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SOCIAL SERVICES, HEALTH AND SPORTS

WEARABLE MOTION SENSORS IN MEASURING THE ACTIVITY OF A REHABILITATION PATIENT

An integrative literature review

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THESIS

Abstract

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Abstract

Rehabilitation is one key part of healthcare services, and one of the most common patient group needing rehabilitation throughout the world and in Finland, are people who have had a stroke. It has been noticed that the patient’s amount of physical activity during recovery and rehabilitation is linked with the outcome. Using technological improvements in healthcare will offer a change in working methods and potentially lower costs in healthcare. The use of new technologies in healthcare will rise in the future, such as the use of sensor technology will increase. It is said that the most promising technology to aid healthcare to provide more cost-effective and efficient care are wearable sensors. Wearable motion sensors to measure activity on rehabilitation patients are a rising opportunity to enhance the rehabilitation services, providing both patients and the rehabilitation professionals a new tool for diversifying rehabilitation. In this thesis, the goal was to find out what kind of wearable motion sensors exists that are suitable for rehabilitation setting. Also, pointing out the needed technology to implement motion sensor systems in rehabilitation and the benefits and challenges of using wearable motion sensing technology in rehabilitation. Smartphones and some sensors that only measure physiological signs, such as heart rate and respiratory rate, were excluded of this thesis.

The research method was chosen to be an integrative literature research, as it offers an opportunity to use research material from a wider spectrum. The integrative literature review progressed by defining the research questions, then searching the relevant literature from databases, choosing the original studies, assessing the quality of literature and analysing it by using a general inductive approach and finally presenting the findings. Databases used in this research were Savonia-FINNA, EBSCHO, Cinahl Complete, PubMed and Google Scholar. Twenty-five (25) research articles were chosen for the literature review.

There were found many types of wearable motion sensors that are suitable for activity monitoring and especially on rehabilitation patients. The types of sensors are accelerometers, pedometers, gyroscopes, Global Positioning System (GPS), magnetometers, Electromagnetic Tracking System (ETS), electromyography (EMG), goniometers, Insole Pressure Sensors (IPS) and smart textiles. Also, the environmental context of motion sensing system is presented amongst the wearables, as it was mentioned multiple times in the original studies. The original studies also provided the information about what technical demands there are to have a working sensor system in rehabilitation use. There were multiple benefits on using wearable motion sensors in activity monitoring with rehabilitation patients, such as them serving as an indicator in assessing the effectiveness of rehabilitation interventions. There were also challenges found, for example the underutilization of e-health interventions in healthcare and the busy clinical environment that will not leave a lot of time for implementing and training to use the new technology. Further research considering this topic could be clinical trials on different wearable motion sensors, and finding out which of them is the most suitable on stroke patient’s activity monitoring during rehabilitation.

Keywords

Rehabilitation, wearable motion sensor, physical activity, activity monitoring, stroke

CONTENTS

LIST OF FIGURES

1 INTRODUCTION

Every year 15 million people around the globe have a stroke and it is one of the most common causes inducing disability in western countries. (Hickey & Livesay 2015, 17.) About 14 000 people suffer from strokes every year in Finland. It has been proven in multiple studies that people suffering from strokes benefit from rehabilitation, especially rehabilitation that is formed from multidisciplinary team working in interprofessional cooperation (Mäntynen 2007, 34.) This thesis focuses on rehabilitation patients that suffer from strokes due to them being typical patients in rehabilitation services, because people who have had a stroke represent a major part of the whole physical rehabilitation population in the world. (Lang, Barth, Holleran, Konrad & Bland 2020, 9).

The amount of patient's activity has a connection on the results of the patient's recovery during rehabilitation. The study from Bernhardt, Dewey, Thrift and Donnan (2004) of observing stroke patients for their first two weeks in a stroke unit shows that early patient's activation and mobilization can improve the outcome. Their research also presents different forms of activity, such as talking, reading and watching tv to more physical activities, such as sitting up, standing, walking and using hands while eating. This thesis is focused on the activity as a term that considers the physical activity of a patient. It is said on Sitra's and Finnish Social Welfare and Health Ministry's publication, that the suggested time of activity for a rehabilitation inpatient is six hours per day in Finland. (Palvelupakettikäsikirja 2017, 47). Physical activity has a major role on preventing complications to recurrent stroke and other cardiovascular diseases. Researches show that regular physical activity has a beneficial impact on stroke survivors when thinking of cardiovascular risk factors, such as hypertension and insulin response. (Billinger et al. 2014, 2533).

Using technological improvements in healthcare will drive a change in working methods, patient and professional relations and potentially lower costs in healthcare. It is said that in the future digital services and using new technologies, such as sensor technology and mobile technology, will increase dramatically in healthcare. Wearable sensors and different applications of them are the most promising technology to support healthcare to provide more cost-effective and efficient care, while also improving people's ability to manage their own health. (Alamäki et al. 2019, 6-7.) The technology considering wearable sensors that are designed to measure human movement in different ways, is evolving rapidly. The wearable motion-sensing devices have extended data storage, are smaller in size and lighter than before. The wearable devices are nowadays well known among general public, as there are multiple types of devices commercially available for health and exercise monitoring at home. Many times wearable devices include multiple sensors, such as magnometers, gyroscopes and light sensors, but accelerometers being the most common of them. (Lang et al. 2020, 1.)

The focus on this thesis' research is to find out what kind of wearable motion sensors exists to measure the activity of a rehabilitation patient, using an integrative literature review as a research method. This thesis' goal is also to show what kind of technology is needed when implementing wearable motion sensor systems in clinical setting and what are the benefits and challenges on usign this kind of technology. This thesis excludes cell phones, such as smartphones, as a wearable device because they are usually used for multipurposes and are not worn routinely and can also be difficult to handle, for example in physical therapy sessions. Also, wearable sensors that measure physiological signals, such as heart rate and respiratory rate, are excluded of this thesis. (Lang et al. 2020, 1.)

