioned culture as well as being a barrier to physical activity. Especially patients from Twente were described as being care avoiders. This means that they often wait too long before they go and see a doctor, meaning their condition has already suffered more than it could have. Participants described other, mostly non-western, cultures as being very careful when people are ill, making the patient rest. The family does everything for a patient, so the patient does not have to do anything or get out of the hospital bed. One participant mentioned that pain complaints being the reason for inactivity is also seen more in non-western cultures.

*It also depends on the patient or the culture. They think: "I have something, I have had surgery, I'm **lying** in the hospital, so I am going to lie in bed." (S8)*

In some cultures, when you are sick, you wear pajamas and lie in bed with a washcloth on your head. You are doing nothing and the food is shoveled into your mouth because you are sick. (S4)

You see it a lot with people from non Western backgrounds. If those people are admitted, you notice that they have a lot of pain complaints, above average when compared to people with a Western background. (S7)

While participants stated that they often see that patients who are physically active before surgery, are more active after surgery as well, this is not always guaranteed. A barrier to mobilisation that was mentioned frequently was the patients current health status. Sometimes patients experience postoperative complications, such as a CVA, delirium, and arrythmias. This makes it very difficult, if not impossible, for patients to mobilise. Furthermore, patients often experience edema, pain, nausea, fear, and fatigue. Some of these barriers can be solved. For example, pain can be made more bearable using the right medication. Therefore, participants mentioned it is always important to ask a patient why he does not want to move or be out of bed, since often there is an underlying problem that needs to be solved.

Starting the conversation about why someone doesn't want to move. If pain is a limiting factor, I can do something about it. (S5)

People can get arrythmias. That feels like they have just ran a marathon. They sweat a lot and feel awful. Then we tell them to rest and not to mobilise. (S6)

Somebody that has been in the ICU for a long time, that might have had a delirium, maybe have muscle weakness, there you should maybe be a little more reserved. (S7)

3.3.3 Environment and expectations

Participants mentioned the hospital room as being a barrier to physical activity. With the bed being in the room all day, it is tempting to go lie down. Patients get bored, because they do not have much to do, and because of this boredom they go to sleep to make the time pass faster. Initiatives mentioned to make the ward more attractive to mobilise are the ergometer including a television screen so patients can cycle through their neighborhood or a different country. There are signs on the wall that indicate how far you have walked, and there has been experimented with a 'move board'. This is a whiteboard that has coloured magnets to indicate what patients can do with or without supervision, so it is directly clear for family and healthcare providers when they visit the patients room. There was also an option to eat in a different room with other people. However, due to COVID-19 restrictions this never took off. One participant stated that an intervention like this is hard to implement, since it takes too much time and adjustments from the personnel. An intervention that has already been implemented and was mentioned by every participant as being motivating for patients and family is the poster designed by the 'Moving is improving' study, which can be seen in Figure 1.2 [20]. The advantages of the poster are that it is always there for patients and family to see, so patients are reminded to do their exercises, and healthcare personnel can always refer to this poster to support their explanations.

It is very tempting, the bed is in the room the entire time. If you are at home, you go downstairs and you do not have the bed that close. Here, the bed is just always there. There are also only two chairs in the room, so if there is family visiting, patients lie in bed, because their visitors need to be able to sit as well. (S4)

Patients say: "I'm bored, so I'm going to sleep." But that is of course the wrong way to think about it. (S6)

Participants also mentioned expectation management as a point to improve mobilisation. It is important to prepare patients for what is expected of them before and after the surgery. If patients understand that the better their condition is before surgery, the better their recovery will probably be, they might be triggered to work on their condition. Furthermore, patients are encouraged to bring good shoes, so they can walk more stable than when wearing slippers. If patients have heard information about the mobilisation protocol prior to surgery, this will help them better understand the information when it is repeated to them after surgery. Participants also considered family and their expectations as a barrier to mobilisation, however, they believe family can be turned into a facilitator as well. Family members are often really worried and protective about their loved ones, slowing the patient down and telling them to take enough rest. They will get everything for the patient, so they do not have to get up and out of bed. By involving family members in the mobilisation process, by telling them the importance of mobilisation and changing their expectations, they can become a motivator for patients to mobilise. Some participants mentioned that if a patient is hard to motivate, including family members and making them talk to the patient can be really helpful.

I think maybe the family is the most limiting factor. If family visits, patients often lie in bed. The family often thinks of heart surgery as a really big surgery, so they tell the patient: "Take it slow." I think 75% of family leaving the patients says something like that. (S2)

3.3.4 Positive approach and communication

Using a positive approach and the way information is communicated is of great influence on patients behaviour, according to the healthcare professionals. Healthcare professionals also stated there is a difference in communication between colleagues and professions. They mentioned that it is beneficial to focus more on communicating in a positive way. Instead of telling a patient what they are not allowed to do, focus should be shifted to what they can do. Knowledge and schooling of healthcare personnel plays a key role in this. There should be more consensus about what patients are allowed to do, so everyone communicates the same information to patients, preferably using a positive approach. Contradicting information and explanations can be confusing for patients. Pointing out achievements to patients, even the smallest ones, was also considered motivating for patients.

Especially when there is new personnel, they will say things like: "You can't do this, and this, and this." That is unfortunate. We should say more of what they ***can*** *do, instead of what they can't. (S2)*

You should always approach people in a positive way, that what they do, they do very well. That they will realise: "I am making progress."... You should stimulate people and approach them positively, that makes them grow. That is very important. (S6)

3.3.5 Responsibility of patients

Although healthcare professionals understand the importance of physical activity and diminishing sedentary behaviour, there is a limit to which extend they try to motivate their patients. For some, this limit is reached earlier than for others. Participants believed that patients should take their own responsibility when it comes to their health. They mentioned that when a person is really unmotivated, they will try to start a conversation about it. They will ask them why they do not want to mobilise and try to solve the underlying problem. For example, if the barrier is pain, medication could be given. If the limiting factor is fear and insecurity about their ability to move, they will work on regaining trust. They will try to make them understand the risks of being inactive, and make people realise that their actions have consequences for their health and recovery. However, they also stated that if this does not work, it feels like a waste of time and they believe that patients are responsible for their own actions. If a patient is not cooperative, participants stated that they rather invest their time in somebody that wants to be helped.