With wearable technology it is possible to change how healthcare is monitored and delivered, but there are some challenges that need to be considered while implementing this kind of new shift in healthcare. Challenges that must be considered include questions about healthcare systems readiness to the implementation of this kind of technology and how the growing amount of information in clinical practice will integrate to the clinical workflows of healthcare professionals and providers. One challenge is also how using this kind of developed technology will add value in the healthcare process, without increasing the costs in the healthcare services and the workload of professionals. The developers of wearable technology must develop solutions that can be easily integrabled and are easy to use by healthcare professionals, while still considering the existing constraints of healthcare. (Alamäki et al. 2019, 7.)

2 STROKES

2.1 Definition

The WHO defines stroke as "rapidly developing clinical signs of focal (at times global) disturbance of cerebral function, lasting more than 24 hours or leading to death with no apparent cause other than that of vascular origin." Stroke can be either a hemorrhage or an infarction and the classification is based on the pathology of the focal brain injury. (Rowland & Pedley 2009, 250.) This means that stroke is a neurological deficit due to an acute focal injury of the central nervous system by a vascular cause. These causes are cerebral infarction, intracerebral hemorrhage and subarachnoid hemorrhage. (Sacco et al. 2013, 2064.) In Western countries, one of the leading causes of persistent disability is stroke. Strokes cause acute deficits in cognition, motion, emotion and sensation. The major cause of a stroke is a interruption in cerebral blood supply, leading into a subsequent ischemic brain damage, an infarction. The second leading cause of a stroke is a intracranial hemorrhage, while >25% of stroke patients suffer from it (Seitz & Donnan 2015, 1.) Signs of a patient suffering from a stroke include abrupt numbness or weakness of arm, leg or face. Typically this occurs on one side of the body. Symptoms also include sudden confusion, troubles in speaking or understanding, and sudden trouble seeing with one or both eyes. Also, dizziness, sudden severe headache, balance loss or troubled walking and coordination, are symptoms of a stroke (Macko 2014, 44.)

In Finland, the age of people suffering from stroke is on average 75 years and the incidence gets higher rapidly due to aging beyond that number. The typical causes behind stroke are hypertension, smoking and high cholesterol levels. By managing these causes by primary prevention from healthcare, the patient amount of people suffering from stroke will stay the same for next decade, even though the population is aging rapidly. In Finland 14% of patients with stroke will have a recurrent stroke in a year after the first one and even 50% at some point in their life will suffer from a recurrent stroke. Due to this it is very important to emphasize the meaning of secondary prevention and also from the view of costs in the healthcare. If a person has a recurrent stroke, the healthcare costs from that patient will be almost 50% more. Because of this, it is necessary to find effective and qualified care- and rehabilitation methods in the future. (Pyöriä et al. 2015, 14.)

2.2 Cerebral infarction

Brain metabolism is altered if the blood supply to it is completely interrupted for 30 seconds, and neuronal function may cease after one minute. If anoxia lasts five minutes, a chain of events is initiated that may result in cerebral infarction. The damage may be reversible, if oxygenated blood flow is restored quickly enough, as with TIA (Transient Ischemic Attack). The infarction may be confined to a single vascular territory, this is when the occlusion affects a distal intracranial branch or small penetrant end-artery. If the occlusion is located more proximal in the arterial tree, the ischemia is likely more expansive and involves more than one vascular territory or border zone. This is when the ischemia may result with limited infarction in the distal fields of the vascular supply. Intracranial proximal occlusions may result in both penetrant artery ischemia and coexisting surface branch territory infarction. (Rowland & Pedley 253, 2009.)

There are many mechanisms that can lead to brain ischemia. Hemodynamic infarction originates from occlusion caused by atherosclerosis and coexisting thrombosis or severe arterial stenosis that result in impediment to normal perfusion. Embolism occurs when a particle of thrombus from a more proximal source , not so frequent causes of an infarction are for example arterial dissection, vasculitis, hypercoagulable disorders, vasospasms and hyperviscosity. The four main causes for a cerebral infarction are cardioembolic, large-vessel atherosclerotic, small vessel and cryptogenic causes. (Rowland & Pedley 253, 2009.)

2.3 Cerebral hemorrhages

Intracerebral hemorrhage, ICH, is defined when there is a bleed into the parenchyma of the brain, usually originating from a small penetrating artery. Subarachnoid hemorrhage, SAH, means when there's a bleed into the subarachnoid space originating from one of the main vessels of the Circle of Willis. (Alexander 2013, 74). The spontaneous and nontraumatic ICH affects more than 2 million people every year worldwide, and it is a major public health issue. (Hickey & Livesay 2015, 150). Due to the population aging and the increased amount of cardiovascular diseases and anticoagulation therapy used for treating those, will likely increase the amount of people who get ICH in the future. The incidence of ICH tends to double every decade of age after 35 years. Overall, the risk for having a ICH is higher in men than in women, although this varies as age advances. (Alexander 2013, 74-76.) When comparing all the stroke types, ICH has the poorest prognosis for survival and functional recovery. (Hickey & Livesay 2015, 149).

ICH can be classified either primary or secondary. The primary ICH emerges from spontaneous rupture of small arterioles, which are damaged by chronically high blood pressure levels and cerebral amyloid angiopathy. The risk factors for this include smoking, diabetes mellitus, excessive alcohol use and illicit drug use. The secondary ICH is usually linked with vascular malformations, abnormal coagulopathies, vasculitides and brain tumors*.* (Hickey & Livesay 2015, 153.) The leading cause for ICH is chronic hypertension which will cause vessel degeneration, especially in the age group of 40 to 70 year olds. Due to hypertension, the vessel wall weakens and ruptures and this leads to blood leaking into the surrounding tissue, causing a mass effect and toxic effects of blood products on the surrounding tissue. Elevated arterial pressure damages the layers of arteriole and the vessel becomes diseased and degenerates. (Hickey & Livesay 2015, 154.)

Subarachnoid hemorrhage (SAH), is a condition when there is a bleed in the space between the arachnoid and the pia. Blood becomes mixed with cerebrospinal fluid and and bathes the exterior of the major cerebral blood vessels. The most common cause for SAH is a rupture of cerebral aneurysm, as it occurs in 85% of patients with subarachnoid hemorrhages. Also, a rupture of an arteriovenous malformation (AVM) or a trauma to the head may cause SAH. Subarachnoid hemorrhages due to ruptured aneurysm or AVM or more common in females than in men. The use of anticoagulation medication or having clotting disorders increase the risk for SAH. The risk for SAH also increases within aging, as the risk for aneurysm rupture increases with age and the average age for aneurysm rupture is 55 years old. Subarachnoid hemorrhages due to trauma are common, they emerge more in men than women and in all ages. Avoidance of smoking or illicit drug use, such as cocaine, can be beneficial as they are known to increase blood pressure. (Alexander 2013, 96-98).