Then I think: "This is where my influence ends and if you do not want to and you are not motivated, then it is your own problem." (S1)

I try it once or twice, depending on the time I have. But I believe: "It is about your own health and if somebody does not want to guarantee their own health, why would I invest time in that every day? You want to do the best for somebody, but if somebody is not cooperative..." (S3)

If somebody decides they are not going to mobilise, I am not going to make them. They are here for themselves, not for me. If they do not want to work on their recovery, even though I explained the consequences, then I am not the one that tries to motivate them very hard. (S4)

3.3.6 Stimulating patients versus guarding their boundaries

Another thing that stood out during the analysis of the interviews, was participants mentioning difficulties with finding the balance between stimulating patients, but also guarding their boundaries. For most patients it is difficult to know what their own boundaries are, since they have never been in a similar situation before. Some patients are scared to move because it might hurt, and therefore they move less than they are able to. Other patients might feel very good the first two days after surgery, leading to them overestimating themselves and doing more than their body is capable of, resulting in a so called 'dip' on the third day. Then they will feel overwhelmed, tired and might experience muscle soreness. Participants mentioned this phenomenon multiple times. Not only for patients this balance between rest and activity is difficult to determine, for healthcare professionals this can be a challenge as well. There is a risk in patients going beyond their capabilities. Healthcare professionals stated that when patients are pushing themselves too much, there is a risk of arrythmias and patients can end up feeling even worse, which can lead to a prolonged hospital stay. One participant mentioned this as a pitfall of the poster. The poster states 'Moving is improving', resulting in patients thinking that doing more is always better and the more they move the faster their recovery is. However, the human body also needs time, rest and energy to heal.

Then they will get muscle soreness. Of course, that does not help either. That does not give you confidence in your body. (S4)

On the second day, the drains will be removed, they make the first steps, and that makes them very happy. "Well, I will go walk again." But then on the third day they think: "Well, I might have done too much." (S3)

If a colleague mentions to me: "Well it is a day two patient and he is doing really great." I will tell them: "You have to be really careful with that and saying that. Because you will always see... They will get a setback." (S6)

3.3.7 Feedback system

Hindrance for patients and/or caregivers

Since the effectiveness of an intervention is also dependent on the willingness of patients and healthcare professionals to work with it, possible points of hindrance were investigated. All healthcare professionals stated that they do not think wearing the accelerometers would cause significant discomfort for patients. Most participants had previous experience working with the sensors from the MOV$_E$M$_E$NTT study [31], and stated that they did not receive complaints about the sensors. There were, however, some points that were brought to attention as possible burdens, which need attention when implementing the use of accelerometers in clinical care. Participants stated that it could be a burden if a lot of action is required before being able to mobilise, for example if patients have to think about applying or taking off the sensors before walking, showering or going to bed. There is a risk of decubitus, especially for patients not being able to get out of bed or patients with insufficient nutritional status. The sensors could be uncomfortable when lying or sleeping. Placement of sensors should not interfere with wound healing or other types of care, and nurses should be able to apply a blood pressure band. Some participants expressed concerns regarding privacy of patients and patients willingness to be monitored at all times. However, they believed that when explaining the importance of monitoring the willingness of patients could be improved.

I wonder how many patients would be willing to wear sensors for their entire stay. I don't know if people want that. Sometimes when patients wear telemetry, they say things like: "They are able to see everywhere that I'm walking to..." (S1)

They might feel like they are being watched too much, maybe it has something to do with privacy. (S3)

Burdens for healthcare personnel that were mentioned had mainly to do with time. Participants expressed concerns with the time it takes to attach the sensors, and if they have to be taken off every time a patient wants to shower. If they come loose easily this could take up too much of valuable time. Furthermore, it would be burdensome if it would take a lot of time to get insight in the data. Another point of discussion was whose job it would be to attach the sensors and show patients how to use them. Nurses stated that they already have a lot of tasks, and it can not just be expected of them to add this to their tasks as well.

I think sometimes a lot is put on our plate. It should not be and this, and this, and this, and... And that we are asked: "Would you also put on the app for the patient or..." We already have a lot to do, you understand? (S6)

Accuracy, moments of measurement and activities of interest

All but one participant stated that a global impression of what a patient is doing would be sufficient for clinical practice. One participant stated that error margins should be as small as possible.

It is about the bigger picture. If someone is going home, it does not matter if they can walk 10000 steps or 9500. It is about reaching a certain minimum. (S1)

For me it is very simple, if a patient walks it should be measured that he walks, if he stands still that should be measured as well, otherwise you can not make a statement. (S7)

The algorithm described in Chapter 2 makes a classification based on 2.56 seconds. Increasing this time interval could decrease calculation time. In order to gain a global impression of the mobilisation status, the participants said that a measurement interval between ten en thirty seconds would be sufficient. Furthermore, the majority would measure the whole stay, including the night, since this provides the most insight. However, this is dependent on the goal you want to achieve. When only interested in mobilisation, measuring during daytime would be sufficient, but nighttime can include other factors such as good night rest. If only daytime is measured, participants suggested to measure from seven a.m. till eleven p.m.

The algorithm described in Chapter 2 has six activity outputs, including lying, sitting, standing, walking, cycling and walking stairs. We investigated if participants considered all these outputs important and if they felt this was complete or if they were missing certain activities. Four participants mentioned that the type of movement was not necessarily important, but rather that a patient is moving. According to those participants, the classes walking, walking stairs, and cycling can all be considered movement, so they could be grouped together in one class. There might be patients that really do not like cycling, so they might be advised to walk more instead of cycling. Patients that have problems walking, for example due to claudication, might prefer cycling over walking. In this way, the mobilisation schedule is adapted to the personal situation of each patient. Healthcare professionals stated that they think it is important to get patients out of bed more and into the chair, emphasizing the importance of correctly differentiating lying from sitting. To verticalise patients is one of the main mobilisation goals, especially in the first few days after surgery. Therefore, it is important to correctly classify when patients are sitting instead of lying.

But if it is walking or cycling, well, somebody is moving. (S1)

Because if you are cycling, walking stairs, or doing exercise behind the bed, to give an example, that is all movement. So basically that is all good. (S3)

I think if someone moves, then it is good. Whether it is on the chair with a exercise bike, that he makes a pedaling movement or just is out of bed, as long as he moves. (S8)

If you can see the difference between lying on the bed, or being on the bed, let's call it that, or sitting, moving, that makes a big difference in practice for us. Ultimately, we want to have people in bed as little as possible and as much as possible just sitting or moving. (S5)

Use of mobilisation goals

Opinions were divided on whether it is possible to integrate standardised mobilisation goals in the feedback intervention. Half of the participants believed setting goals would be feasible and they mentioned advantages such as that it is motivating to have goals, it provides patients something to hold on to so they know what they can and are allowed to do. Other participants stated that it would not be feasible to incorporate standardised goals. Their argumentation was that since every patient is different, it would not be desirable to set standardised goals for everyone. If goals are too easy, patients might not do enough, and if goals are too hard, patients will feel demotivated. According to them the protocol exists, but needs to be adapted to the personal needs of each patient, so standardised goals are not realistic. Suggestions that were made to incorporate goal setting would be to divide patients into categories, based on age and physical status before and after surgery. Furthermore, goals could be put as a reference, but it can be explained to patients that goals are adaptable and for each patient they need to figure out what is feasible. If goals are not met by patients for a good reason, goals could be set lower.