2.4 Recovery

The recovery process from a stroke is a multilateral process depending on different mechanisms that become operational at different phases, after the acute injury and the first hours to many months. The use of intravenous and intra-arterial thrombolysis have opened new ways to substantially reverse the amount of brain damage and the neurological deficits from the stroke. (Seitz & Donnan 2015, 1.) The capability level to function in stroke patients have been proven to be better depending on how fast they have recovered their functions in the first days and weeks onset of the stroke. Researches show that the capability to gain walking functions can be predicted even on the first two days since stroke, by monitoring the static sitting balance and muscular activity of the paretic leg. Researches also show that those stroke patients who could remain 30 seconds their sitting balance or could visibly contract one of the large muscles on the paretic leg, could walk independently in six months after having the stroke. While the capability to achieve independent walking reduced when the patient could not perform those tasks mentioned earlier, in nine days. Having cognitive disorders in the early stage also predicts on how the patient's capability to function independently will recover. The more difficult the cognitive disorders are, the higher risk there is to end up in long-term institutional care, to having problems on performing everyday tasks and to weak quality of life. (Pyöriä et al. 2015, 21.)

The national stroke patient registry tells that patients that have had thrombolytic therapy when having a stroke, 68% of them are independent on their everyday activities. That kind of independency predicts better capability and lower incidency for death for many years. Also, if the paretic arm gains function to flex fingers in 72 hours after having the stroke, it will indicate the return of the hand functions in six months of time. (Aivoinfarkti ja TIA 2020.)

2.5 Impact on society

About 25% of the people having a stroke are in working-age. (Kalkasmaa & Multaharju 2017, 1.) Some stroke survivors are able to return home and to their normal life in a relatively short period of time, still the vast majority, up to 75% of them will require some level of postacute rehabilitation to reintegrate back to their community. (Hickey & Livesay 2015, 366). 10% of the patients will recover so poorly that rehabilitation can not be initiated and 10% of the patients will recover soon to almost as they were before having the stroke. Over 40% of the patients need intensive rehabilitation. (Kalkasmaa & Multaharju 2017, 1.) A research from the year 2009 shows that the incidency for the people in Finland to have a stroke is about 1,5% of the population. (Aivoinfarkti ja TIA 2020). About 22% of the people with stroke will be deceased in a year after having the stroke, which makes it a common cause of death in Finland. (Pyöriä et al. 2015, 14).

The burden caused by stroke on society is projected to rise from the year 1990s number of 38 million disability adjusted life years lost globally, to 61 million years in the year 2020, because of the population aging. Over 50% of stroke survivors have long-term therapy needs, and they remain dependent on others for evereyday activities. (Macko 2014, 34.)

2.6 Impact on economy

Stroke is one of the most expensive conditions in Finland, right after Alzheimer's disease and schizophrenia when comparing the costs. Having a stroke will usually lead into years of need of healthcare services and use of resources, or even permanent institutional care. The care of stroke patients now make about 7% of healthcare costs every year, about 1,1 billion euros. (Pyöriä et al. 2015, 23.) In US dollars, the lifetime costs per stroke patient range from 59,800 to 230,00 dollars. (Macko 2014, 34). There has been a rise on the cost of stroke treatment, as the developed care for the acute phase, such as thrombolytic therapy and the new secondary-preventive medications for stroke patients have become common in stroke care. (Pyöriä et al. 2015, 23.)

Providing this level of care is still cost-effective, as it reduces the costs in the future when thinking of the stroke survivors ability to manage their life at home and not ending up in a institutional care facility. The most costs in the first year of stroke are coming from the cost of institutional care. In the future it is probable that the costs from the care of stroke patients will reduce, due to preventive care and using stroke specialized care units and specialized rehabilitation units. (Pyöriä et al. 2015, 23.)

2.7 Impact on a person

Every stroke survivor will have a different set of challenges post stroke, which can range from minor deficits to severe disabilities. (Hickey & Livesay 2015, 377). 80% of the stroke patients will suffer from muscle weakness typically on other side of the body, the symptoms can variate between total hemiplegia to not so severe hemiparesis. The timely performance of using muscles gets impaired, starting the movement gets more difficult and there is less power. (Pyöriä et al. 2015, 14.) These kinds of motor deficits can impact the survivor's ability to write and ambulate, transfer and grasp objects. Some patients may have dysphagia or difficulty with swallowing, and that makes eating difficult and the patient may require, for example a feeding tube. Typically, stroke patients may feel a loss of dignitity and independence, as they need help with the different activities of daily living, such as bathing and toileting. Some stroke survivors experience sensory changes due to the stroke, for example they may lose the ability to feel pain or experience numbness on the limbs affected. Chronic pain syndromes are common within stroke patients, they might be a result of damaged pathway in the brain or due to weakness or lack of use of a limb. It is extremely important to identify the cause of pain and provide treatment, as it has been shown that if the stroke patients suffer from chronic pain, the likelihood for poststroke depression increases. (Hickey & Livesay 2015, 377.)

Spasticity develops on 20-30% of the patients. Main part of stroke patients suffer from balance dysfunctions. The balance also may be disrupted because of the disorders in sensory, motor and cognitive systems. The balance disfunctions lead to increased fall risk among stroke patients. (Pyöriä et al. 2015, 14.) Many studies indicate that over half, or even 75% of the stroke patients have decreased cognitive functions. After the stroke the cognition might be affected on every main part, such as memory, executive functions, inference, conceptualization, language and attention. After a year of having the stroke, significant part of the stroke survivors still have dysfunctions in cognition. Even 83% of stroke survivors in working-age might have cognitive dysfunctions after a year from having the stroke. (Pyöriä et al. 2015, 16.) Language problems affect about 25% of stroke patients.

Language problems can involve the ability to write and speak and also understanding the spoken or written language. The language problems typically make the patient feel frustrated as they can not communicate needs or feelings or socially interact as the same way they have used to. (Hickey & Livesay 2015, 378.)