I think it is very difficult to set movement goals, because an eighty year old is different than a 65 year old. And some fifty year old people, they might be less physically active before surgery than a 75 year old, so I think that is very difficult. I think a goal is patient dependent. If I say: "you have to walk five minutes," and if a patient did that, even though he can do more, he might think: "Well, I have achieved my goal, so it is fine." So I think you have to set goals per patient. (S2)

There are always deviations from the protocol and every patient is different, and if someone is very nauseous then he does not have to walk three times a day according to me. Then I am already glad if he can keep down his food. (S4)

If I look at myself, and if I see on my smartwatch that I have to walk the stairs three times, then I won't go to bed, I would first want to walk the stairs three times. That is motivating, if you do not set the bar too high, if you set realistic goals. You can not expect somebody here to reach 10000 steps. (S5)

Data visualisation

Participants stated that visualisation of mobilisation data should be as simple as possible. It should be clear for everyone in one glance what the mobilisation status is. Patients already got a lot on their plate and they get a lot of information before and after surgery. Participants expressed doubts about how much information is actually remembered and understood by patients. Especially the morning is hectic for patients. The nurses get them out of bed, the nurse practitioner or surgeon does their round, the physical therapist comes to exercise with them. This can be exhausting for patients. Therefore, data on mobilisation status should be kept simple, as to not further overwhelm patients with information. Since all patients already have a personalised iPad in their room, participants suggested to make a dashboard for data visualisation that could be presented on this iPad. They suggested to make use of simple graphs with colors, and to use as few numbers as possible. For example, to display the amount of minutes patients perform a certain activity would be too hard to interpret. It is easier to use graphs with percentages, so the proportion of time certain activities are performed can be seen immediately. It was suggested that by incorporating the course over the days, patients and healthcare professionals could in a straightforward way see whether there was progression, which is motivating for patients. If there is stagnation in the progress, healthcare professionals can earlier intervene and investigate if there are underlying factors which cause this stagnation. Another suggestion was providing insight in the division of activities per part of the day. If patients are, for example, very active in the morning, but inactive in the afternoon, this could be a sign for physical therapists to change the mobilisation schedule. Giving patients insight in their data might give patients the feeling of more autonomy over their own recovery, rather than just being told what to do or what not to do. Finally, one participant suggested to make it interactive, meaning that patients can also indicate how they feel during certain activities, for example if they are short of breath or tired, because this would provide even more insight for healthcare professionals.

I would make it very visual with not too much information. Just one, two or three items. That's it. As simple as possible, graphical. That motivates patients. That they can see: "There is an upward trend. In the beginning I could do nothing, now I can already do this." (S8)

3.4 Discussion

This interview study aimed to gain more understanding of the current practice regarding mobilisation of patients after cardiac surgery and how an accelerometer-based feedback system can be used to improve mobilisation in these patients. Main problems regarding mobilisation of patients were the patient characteristics and health status, the hospital environment and expectations of the hospital stay. Using a positive approach and the way information is communicated is of great influence on peoples behaviour and mindset. Healthcare professionals mentioned having difficulties finding the balance between stimulating patients, but also guarding their boundaries. Accelerometers were considered not to be a burden for patients, however concerns were expressed about how much time it would take for the personnel to work with such a system and whose job it would be. If a feedback system is implemented, data about mobilisation should be presented as simple as possible, with the use of simple graphs and colours. Healthcare professionals believed that providing patients and healthcare professionals with insight in mobilisation data is motivating for patients, and would help the healthcare professionals to detect problems in an earlier stage.

To our knowledge, this study is the first to focus specifically on problems regarding physical activity of patients after cardiac surgery in the hospitalised setting. However, many of the findings in this study are comparable to outcomes of earlier interview studies investigating barriers to physical activity in a more general patient population. Patient characteristics and background, such as age, lifestyle, culture and pre-admission physical activity levels were also found as barriers to physical activity by Koenders et al. and Geelen et al. [14, 59]. In this study, healthcare professionals believed that patients who had a more active lifestyle prior to their admission, were also more likely to be more active during their hospital stay, provided that they have no other postoperative complications. Seemingly this positive effect towards activity contradicts de Klein et al., who found that patients believed that their pre-admission activity level did not influence their hospitalised activity level [18]. Patients interviewed by de Klein et al. all considered themselves inactive during admission. However, in their study it is not specified what those patients mean by inactivity, so patients perceptions of inactivity may differ. The finding that the patients current health status is a main barrier to physical activity as well is supported my multiple studies [18, 61, 62]. If patients need support with walking or getting out of bed, they are dependent on healthcare professionals, who might not always have the time to help them. If drains are still in, or if a patient is still connected to other medical devices, going for a walk can become quite challenging. Being tired, experiencing pain and fatigue can also lead to patients being inactive and rather staying in bed. When applying an intervention aiming to increase physical activity, these underlying reasons of inactivity should be taken into account. If patients simply cannot mobilise by themselves, it is questionable if objectively measuring their activity will be helpful. Even if they would want to move more, they are not able to. However, in a patient group that is able to mobilise by themselves, if objective measurements detect low activity levels, underlying reasons for inactivity can be detected earlier and healthcare professionals can try to solve these problems with the patient.

The finding of this study that patient expectations and the hospital environment play a major role in the lack of physical activity is supported by other studies [14, 18, 59]. By explaining to patients the importance and advantages of mobilisation prior to their admission, their expectations of the hospital stay might change. Some participants in this study mentioned that including family members in this process is important as well, which is in correspondence with the findings of Geelen et al.[59]. By often repeating information to patients, they start recognising and better understanding the importance of mobilisation. By preparing them so they know what is expected of them during the hospital stay, they will be more likely to be cooperative after surgery. This finding is supported by a previous study, that found that patients who have been admitted to a hospital before were more aware of the importance of mobilisation, since they personally have experienced the downsides of excessive bed rest [63]. At TCT patients are prepared for surgery during the preoperative screening conversations. During these conversations it is mentioned to bring good clothes and shoes. Healthcare providers believe that patients who are in pajamas all day are more likely to be inactive, so patients are encouraged to get dressed in the morning if they are able to. The participants in the study of de Klein et al., also confirmed that patients wearing pajamas all day were in bed more, regardless of their physical status [18]. The bed being the main object in the room was also described as being a barrier to physical activity by participants in this study. This finding is supported by Geelen et al. and Koenders et al., who state that having the bed as a centerpiece, where everything is brought to them on the bed, adds to the patient's expectation that they never have to get out of bed [14, 59]. At TCT adaptions to the ward have already been made to make it more tempting to move for patients, for example by placing an ergometer with television screen that patients can use at all times. Furthermore, signs have been placed on the wall that indicate the amount of meters that patients walk. In this way, they can see their progression and this makes it easier to understand the instructions given by the physical therapist. An attempt to implement a 'move board' and giving patients the opportunity to eat outside of their room has not succeeded, due to COVID-19 and the amount of change it requires from healthcare personnel. From this previous experience, it can be concluded that for an intervention to be implemented, it should be easy to use and it should not interfere with the workflow of personnel in a disproportionate extend.

A finding from this study, that has not been explicitly described by other literature, is the participants mentioning the use of a positive approach and the importance of pointing out improvements to patients. By telling patients what they are allowed to do, instead of what they are not allowed to do, they are likely to do more. By pointing out even small improvements, patients will regain trust in their body and this will help them obtain a more positive mindset. This will motivate patients to work more on their recovery. Nevertheless, it should be kept in mind that more is not always better. Finding the balance between activity and rest is difficult for both patients and healthcare professionals. This finding is supported by Koenders et al.[14]. Other studies do not mention the importance of rest. This could lead to the misconception that moving more is always better, but this is not true. Statements such as 'Moving is improving!' might give patients the impression that if they move more, they will recover faster. However, participants in this study frequently mentioned a dip on the third day post surgery, especially if patients were going beyond their boundaries on the first two days. When implementing an intervention aimed to increase physical activity, this should be taken into account. By objectively measuring the activity of patients, it can be detected earlier if patients seem to overestimate themselves, and healthcare professionals can intervene before other complications arise. However, the line between doing enough and doing too much is different for every patient. There is no consensus between healthcare professionals on what patients should do on a particular day. The mobilisation protocol is adjusted per patient, but the adjustments are based on the expertise of the physical therapist that is working that day. That there seems no consensus on what a patient should do each day, is also illustrated by the fact that half of the participants in this study claimed that it would be feasible to use standardised mobilisation goals, whereas the other half of the participants stated that this would not be feasible. Since the success of goal setting is mainly dependent on the ability to set challenging but realistic goals [48], it is recommended not to use standardised goal setting in this particular patient population. First, more research needs to be done on what realistic goals for these patients are, and there needs to be consensus on what is expected of patients on each day. Healthcare professionals should be trained using this knowledge, so information that is given to patients is not contradictory or confusing for patients.

Based on the answers given by healthcare professionals about the sensors, not much hindrance is expected when working with such a system. The most important thing to consider is time investment. When a task is very time consuming, it is more likely not to be completed [64]. Sensors should stay on when attached, and data extraction should be made easy and fast. The sensors that are currently used are the AX3 Axivity accelerometers. These sensors are not wireless, meaning that every time data is extracted, sensors needs to be taken off and put back on again. This is considered burdensome by the healthcare professionals. Therefore, it is recommended to use wireless sensors for further research, to limit the time needed for applying the sensors.

This study adds to the believe that the algorithm developed in Chapter 2 is sufficiently accurate for its intended use. Most participants stated that a global impression of a patients activity status is sufficient. Even if the system not 100% accurate, it can still give a good impression of a patients mobilisation status. What is notable in this study, is the fact that most participants state that the type of movement is not particularly important. It is easier to detect movement, than to divide movements in to different classes. However, we believe that since the algorithm is good at differentiating between the different activity classes, the activities can be classified separately. When implementing the feedback system, it can be chosen to first show the dynamic activities together as movement, and if a patient or healthcare professional is interested in what activities made up these movement times, this can be further inspected. If then it is noted that a person does not walk much, but cycles more often, the mobilisation protocol can be adapted to the wishes of a patient. In this study the importance of differentiating lying from sitting is mentioned as well. As described in Chapter 2, many studies investigating physical activity of patients classify lying and sitting together as sedentary behaviour [35, 36]. The current findings add to the believe that since getting out of bed is such a crucial part of in-hospital mobilisation, these two classes should be measured separately. We believe that with the current algorithm using two sensors, we are able to correctly distinguish lying from sitting. However, the headrest of the bed can be put upwards, which means that patients can sit in bed instead of in a chair. The accelerometers can not differentiate between sitting in bed and sitting in a chair, since the position of the accelerometers is the same in both cases. In order to know for certain whether or not patients are in bed or in the chair, a pressure sensor could be added under the mattress or on the chair.

When and how feedback is delivered plays a role in how effective the intervention is [48]. This study found that healthcare professionals state that data should be visualised as simple as possible, using simple graphs rather than numbers. This finding is supported by a study of Houts et al., who found that pictures can help patients better understand and remember information, especially in patients with low literacy [65]. Western et al., investigated the understanding and interpretation of technology-enabled multidimensional physical activity feedback and found that participants acknowledged an enhanced understanding of physical activity in response to receiving personalised feedback. Participants experienced a discrepancy between their own perceptions and the objective data [66]. This underlines the importance of objective measurements. They found that healthcare professionals were sceptical about the ability of patients to self-monitor without support, whereas patients felt that they could effectively self-monitor their own behaviour without support. Based on the results of the interviews at TCT, were healthcare professionals stated as well that it is very hard for patients to find a balance between moving and resting, we advise that patients are guided in this process. Since physical therapists see patients daily, we suggest that the mobilisation data of the day before is shown to the patients by them during their visit. This can help the physical therapists to make a plan for the day, and can help patients better understand their own activity patterns. It should be taken into account when designing a feedback system that patients should not be given the impression that more is always better.

3.4.1 Limitations

A limitation of this study is that the interviews have been conducted by only one researcher. Qualitative studies are sensitive to interpretations and subjective opinions of the researchers. When conducting semi-structured interviews, there is an opportunity to ask follow-up questions based on the answers participants give. However, the interviewer decides in that moment what they notice as interesting answers and what follow-up questions they want to ask. Therefore, it could be better to have multiple researchers conduct the interviews. On the other hand, having all the interviews conducted by the same interviewer provides consistency. The analysis of the data was also performed by only one researcher. In qualitative studies it is common to have two or more researchers independently analyse and code the data, to see if the same codes and themes emerge. In a consensus meeting codes, categories and themes can be redefined, and differences and unclear quotations can be discussed. This will lead to the analysis being less subjective to the interpretations of only one researcher.