Different studies show that the amount of stroke survivors with poststroke depression has varied between 25-75%. Studies made in Finland present the number to be quite high, as 40-54% of stroke patients. The depression is more common with stroke patients who have lower capability to function, and more difficult physical and cognitive disabilities. Depression can also make the rehabilitation process more difficult, as the motivation towards rehabilitation is lower and it has been shown that they have lower quality of life and longer hospital stays. Overall the quality of life seems to decrease due to having a stroke, but behind the stroke as a cause has been proven to be the depression, cognitive disorders and mental load. It has been shown that stroke patients with better quality of life have had care on a specialized stroke unit at the acute phase. (Pyöriä et al. 2015, 17.)

3 REHABILITATION

3.1 Definition

The World Health Organization defines rehabilitation as a "restoration of the person to the highest the physical, mental, social, vocational and economic capacity". Rehabilitation endeavours to prevent further disability, restore lost functions and maintain the patient's remaining abilities. The idea that all individuals have inherent worth and have the right to be experts in their own healthcare is the base of the rehabilitation philosophy. (Hickey & Livesay 2015, 318-319.) Rehabilitation is a dynamic and active process where a disabled person is helped to acquire skills and knowledge in order to maximize sozial, psychological and physical functions. It is a process that maximizes functional ability and minimizes disability and handicap, while promoting participation and activity. (Barnes & Ward 2005, 12.) Rehabilitation is also described as a process, where the goal is that a disabled person can cope with as little support as possible in every part of his life, including family, friends and leisure. It is a process that not only considers the physical disease, but also deals with the psychological consequences of disability, as well as the social milieu where the rehabilitee functions. (Barnes & Ward 2005, 2.) There are a few main approaches in rehabilitation, one approach is to reduce disability, second one is an approach to acquire new skills and strategies for reducing the impact of disability and the third one is an approach that helps to alter the environment, the physical and the social environment, so that given disability carries with it as little handicap as possible. (Barnes & Ward 2005, 12.)

The disabled person is in the central of the rehabilitation process, making plans and setting goals that are important and relevant from their own view and to their own circumstances. Rehabilitation is not a process that is done to the handicapped person, instead it is a process that is done by the person with the guidance, help and support of the person's family, friends and a wide range of professionals. (Barnes & Ward 2005, 2.) The rehabilitation process is based on the rehabilitee's own set goals and it needs both commitment and will to participate in the process from the rehabilitee. (Kalkasmaa & Multaharju 2017, 3). It is said that the essence of rehabilitation is goal setting, for some the longterm goal could be returning to completely normal lifestyle, for some it could be returning home with the help of carers. It is necessary that all parties in rehabilitation process will agree on a realistic long-term goal and after the goal has been set it is important to identify the steps needed in order to achieve that goal. (Barnes & Ward 2005, 14.)

Multiple studies show that coordinated interdisciplinary rehabilitation approach produces better functional outcomes than traditional unidisciplinary service delivery. When thinking of stroke patients, this would mean that a rehabilitation unit will produce more functional gain, more quickly and with a better chance of returning home with decreased morbidity and mortality. There is also evidence on this considering rehabilitating patients with deteriorating conditions, for example patients with multiple sclerosis. (Barnes & Ward 2005, 18.) The most effective form of interdisciplinary rehabilitation is interprofessionality, where there is continuous interaction, knowledge sharing, patient participation, and an integrated collaborative workflow. (Hickey & Livesay 2015, 70).

It has been proven that rehabilitation is more effective on specialized rehabilitation units than in ordinary hospital wards. (Kalkasmaa & Multaharju 2017, 3). It is said that the additional benefit received from the care at a specialized rehabilitation unit will preserve for 10 years. (Aivoinfarkti ja TIA 2020). Rehabilitation has also been proven to be more effective when it has been started as soon as possible after the condition or disability needing rehabilitation occurs. (Kalkasmaa & Multaharju 2017, 4). The individual's situation should always be assessed thoroughly when there is a need for rehabilitation and to think the situation not from only one professional's view, but how other professionals could help and be a part of the rehabilitation process. (Autti-Rämö, Salminen, Rajavaara & Ylinen 2016.) The best way to assess the patient is that each team member from an interprofessional team would do the assessment and identify the patient's strengths and barriers in the patient's condition, and then communicate the information to other team members. (Hickey & Livesay 2015, 367). The assessment of will patient benefit from rehabilitation should always be done multiprofessionally. (Aivoinfarkti ja TIA 2020).

3.2 Stroke rehabilitation

Major part of stroke partients will need rehabilitation services and the rehabilitation should start as early as possible in the hospital setting. (Hickey & Livesay 2015, 67.) The exact and the most beneficial time to initiate rehabilitation and physical activity after the stroke has not been established, but it has been proven that there is a beneficial outcome association with early initiation of rehabilitation. Encouraging outcomes have been seen on stroke units where the patients are helped out of bed within the first 48 hours after the hospital admission. (West & Bernhard 2012, 1.)

The difficulty level of the stroke is the most important indicator in predicting the recovery in the future. (Aivoinfarkti ja TIA 2020). The acute phase in stroke rehabilitation means that the patient's condition is not stable, but the subacute phase, which lasts about 3-6 months, is the most efficient and rapid phase in recovery and rehabilitation. (Aivoinfarkti ja TIA 2020). The formal rehabilitation may occur for months, but the adjustment and recovery process is lifelong. (Hickey & Livesay 2015, 67). Stroke rehabilitation will help 50% of patients to get back to their normal life. (Kalkasmaa & Multaharju 2017, 1).

Rehabilitation works most efficiently by an interprofessional team, that is directed not only for restoration of functions and compensating lost functions, but also preventing secondary complications. (Seitz & Donnan 2015, 7). The team usually consists of nurses, a physician, such as neurologist or physiatrist, physiotherapists, occupational therapists, speech therapists, neuropsychologist, social workers and later on also a rehabilitation counsellor is included. The stroke patients will benefit from individualised multiprofessional rehabilitation regardless of their age, sex and the difficulty level of stroke. (Aivoinfarkti ja TIA 2020.) Studies show that patients benefit as much from intensive rehabilitation when thinking of neurological deficits, whether the patients were young or older than 65 years. Younger patients typically improve better on walking, balance, mobility and grip strength. Also, the intensity of training seems to determine long-term improvement of motor functions rather than the type of training. (Seitz & Donnan 2015, 7.) Cognitive functions recover most on the first months after the stroke. (Kalkasmaa & Multaharju 2017, 1).

3.3 Impact on society

With rehabilitation, it is possible to reduce the impact of a wide range of different health conditions, including illnesses or injuries, and acute or chronic diseases. It is also possible to reinforce other health interventions with rehabilitation, such as surgical and medical interventions, by helping them to achieve the best outcome as possible. Rehabilitation can help to manage, prevent or reduce complications that are associated with multiple health conditions, such as stroke, fracture, or a spinal cord injury. Rehabilitation also helps to slow down or minimize the disabling effects of chronic health conditions and this will help to maintain or increase the patient's participation level to society. (Rehabilitation 2020.) It has been shown that patients continue to benefit from rehabilitation well beyond the time period when the most natural recovery would take place. Multiple benefits have been shown in every indices of social outcome, for example functional ability and performance of social roles. (Worthington, Matthews, Melia & Oddy 2005, 947.)

Multiple studies indicate that the most successful result on reintegrating into the community have had the patients who got rehabilitation from an interprofessional team. (Hickey & Livesay 2015, 367). Within three months after stroke about 50-70% of stroke survivors will rehabilitate to be independent on their daily activities and about 15-30% will have permanent invalidity. (Reijula 2020, 17). Some studies show that about 50% of the stroke patients leave rehabilitation unit in a wheelchair, leaving those patients with persistent disabilities with walking, which may restrict them from participating in society. When considering this kind of mobility level of the patients leaving the hospital, it is important to keep the rehabilitation goal, such as gait recovery, even in the chronic phase. The need for effective, affordable and accessible long-term rehabilitation will remain. (Schröder 2019, 2.)

3.4 Impact on economy

Rehabilitation can be described as an investment that will give cost benefits for both society and individuals. Rehabilitation can help to reduce the length of hospital stays and prevent re-admissions to hospital, and through these to avoid costly hospitalization (Rehabilitation 2020). Calculations show that economically the initial costs of rehabilitation are usually compensated by savings in care costs within two years. Analysis on the estimated savings in care costs yielded the projected lifetime savings of 0,8-1,1 million UK pounds for persons admitted for rehabilitation within 12 months of injury. 0,5-0,7 million within 2 years of injury and 0,36-0,5 million for admission after two years. (Worthington, Matthews, Melia & Oddy 2005, 947.)

It seems self-evident, that avoidance of unnecessary complications and better functional gains will be economically beneficial, by reduced hospital outpatient visits and reduced hospital bed usage. It is said that a major cost saving for the national economy can be achieved, if a disabled person can be assisted back to work, even working on part-time. About 80% of the costs of disability are caused by lost employment opportunities. (Barnes & Ward 2005, 18-19.)

3.5 Impact on a person

Rehabilitation is very focused on the individual, this means that the approaches and interventions selected for each individual depends on their own goals and preferences. (Rehabilitation 2020). Rehabilitation will help disabled persons to return to their lives as they lived them before. It is done by helping them to increase strength and movement, build endurance, increase awareness, obtain assistive devices such as self-care tools and wheelchairs, acquire accessible housing and gain access to barrier-free workplaces and communities. To accomplish all this, the rehabilitation professionals need to extend their interventions beyond the person's immediate impairments to focus on long-term health needs. It is important to help the disabled person to develop healthy behaviours to improve their health and well-being. By doing this it will also minimize their long-term health costs associated with the dysfunction. (Gillen 2015, 48.)

Usually when a person is hospitalized, the goal is on achieving independence in self-care. For example hygiene tasks and eating are essential for health and survival, but grooming and dressing are very important to participation and social interaction. Participation can be supported or limited by the psychological, physiological, sensory, motor and cognitive capacities of the individual. Being able to do what one wants to do, being able to go where one wants to go, and have the freedom in the choice of activities at the time at which one wants do them, is essential to personal independence. The experience of success in doing things will form a positive sense of oneself as effective or competent. (Gillen 2015, 46-47.) Rehabilitation makes it possible for individuals to participate in gainful employment and education, remain independent at home or with the help of personal attendant, and minimize the needs for financial or caregiver support. (Rehabilitation 2020).

4 IMPORTANCE OF ACTIVITY DURING REHABILITATION

4.1 Physical activity

Physical activity is described as "any bodily movement produced by skeletal muscles that results in energy expenditure". (Ainsworth & Macera 2012, 167). In other words physical activity can be defined as voluntary bodily movement using skeletal muscles that requires energy beyond resting levels. (Block et al. 2016, 2). It is essential to recognize the difference between physical activity and physical fitness, as physical fitness is the outcome of physical activity. (Ainsworth & Macera 2012, 54). It has been shown that it does not matter how physical activity is achieved within a given day, during either work or spare time, maintaining adequate activity levels has been proven to decrease the risk of premature death and development of multiple chronic diseases and also to improve mental health and physical function. (Ainsworth & Macera 2012, 147). It is inevitable that incorporating regular physical activity into person's life, it promotes health, well-being and the quality and the length of life. (Ainsworth & Macera 2012, 21).

Physical activity has also been shown to be a critical matter considering healthy aging, a term used to characterize optimal physical, social and mental well-being in older adults. It has been shown that maintaining the activity levels combined with avoiding prolonged exposure to sedentary activities in adulthood will predict a healthy aging process by reducing risk of disabling chronic diseases while maximizing cognitive and functional ability. It is requested that all healthy adults should participate in both muscle-strengthening and aerobic activity to achieve optimal health. (Ainsworth & Macera 2012, 134-135.)

4.2 Activity and stroke rehabilitation

Condition such as stroke may reduce the ability to activate muscles and produce movement. This commonly affects patient's functional capacity and ability to perform daily tasks. This kind of limitation in mobility increases the risk of chronic diseases, for example diabetes, cardiovascular disease, osteoporosis and depression. The mobility limitations have a dramatic negative effect on the quality of life overall. Individually planned and prescribed exercise programs are needed for stroke patients to improve health status and the quality of life. (Burr, Shephard & Zehr 2012, 1236.) It has been shown that the increased activity in the first six months after stroke has improved the functional outcome, but it is unclear what is the optimal dose of physical activity to aid the recovery process after the stroke. (West & Bernhard 2011, 1).