The second limitation is that the interviewer had no previous experience in conducting interviews. Interviewing is a skill that needs to be developed by experience. It is quite difficult to ask open questions and not already mentioning some possible answers. The questions were discussed with one of the supervisors beforehand, and adjustments were made to make the questions as open as possible.

Another limitation of this study is that it includes only healthcare professionals and not patients. Healthcare professionals have a lot of experience in their field, and every profession has a different outlook and different connection to the patient and the mobilisation process. Because of their experience, they can give a good indication about what they think would be feasible in practice and what would not be feasible. Nevertheless, the intervention is aimed to increase physical activity in patients, so it would provide more insight when patient perspectives are included as well. However, based on the results of this study, patients are very different from each other, so interviewing them will probably lead to a great variance in answers given to the questions. Since this study is very exploratory in nature, we believe that including patients in this stage might lead to too much contradictory information. In a later stage, we consider it to be beneficial to include patients opinions, since patient adherence is important and if they are not content with an intervention, they are not going to use it.

3.5 Conclusion

This study aimed to investigate current problems regarding mobilisation of patients after cardiac surgery, how patients are currently motivated to mobilise, and how a accelerometer-based feedback system can help to better guide the mobilisation process. Main barriers regarding mobilisation are the patient characteristics and health status, the hospital environment and expectations. Using a positive approach can help motivate patients, but healthcare professionals also state that patients should take their own responsibility. Extra attention should be paid to guarding patients boundaries, as this can be difficult for themselves. When implementing a feedback system, it should be taken in to account that it would not cost much time for the personnel to work with it. The use of standardised mobilisation goals is not recommended for now. The feedback system should be used to inform patients and healthcare providers about the mobilisation process, and data should be visualised as simple as possible. By seeing objective mobilisation data, healthcare professionals gain better insight in the mobilisation process, and they can intervene earlier if a patient needs more stimulation or needs to be slowed down.

Chapter 4

General discussion and recommendations for future research

This study aimed to validate a neural network developed to objectively measure mobilisation in patients after cardiac surgery, and investigate how to use these measurements to better guide the mobilisation process. Mobilisation of patients after cardiac surgery can be objectively measured using two accelerometers worn at the upper thigh and upper arm. The neural network developed in this study can detect walking, sitting, standing, lying, cycling and walking stairs with an overall accuracy of 93%. The neural network is trained based on data collected from patients pre- and postoperatively, to include the different movement patterns from patients directly after surgery and when they gain back their normal movement. The interviews with healthcare professionals revealed that the most important barriers to mobilisation were the patient characteristics and health status, the hospital environment and patient expectations. Using a positive approach motivates patients, but there is a limit to the motivation by healthcare professionals. They believe that patients should also take their own responsibility. Objective mobilisation data should be visualised as simple as possible, by using simple graphs and colours. Progression over the days should be visualised as well, and insight in the division of activities per part of the day can be helpful and indicate if there is a need for adaptations in the mobilisation protocol.

Based on the results of this study, we currently suggest to first start by implementing only informative information on the mobilisation status of patients. This can be done by making a graph that shows the division of time spent doing the different activities. There have been previous studies investigating feedback strategies using goal setting. For example, Western et al. used traffic light colours to show patients and healthcare professionals if goals are being met [66]. Patients and healthcare professionals found this information very clear and motivating. While incorporating goals in a feedback system can be useful, this requires the use of challenging but realistic goals. This study has shown that there is not yet a consensus on goals. Having goals that are too easy will not be challenging enough, but having goals that are too difficult can be stressful and demotivating [48]. In current practice, physical therapists sit with the patient each day to talk about the mobilisation plan for the day. This is also goal setting in some way. The use of objectively measured data can help them in this process, and the following day physical therapists can check if goals are being met. If this is the case, they can tell this to their patients, which will give them more positive feelings towards mobilisation. If the mobilisation data shows that patients are mobilising inadequately, or are specially inactive during a particular part of the day, this can be incorporated in the strategy for the next day.

We also suggest that when starting with the implementation of the accelerometer-based feedback, it is important to include patient opinions as well. There might be differences between perceptions of healthcare professionals and patients in what information is clear and what is not. In the current stage of the research, we believed that including patients might be too early, since it is still very broad and patients opinions might differ even more than those of healthcare professionals. In a later stage, designs should be checked with a variety of patients for clarity and readability. It is also worthwhile to investigate which patients would benefit from such an intervention. Based on the results of the interviews, we concluded that patient characteristics play a major role in the mobilisation process and their willingness to cooperate. When patients do not seem to care about their health and do not listen to the advises of healthcare professionals to get out of bed and start moving, it is questionable if they would be willing to wear the sensors. Some patients, even though they understand the risks of being inactive, do not take responsibility for their own health. Therefore, it might be a challenge to get this type of patients to make an attitude shift. One way to address this problem could be to focus on interventions that are targeted specifically at this group and how to get them on board even before they are admitted to the hospital. Another group of patients that might not be helped with an intervention like this, is the group that is not able to ambulate by themselves. If patients are dependent on other persons to get out of bed or to move, showing to them that they are inactive will not change the situation. Even if they wanted to do more, they are not able to do so. It might even be frustrating for patients to see how little they do, but not being able to do something about it. This believe is supported by a study by Dall et al. investigating a technology assisted physical intervention among hospitalised patients [67]. They found that across all included patients, which were patients admitted to a pulmonary ward, visual feedback provided no statistically significant improvement in time spent out of bed compared to a control group without visual feedback. However, when doing a subgroup analysis, it revealed that patients with independent walking ability spent statistically more time standing and more time out of bed when receiving visual feedback compared to no feedback. A similar trend was seen towards time spent walking, but this was not significant. Therefore, it should be determined what patients would benefit from such an intervention, and which patients will probably not benefit from a physical activity intervention.

Although previous studies have reported an association between physical activity and shorter hospital length of stay, this finding was not supported by a large review by Taylor et al. investigating what behaviour change interventions can increase physical activity in hospitalised patients [54]. They found that even though physical activity increases, hospital length of stay did not decrease and it was not associated with mobility-related function. Patients after cardiac surgery generally stay for five days, unless there are other complications. Therefore, it should be investigated if an intervention increasing physical activity will lead to better outcomes. It could be that an intervention period of approximately five days is insufficient to promote changes in other outcomes, such as hospital length of stay. However, by focusing on the importance of physical activity and being out of bed during the hospital stay, patients might be triggered to keep working on their physical status when they are discharged to home, which can lead to them being in a better condition when the rehabilitation start.