Studies show that even the simple exposure to gravitational or orthostatic stress appears to dissolve a significant portion of the deterioration in functional capacity that normally follows after a stroke. In practice it is important to notice the range of factors that are included in patient stability, even though the stability of a patient is not well-defined, when prescribing early physical out of bed activity. Simply getting out of bed in the first 24 to 48 hours has been shown to significantly increase blood pressure, heart rate, oxygen saturation and improve conscious state. It is important to keep in mind that not all acute stroke survivors can tolerate activity this early. (Billinger et al. 2014, 2532.) Training approaches that include the very early mobilization, basic arm training, antigravity support for walking and arm ability training can be tailored to the patient's neurological deficits and by that optimally engage the residual capacities of the patient. (Seitz & Donnan 2015, 1).

Stroke patient's physical activity is affected by physical limitations, depression, cognitive disabilities, fatigue and the experience of low capacity. Without addressing completely the functional capacity of the patient, the gained benefits made with rehabilitation interventions may be lost after the patient is discharged from the rehabilitation unit. (Pyöriä et al. 2015, 12-13.)

Studies show that exercise after stroke can improve walking ability, upper-extremity muscle strength, cardiovascular fitness, poststroke fatigue and depressive symptoms. It is evident that stroke survivors benefit of participation in physical activity. (Billinger et al. 2014, 2532.) A research of activity supporting physiotherapy has showed that by using activating physiotherapy instead of traditional physiotherapy, it is possible to improve more widely the person's functional capacity, independent living and reduce hospital stays within a year of time. Also by using activating physiotherapy the cognitive functions of a patient showed to recover better than in traditional physiotherapy. Also memory seemed to improve better on patients that had activating physiotherapy. (Pyöriä et al. 2015, 13.)

It has been shown that patients that are managed in a regular hospital ward instead of a rehabilitation unit, spend a greater portion of the day inactive. (West & Bernhard 2011, 6). A study about sedentary behaviour on stroke patients has shown that patients in rehabilitation units may spend a large amount of the day inactive, up to 74%. Even though the amount is better than in regular hospital wards, it has to be noticed that each additional hour spent sedentary is associated with a progressive rise in mortality risk. (Sjöholm et al. 2014, 4-5.) For example, a study by Foley showed that the average time that rehabilitation patient received active therapy from physiotherapists and occupational therapists on a day was 37 minutes. (Foley et al. 2012, 2132). This is why it is important to measure the activity of s stroke patient, for example by using behavioural mapping or technological devices. (West & Bernhard 2011, 11-12).

5 DIGITALIZATION IN REHABILITATION

5.1 E-health and telemedicine in rehabilitation

A need of innovative and efficient rehabilitation is created form rising healthcare costs and the lack of healthcare professionals, as well the increasing number of patients that have access to the Internet. By using e-health solutions that are cost-effective in disease management, health promotion and patient empowerment, it is possible to produce efficient care and rehabilitation. Long-term medical care needs could be addressed by significantly lower expenditures by the means of e-health creating improved accessibility to rehabilitation programs. E-health can be defined as "the use of new Information and communication technologies, mostly internet technology, to improve or support health and healthcare." E-health in rehabilitation can include computer games, virtual reality, online communicating tools and assistive technology. It has been shown that especially the subgroup of patients in rehabilitation care are very accepting on the use of e-health. (Wentink et al. 2018, 620.)

One tool for overcoming the restrictions of accessibility to rehabilitation could be tele-rehabilitation. Virtual reality can increase motivation allowing more and longer training sessions, for example amongst the stroke survivors. Virtual reality (VR) -based interventions are game-like and seem to provide a motivational and encouraging environment that also increases greater adherence to therapy. It has been shown that the functional improvements using VR and telerehabilitation seem to be equal when compared to a similar intervention with therapist supervision in the clinic. Therefore combining ordinary rehabilitation to tele-rehabilitation has been beneficial. This means that parts of therapy can be transferred to the homes to produce cost-efficient rehabilitation. (Schröder et al. 2019, 1.)

Remote rehabilitation can be called in many terms, it can be net therapy, virtual rehabilitation, mobile rehabilitation or telehealth, but all of these terms are too limited to describe it in general. Remote rehabilitation must be controlled by a professional and it has to have set goal as the other conventional rehabilitation. Remote rehabilitation can include various technological applications, for example mobile phone, computer, phone and computer sharing and television applications. Remote rehabilitation can work synchronously or asynchronously. Synchronous means that the client and the service producer are connected in real time, this kind of rehabilitation can be counselling, assessment, rehabilitation or rehabilitation monitoring by video or phone connection. This form of rehabilitation can be implemented by a group or individually. Asynchronous remote rehabilitation is a situation where the rehabilitee uses independently, for example training programs or games provided or utilizes supportive online material. In remote rehabilitation it is common to combine the synchronous and asynchronous methods, as in rehabilitation overall it is typical to combine remote rehabilitation and face to face rehabilitation. (Alamäki et al. 2019, 11.)

It is recommended that the implementation of telemedicine should be used more in acute stroke care in underserved areas. Telemedicine can be described as "the use of telecommunication technologies to provide medical information and services". Stroke telemedicine could bridge the geographical disparities and would allow the access to stroke experts through the use of technology. It commonly includes patient access to stroke neurology and radiology services. Teleradiology is used to support telemedicine by ability to obtain radiographic images at one location and transmit to another for consultative and diagnostic purposes. The telestroke service is usually done with two-way audiovisual communication through a computer, with access to imaging archives and communication systems that allow the interaction between a healthcare professional and the patient and his family at remote sites. Telemedicine can also be used to provide ongoing care for subacute stroke, to support intensive care surveillance and it can improve the transition in care from acute to subacute level. (Hickey & Livesay 2015, 66.)