Currently, there are approximately six weeks between discharge from the hospital to the start of a rehabilitation program, because this is the time needed for the sternum wound to heal. Physical therapists have mentioned that sometimes when they see patients again after those six weeks, their physical status has not improved, and sometimes is even worse. Recently, guidelines have been developed at TCT so patients are better informed about what they can and are allowed to do when they are at home. However, patients do not get guidance in this process. This guidance only starts at the start of the rehabilitation. Accelerometers can be used in this case to help patients get more insight in what they do, and how this is related to the guidelines that have been developed. By implementing such an intervention, people can better self-manage their recovery, which has been shown to lead to better outcomes in physical activity [51]. This might lead to patients being in a better condition when rehabilitation starts, which might lead to better outcomes.

Finally, we suggest that patients are informed about the sensors and the feedback system prior to their surgery. It has been proven that patients after cardiac surgery often experience cognitive impairment or delirium [68], which makes it harder for patients to understand information. This has also been mentioned by participants in this study. Since expectation management is important as well, providing patients with information about the sensors and the feedback prior to their surgery will prepare them for what is expected of them after surgery. Using this approach people can be informed and expectations can be managed at the same time. If they have already seen how the sensors work and what the importance of the sensors is, they will be more likely to be cooperative afterwards. This might lead to better adherence and acceptability of wearing the sensors.

Bibliography

[1] Y. Koop, R. Wimmers, I. Vaartjes, and M. Bots, "Hart- vaatziekten in nederland, 2021," Dec. 2021.

[2] P. Smits and M. Marteijn, "Openhartoperaties en percutane coronaire interventies bij patiënten met hartziekten in nederland," 2018.

[3] Nederlandse Hart Registratie, "NHR complete rapportage," Aug. 2022.

[4] L. Ball, F. Costantino, and P. Pelosi, "Postoperative complications of patients undergoing cardiac surgery," *Current Opinion in Critical Care*, vol. 22, pp. 386–392, Aug. 2016.

[5] A. H. Herdy, P. L. B. Marcchi, A. Vila, C. Tavares, J. Collaço, J. Niebauer, and J. P. Ribeiro, "Pre- and postoperative cardiopulmonary rehabilitation in hospitalized patients undergoing coronary artery bypass surgery," *American Journal of Physical Medicine & Rehabilitation*, vol. 87, pp. 714–719, Sept. 2008.

[6] B. J. Kalisch, S. Lee, and B. W. Dabney, "Outcomes of inpatient mobilization: a literature review," *Journal of Clinical Nursing*, vol. 23, pp. 1486–1501, Sept. 2013.

[7] A. Yayla and N. Özer, "Effects of early mobilization protocol performed after cardiac surgery on patient care outcomes," *International Journal of Nursing Practice*, vol. 25, Oct. 2019.

[8] P. Santos, N. Ricci, É. Suster, D. Paisani, and L. Chiavegato, "Effects of early mobilisation in patients after cardiac surgery: a systematic review," *Physiotherapy*, vol. 103, pp. 1–12, Mar. 2017.

[9] Y. Kanejima, T. Shimogai, M. Kitamura, K. Ishihara, and K. P. Izawa, "Effect of early mobilization on physical function in patients after cardiac surgery: A systematic review and meta-analysis," *International Journal of Environmental Research and Public Health*, vol. 17, p. 7091, Sept. 2020.

[10] M. Zanini, R. M. Nery, J. B. de Lima, R. P. Buhler, A. D. da Silveira, and R. Stein, "Effects of different rehabilitation protocols in inpatient cardiac rehabilitation after coronary artery bypass graft surgery," *Journal of Cardiopulmonary Rehabilitation and Prevention*, vol. 39, pp. E19–E25, Nov. 2019.

[11] A. Abeles, R. M. Kwasnicki, C. Pettengell, J. Murphy, and A. Darzi, "The relationship between physical activity and post-operative length of hospital stay: A systematic review," *International Journal of Surgery*, vol. 44, pp. 295–302, Aug. 2017.

[12] M. van der Leeden, C. Balland, E. Geleijn, R. J. Huijsmans, J. Dekker, M. A. Paul, C. Dickhoff, and M. M. Stuiver, "In-hospital mobilization, physical fitness, and physical functioning after lung cancer surgery," *The Annals of Thoracic Surgery*, vol. 107, pp. 1639–1646, June 2019.

[13] F. Shirvani, S. A. Naji, E. Davari, and M. Sedighi, "Early mobilization reduces delirium after coronary artery bypass graft surgery," *Asian Cardiovascular and Thoracic Annals*, vol. 28, pp. 566–571, Aug. 2020.

[14] N. Koenders, R. van Oorsouw, J. P. H. Seeger, M. W. G. N. van der Sanden, I. van de Glind, and T. J. Hoogeboom, "I'm not going to walk, just for the sake of walking: a qualitative, phenomenological study on physical activity during hospital stay," *Disability and Rehabilitation*, vol. 42, pp. 78–85, Aug. 2018.

[15] J. Hussey, T. Yang, J. Dowds, L. O'Connor, J. Reynolds, and E. Guinan, "Quantifying postoperative mobilisation following oesophagectomy," *Physiotherapy*, vol. 105, pp. 126–133, Mar. 2019.

[16] M. M. Pedersen, A. C. Bodilsen, J. Petersen, N. Beyer, O. Andersen, L. Lawson-Smith, H. Kehlet, and T. Bandholm, "Twenty-four-hour mobility during acute hospitalization in older medical patients," *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, vol. 68, pp. 331–337, Sept. 2012.

[17] C. J. Brown, D. T. Redden, K. L. Flood, and R. M. Allman, "The underrecognized epidemic of low mobility during hospitalization of older adults," *Journal of the American Geriatrics Society*, vol. 57, pp. 1660–1665, Sept. 2009.

[18] K. D. Klein, K. Valkenet, and C. Veenhof, "Perspectives of patients and health-care professionals on physical activity of hospitalized patients," *Physiotherapy Theory and Practice*, vol. 37, pp. 307–314, June 2019.

[19] R. Dubb, P. Nydahl, C. Hermes, N. Schwabbauer, A. Toonstra, A. M. Parker, A. Kaltwasser, and D. M. Needham, "Barriers and strategies for early mobilization of patients in intensive care units," *Annals of the American Thoracic Society*, vol. 13, pp. 724–730, May 2016.

[20] N. Wielens, S. Hulskotte, F. Halfwerk, and J. Grandjean, "Klinische mobilisatie voor de hartchirurgische patiënt: Bewegen is herstellen!," *Cordiaal*, vol. 39, pp. 118–120, Sept. 2018.

[21] F. R. Halfwerk, *Innovations in cardio-thoracic surgery: predicting and optimising outcome with state of the heart technology.* PhD thesis, University of Twente, 2020.