5.2 Rehabilitation technologies

Different rehabilitation technologies provide treatment interventions that are repeatable and quantifiable, which allows the measurement of the impact of the rehabilitation interventions on impairments of motor function. One example is robotic devices, that can be used to quantify changes in motor functions during stroke rehabilitation by gathering kinetic and kinematic data related to variables such as forces exerted during training and the smoothness of reach, speed and accuracy of task completion. Technology in rehabilitation is not supposed to replace occupational or physical therapists, but it will be an essential part of their treatment arsenal in the future. It is predicted that these kinds of technological rehabilitation tools will help to reduce costs in rehabilitation by providing intensive movement therapies with only minimal supervision by a therapist. Some researches show that the rate of motor recovery after the stroke may accelerate when using intensive robot-assisted therapy, and this leads to that the use of rehabilitation technology will help to shorten the hospital stays and improve the functional outcomes in long-term. (Gillen 2015, 486.)

Many innovative technologies are rising in the field of rehabilitation, for example a successful study has been made with stroke survivors using smart insoles, that analyzed walking speed and heel strike and symmetry. The smart insole then forms a gait characteristic for a stroke patient. (Alamäki et al. 2019, 38.) Different technologies are also used in speech therapy rehabilitation, for example the use of non-immersive virtual reality systems to provide speech-language pathology assessments or interventions for people with communication disabilities has been shown to have positive outcomes. Evidence was shown about the functional communication skills transfer from virtual to real-world environment. (Bryant, Brunner & Hemsley 2020, 372.) A study of a 3D printed hand exoskeleton for a stroke patient proved to be successful, as it assisted the rehabilitee to accomplish rehabilitation outcomes by increasing the function of the affected hand by improving hand dexterity and assisting functional grasps with a lower patient’s level of perceived exertion. The exoskeleton was printed with new 3D printing polymers that are antimicrobial and it can prevent skin infections during rehabilitation. (Dudley et al. 2021, 209-213.)

Environmental control systems (ECS), can also help a rehabilitee to manage at home. ECS’s are dedicated devices that are designed to help people with physical limitations to independently control different electronic items in their close environments. The devices can be programmed to operate typical household appliances, such as telephones, air-conditioning units and televisions. ECS can be controlled and activated through different kinf of movements, for example hand, elbow and eye movements. ECS technology include devices with wireless design and input methods, such as touch screens, switches and voice recognition. Also, smart devices with Bluetooth® and different applications allow the direct controlling of different appliances through a smart phone or tablet. (Hooper, Verdonck, Amsters, Myburg & Allan 2018, 724.)

There are many computer based training approaches for neurorehabilitative purposes, for example the rehabilitation gaming system (RGS) which is a virtual reality(VR) -based device for rehabilitating neurological patients. RGS has been proven to improve arm function effectively in acute and chronic stroke patients. RGS engages human mirror neuron mechanisms that underly visuomotor coordination. For example, the PABLO® device is a handhold multifunctional device that has been proven to improve visuomotor coordination of hands in stroke patients. These kinds of gaming applications have a significant positive effect on the patients and engage their brain structures that are known to be related to emotional processing. Gaming approaches point to new ways of post-stroke rehabilitation and for the recovery potential after stroke. (Seitz & Donnan 2015, 8.)

6 ACTIVITY TRACKING AND MOTION SENSORS

6.1 Measuring patient activity

The common methods that are used to measure patient activity include behavioural mapping, therapist reporting and video recording. All these methods have been proved to have high inter-rater reliability, but validity is not typically tested or proven in these methods. (West & Bernhard 2011, 6.) More specifically, physical activity can be measured using logs, subjective questionnaires, recalls, and several objective electronic devices. (Ainsworth & Macera 2012, 54).

The use of electronic devices, such as accelerometers and step counters is becoming more common and might provide more precise monitoring of activity. The reliability and accuracy must be considered when used on very low functioning patients, and the ease of use and the wearing comfort must be considered when using these kinds of devices. The methods that are based on observation of the patient may provide more information in some cases, for example about who was with them during activity and the location of patients when they are active. (West & Bernhard 2011, 11-12.)

The activity monitoring can focus on many things, such as upper and lower limb function, gait or other body movement or behaviour. The potential variables when measuring physical activity include activity count or bouts, step count, active minutes and energy expenditure. Wearable physical activity motion sensors have become progressively more common as consumer products, primarily designed for fitness use. The questions arise about the validity, reliability, feasibility and responsiveness when considered whether physical activity monitoring can inform decision-making while used in clinical populations. (Block et al. 2016, 2.)

6.2 Wearable motion sensors

The wearable sensors that are most commonly used are small sensor units or activity trackers, that usually contain accelerometers, magnetometers and gyroscopes. The sensors measure physiology, posture and motion, and this data is then transmitted using a suitable communication protocol, for example Bluetooth, to a nearby processing unit. The processing unit, for example a smart phone or computer, has the sensor systems software which applies algorithms to the raw data to extract clinically important information. (Alamäki et al 2019, 18.) There is a wide range of different kinds of wearable sensors available commercially that provide raw data to describe lower extremity, arm and trunk actions outside of a motion analysis gait laboratory. The choices of the sensors, the number of them and their placement will depend on the activity and movement variables that are ascertained. (Dobkin 2013, 2-3.)

There are several things to be noticed when designing wearable electronics. The elements that make an electronic product wearable are comfort (size, weight, shape), placement, durability (stands wearing, washing), aesthetics and usability. The measuring sensors can be integrated into textiles, clothes or elastic bands to make them wearable. When thinking of sensors, a minimum number of sensors supports moderate pricing, time efficiency and comfort. Comfort has a major value when thinking of implementing this kind of device in use, as comfort must be perceived by both patients and users of the system, if not, then the system will not be adapted for clinical practice. (Alamäki et al. 2019, 16-18.)

It has been shown that the accelerometer-based technology has mostly been used in laboratory settings, but there is a need to focus the use in clinical practice. Patients and clinicians prefer the wearable sensor to be compact, embedded and simple to maintain and operate. A body-worn sensor should not replace a healthcare professional and it should not effect on the patient's daily behaviour. (Alamäki et al. 2019, 16-17.) With stroke patients it is possible to do an ambulatory monitoring of arm movement done by accelerometes, that will provide an objective method for assessing real-world upper-extremity motors status and rehabilitation outcome with patients that had mild-to-moderate hemiparesis. In this case two wrist-worn accelerometers are needed because of the ratio of impaired to unimpaired arm. (Uswatte et al. 2006, 1344.)