[22] S. A. Prince, K. B. Adamo, M. Hamel, J. Hardt, S. C. Gorber, and M. Tremblay, "A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review," *International Journal of Behavioral Nutrition and Physical Activity*, vol. 5, no. 1, p. 56, 2008.

[23] K. Valkenet, P. Bor, L. van Delft, and C. Veenhof, "Measuring physical activity levels in hospitalized patients: a comparison between behavioural mapping and data from an accelerometer," *Clinical Rehabilitation*, vol. 33, pp. 1233–1240, Mar. 2019.

[24] I. G. van de Port, K. Valkenet, M. Schuurmans, and J. M. Visser-Meily, "How to increase activity level in the acute phase after stroke," *Journal of Clinical Nursing*, vol. 21, pp. 3574–3578, Aug. 2012.

[25] L. G. Sylvia, E. E. Bernstein, J. L. Hubbard, L. Keating, and E. J. Anderson, "Practical guide to measuring physical activity," *Journal of the Academy of Nutrition and Dietetics*, vol. 114, pp. 199–208, Feb. 2014.

[26] D. Arvidsson, J. Fridolfsson, and M. Börjesson, "Measurement of physical activity in clinical practice using accelerometers," *Journal of Internal Medicine*, Apr. 2019.

[27] T. Amin, R. J. Mobbs, N. Mostafa, L. W. Sy, and W. J. Choy, "Wearable devices for patient monitoring in the early postoperative period: a literature review," *mHealth*, vol. 7, pp. 50–50, July 2021.

[28] S. E. R. Lim, K. Ibrahim, A. A. Sayer, and H. C. Roberts, "Assessment of physical activity of hospitalised older adults: A systematic review," *The journal of nutrition, health &amp aging*, vol. 22, pp. 377–386, May 2017.

[29] J. L. Anderson, A. J. Green, L. S. Yoward, and H. K. Hall, "Validity and reliability of accelerometry in identification of lying, sitting, standing or purposeful activity in adult hospital inpatients recovering from acute or critical illness: a systematic review," *Clinical Rehabilitation*, vol. 32, pp. 233–242, Aug. 2017.

[30] C. E. Baldwin, S. M. Parry, L. Norton, J. Williams, and L. K. Lewis, "A scoping review of interventions using accelerometers to measure physical activity or sedentary behaviour during hospitalization," *Clinical Rehabilitation*, vol. 34, pp. 1157–1172, June 2020.

[31] F. R. Halfwerk, J. H. L. van Haaren, R. Klaassen, R. W. van Delden, P. H. Veltink, and J. G. Grandjean, "Objective quantification of in-hospital patient mobilization after cardiac surgery using accelerometers: Selection, use, and analysis," *Sensors*, vol. 21, p. 1979, Mar. 2021.

[32] I. C. Gyllensten and A. G. Bonomi, "Identifying types of physical activity with a single accelerometer: Evaluating laboratory-trained algorithms in daily life," *IEEE Transactions on Biomedical Engineering*, vol. 58, pp. 2656–2663, Sept. 2011.

[33] J. E. Sasaki, A. M. Hickey, J. W. Staudenmayer, D. John, J. A. Kent, and P. S. Freedson, "Performance of activity classification algorithms in free-living older adults," *Medicine and Science in Sports and Exercise*, vol. 48, pp. 941–950, May 2016.

[34] H. Oinas-Kukkonen and M. Harjumaa, "Persuasive systems design: Key issues, process model, and system features," *Communications of the Association for Information Systems*, vol. 24, 2009.

[35] H. C. van Dijk-Huisman, W. Bijnens, R. Senden, J. M. N. Essers, K. Meijer, J. Aarts, and A. F. Lenssen, "Optimization and validation of a classification algorithm for assessment of physical activity in hospitalized patients," *Sensors*, vol. 21, p. 1652, Feb. 2021.

[36] K. Taraldsen, T. Askim, O. Sletvold, E. K. Einarsen, K. G. Bjåstad, B. Indredavik, and J. L. Helbostad, "Evaluation of a body-worn sensor system to measure physical activity in older people with impaired function," *Physical Therapy*, vol. 91, pp. 277–285, Feb. 2011.

[37] S. Oniga and J. Suto, "Human activity recognition using neural networks," in *Proceedings of the 2014 15th International Carpathian Control Conference (ICCC)*, IEEE, May 2014.

[38] C.-C. Yang and Y.-L. Hsu, "A review of accelerometry-based wearable motion detectors for physical activity monitoring," *Sensors*, vol. 10, pp. 7772–7788, Aug. 2010.

[39] S. Katz, "Studies of illness in the aged," *JAMA*, vol. 185, p. 914, sep 1963.

[40] D. Anguita, A. Ghio, L. Oneto, X. Parra, and J. L. Reyes-Ortiz, "A public domain dataset for human activity recognition using smartphones," *21th European Symposium on Artificial Neural Networks, Computational Intelligence and Machine Learning, Bruges, Belgium*, Apr. 2013.

[41] M. Janidarmian, A. R. Fekr, K. Radecka, and Z. Zilic, "A comprehensive analysis on wearable acceleration sensors in human activity recognition," *Sensors*, vol. 17, p. 529, Mar. 2017.

[42] A. Mannini and A. M. Sabatini, "Machine learning methods for classifying human physical activity from on-body accelerometers," *Sensors*, vol. 10, pp. 1154–1175, Feb. 2010.

[43] G. Bunkheila, "Code for webinar "signal processing and machine learning techniques for sensor data analytics"," 2020.

[44] Google Developer Groups, "Classification: Precision and recall." `https://developers.google.com/machine-learning/crash-course/classification/precision-and-recall`, 2022. Accessed: 2022-10-20.

[45] W. Bijnens, J. Aarts, A. Stevens, D. Ummels, and K. Meijer, "Optimization and validation of an adjustable activity classification algorithm for assessment of physical behavior in elderly," *Sensors*, vol. 19, p. 5344, Dec. 2019.

[46] S. N. Blair, G. D. Smith, I.-M. Lee, K. Fox, M. Hillsdon, R. E. McKeown, W. L. Haskell, and M. Marmot, "A tribute to professor jeremiah morris: The man who invented the field of physical activity epidemiology," *Annals of Epidemiology*, vol. 20, pp. 651–660, Sept. 2010.

[47] Rijksinstituut voor volksgezondheid en milieu, "Cijfers en feiten sport en bewegen." `https://www.loketgezondleven.nl/gezondheidsthema/sport-en-bewegen/cijfers-en-feiten-sport-en-bewegen`, 2022. Accessed: 2022-10-26.

[48] L. Gormley, C. A. Belton, P. D. Lunn, and D. A. Robertson, "Interventions to increase physical activity: An analysis of candidate behavioural mechanisms," *Preventive Medicine Reports*, vol. 28, p. 101880, Aug. 2022.

[49] D. P. French, E. K. Olander, A. Chisholm, and J. M. Sharry, "Which behaviour change techniques are most effective at increasing older adults' self-efficacy and physical activity behaviour? a systematic review," *Annals of Behavioral Medicine*, vol. 48, pp. 225–234, Mar. 2014.

[50] K. A. Cradock, G. ÓLaighin, F. M. Finucane, H. L. Gainforth, L. R. Quinlan, and K. A. M. Ginis, "Behaviour change techniques targeting both diet and physical activity in type 2 diabetes: A systematic review and meta-analysis," *International Journal of Behavioral Nutrition and Physical Activity*, vol. 14, Feb. 2017.

[51] O. Draper, I. Goh, C. Huang, T. Kibblewhite, P. L. Quesne, K. Smith, E. Gray, and M. Skinner, "Psychosocial interventions to optimize recovery of physical function and facilitate engagement in physical activity during the first three months following CABG surgery: a systematic review," *Physical Therapy Reviews*, vol. 25, pp. 381–398, Oct. 2020.

[52] K. P. Izawa, S. Watanabe, K. Omiya, Y. Hirano, K. Oka, N. Osada, and S. Iijima, "Effect of the self-monitoring approach on exercise maintenance during cardiac rehabilitation," *American Journal of Physical Medicine &amp Rehabilitation*, vol. 84, pp. 313–321, May 2005.

[53] L. Butler, S. Furber, P. Phongsavan, A. Mark, and A. Bauman, "Effects of a pedometer-based intervention on physical activity levels after cardiac rehabilitation," *Journal of Cardiopulmonary Rehabilitation and Prevention*, vol. 29, pp. 105–114, Mar. 2009.

[54] N. F. Taylor, K. E. Harding, A. M. Dennett, S. Febrey, K. Warmoth, A. J. Hall, L. A. Prendergast, and V. A. Goodwin, "Behaviour change interventions to increase physical activity in hospitalised patients: a systematic review, meta-analysis and meta-regression," *Age and Ageing*, vol. 51, July 2021.

[55] N. M. Peel, S. K. Paul, I. D. Cameron, M. Crotty, S. E. Kurrle, and L. C. Gray, "Promoting activity in geriatric rehabilitation: A randomized controlled trial of accelerometry," *PLOS ONE*, vol. 11, p. e0160906, Aug. 2016.

[56] M. Kanai, K. P. Izawa, M. Kobayashi, A. Onishi, H. Kubo, M. Nozoe, K. Mase, and S. Shimada, "Effect of accelerometer-based feedback on physical activity in hospitalized patients with ischemic stroke: a randomized controlled trial," *Clinical Rehabilitation*, vol. 32, pp. 1047–1056, Feb. 2018.

[57] A. Mansfield, J. S. Wong, J. Bryce, K. Brunton, E. L. Inness, S. Knorr, S. Jones, B. Taati, and W. E. McIlroy, "Use of accelerometer-based feedback of walking activity for appraising progress with walking-related goals in inpatient stroke rehabilitation," *Neurorehabilitation and Neural Repair*, vol. 29, pp. 847–857, Jan. 2015.

[58] A. K. Dorsch, S. Thomas, X. Xu, W. Kaiser, B. H. Dobkin, T. Emara, D. Edwards, P. Fonzetti, J. Maasch, S.-G. Lee, M. O. Owolabi, T. K. Hamzat, C. J. LeBlanc, R. Morse, N. Swaminathan, G. K. Karatas, R. Boza, A. W. Brown, I. Miyai, T. Kawano, S.-Y. Chen, H. C. Hanger, C. Zucconi, S. Mammi, C. Ghislanzoni, F. Juan, and C. E. Lang, "SIRRACT," *Neurorehabilitation and Neural Repair*, vol. 29, pp. 407–415, Sept. 2014.

[59] S. J. G. Geelen, B. M. Giele, R. H. H. Engelbert, S. de Moree, C. Veenhof, F. Nollet, F. van Nes, and M. van der Schaaf, "Barriers to and solutions for improving physical activity in adults during hospital stay: a mixed-methods study among healthcare professionals," *Disability and Rehabilitation*, vol. 44, pp. 4004–4013, Feb. 2021.

[60] S. Lee and E. G. Collins, "Factors influencing physical activity after cardiac surgery: An integrative review," *Heart & Lung*, vol. 50, pp. 136–145, Jan. 2021.

[61] C. J. Brown, B. R. Williams, L. L. Woodby, L. L. Davis, and R. M. Allman, “Barriers to mobility during hospitalization from the perspectives of older patients and their nurses and physicians,” *Journal of Hospital Medicine*, vol. 2, pp. 305–313, Sept. 2007.

[62] C. So and E. Pierluissi, “Attitudes and expectations regarding exercise in the hospital of hospitalized older adults: A qualitative study,” *Journal of the American Geriatrics Society*, vol. 60, pp. 713–718, Mar. 2012.

[63] S. Lafrenière, N. Folch, S. Dubois, L. Bédard, and F. Ducharme, “Strategies used by older patients to prevent functional decline during hospitalization,” *Clinical Nursing Research*, vol. 26, pp. 6–26, July 2016.

[64] B. J. Kalisch, “Missed nursing care,” *Journal of Nursing Care Quality*, vol. 21, pp. 306–313, Oct. 2006.

[65] P. S. Houts, C. C. Doak, L. G. Doak, and M. J. Loscalzo, “The role of pictures in improving health communication: A review of research on attention, comprehension, recall, and adherence,” *Patient Education and Counseling*, vol. 61, pp. 173–190, May 2006.

[66] M. J. Western, O. J. Peacock, A. Stathi, and D. Thompson, “The understanding and interpretation of innovative technology-enabled multidimensional physical activity feedback in patients at risk of future chronic disease,” *PLOS ONE*, vol. 10, p. e0126156, May 2015.

[67] C. H. Dall, H. Andersen, T. M. Povlsen, and M. Henriksen, “Evaluation of a technology assisted physical activity intervention among hospitalised patients: A randomised study,” *European Journal of Internal Medicine*, vol. 69, pp. 50–56, Nov. 2019.

[68] D. Greaves, P. J. Psaltis, T. J. Ross, D. Davis, A. E. Smith, M. S. Boord, and H. A. Keage, “Cognitive outcomes following coronary artery bypass grafting: A systematic review and meta-analysis of 91, 829 patients,” *International Journal of Cardiology*, vol. 289, pp. 43–49, Aug. 2019.