It must be noted that, the measurement of physical activity in people with neurological disease may be complicated because of the neurological impairments, such as weakness, gait abnormalities, tremor or spasticity that could confound the measurement result. (Block et al. 2016, 2.) There are some neurological deficits than must also be considered when using this kind of technology on stroke patients, as there might be impairment to perform actions on command and there is a decrease in spontaneous motor activity which may be functionally relevant. (Seitz & Donnan 2015, 6.) But stroke patients are also a typical patient group that might benefit from wearable sensors in their clinical practice, because they require long rehabilitation periods. (Alamäki et al. 2019, 31.)

7 RESEARCH METHOD

7.1 Purpose and execution

The purpose of this study was to find out what kind of wearable motion sensors exists to measure the activity of a rehabilitation patient. Also, pointing out what is needed when using this kind of technology with rehabilitation patients in clinical setting. The chosen research method is an integrative literature research, as it allows to form a wider view of the collected material for the research. (Salminen 2011, 6.) In this thesis smartphones were excluded as a wearable device, since they are used for multipurposes and not worn routinely. Also, wearable sensors that measure physiological signals such as heart rate and respiratory rate, are excluded. (Lang et al. 2020, 1.)

The research questions:

1. What kind of wearable motion sensors exists that are suitable for monitoring the activity of a rehabilitation patient?

2. What are the technical demands for this kind of monitoring to work in rehabilitation setting?

3. What challenges and benefits there are using wearable motion sensors in activity tracking?

7.2 Integrative literature review as a method

Narrative literature review is one of the most used types of literature reviews. It can be described as an overview without strict restrictions and rules. The used literature is gathered from a wide spectrum and it is not defined by methodological rules. The research questions are not so strictly defined as in systematic literature review or in meta-analysis. The narrative literature review is an independent method and it can provide more material for further research, for example for a systematic literature review. There are two different orientations from the narrative literature review, a descriptive literature review and an integrative literature review. (Salminen 2011, 6.)

The integrative literature review is typically used when wanted to have a broad perspective of the research topic. Integrative literature research is also a good way to produce new information from an already researched topic. Comparing to systematic literature review, the integrative literature review forms a notably wider picture of the handled topic. Integrative literature review does not select the material for the research with so strict scale, as in the systematic literature review. In integrative literature research it is possible to use material that has been made with different kind of research methods for the foundation in the research analysis phase. Literature and perspectives used are more diverse and due this it is possible to gather a wide spectrum of material for the research. There are five phases in the integrative literature review; placing the research questions, gathering the data, evaluating the data, data analysis, interpreting and presenting the research results. (Salminen 2011, 8.)

It is possible to combine diverse methodologies, for example experimental and non-experimental research, in an integrative literature review, and so far it is the only research method that allows it.

This method has the potential to allow this kind of diverse primary research methods to become more fundamental part of evidence-based practice initiatives. (Whittemore & Knafl 2005, 546-547.) Detailed and thoughtful work must be done with the integrative literature review, as the outcome can be a significant contribution to a particular body of knowledge, and through this to research and practice. (Russell 2005, 8-13.)

7.3 Database search and keywords

The original studies were gathered by doing a database search using keywords. The keywords defined were: rehabilitation, physical activity, motion sensor, activity measuring, activity tracking, wearable motion sensor and stroke. The keywords were chosen carefully to follow the topic and the set research questions. Literature searches were conducted both in Finnish and international databases, using Savonia-FINNA, EBSCHO, Cinahl Complete, PubMed and Google Scholar databases. The criteria considering the researches chosen to be utilized as a material in this thesis were that the research was conducted in English or in Finnish language, the study was made between the years 2005-2020, and there was a full access to the whole article. To be chosen as a material, the r search article had to have two or more keywords in it. See Figure 1. on the next page for more information on the criteria.

Database search and keywords

Databases used	Savonia-FINNA EBSCHO Cinahl Complete PubMed Google Scholar
Keywords used	Rehabilitation Activity measuring Wearable motion sensor Physical activity Motion sensor Activity tracking Stroke
Acceptance criteria	Conducted in English or in Finnish language Study made between the years 2005-2020 Full access to the whole article
Exclusion criteria	Studies that consider mainly children Article does not answer any set research questions Did not have two or more keywords included
Chosen articles	25 articles were chosen based on the heading, abstract and full text to be utilized as a material in the research

FIGURE 1. Database search and keywords

7.4 Analysis

In integrative literature research the goal in analysis phase is to analyze the material carefully and from an objective view, and to form a synthesis. (Whittemore & Knalf 2005, 550). In this thesis the analysis was done by using general inductive approach, which is one form of qualitative analysis approaches. The general inductive approach is frequently used in health and social science research. There are three key features in the general inductive analysis, first is to condense the extensive and varied data into a brief, summary format. Second one is to establish links between the research objectives and summary findings derived from the raw data. These links have to be transparent, which means that they must be able to be demonstrated by others, and defensible. Third key feature is to develop a model or theory about the underlying structure of experiences or processes that are evident in the raw data. (Thomas 2003, 2-3.)

The analysis was done by reading through the original studies (Figure 2) carefully several times and then pointing out the parts in the material that answered one or more of the research questions. Those parts of the material were underlined with different colours to form a better view which words and sentences were chosen to be categorized into units that had either similarity or divergence. Then the following units formed a larger unit that would show the compiled material with similarities to each other. For example, all the raw data that included sentences considering activity monitoring and accelerometers, were analyzed to have similar emerging themes and then were brought together into a larger unit. (Thomas 2003, 3.)

Original studies

WRITER(S) & YEAR	ARTICLE	RESEARCH METHOD	MOTION SENSORS USED IN THE STUDY
Porciuncula et al. 2018	Wearable Movement Sensors for Rehabilitation: A Focused Review of Technological and Clinical Advances	Literature review	Smart textiles IPS Accelerometers Gyroscopes Magnetometers
Prasanth et al. 2021	Wearable Sensor-Based Real-Time Gait Detection: A Systematic Review	Systematic review	Accelerometers IPS Gyroscopes EMG Goniometers
Lang et al. 2020	Implementation of Wearable Sensing Technology for Movement: Pushing Forward into the Routine Physical Rehabilitation Care Field	Literature review	Accelerometers Magnetometers Gyroscopes
van der Pas et al. 2011	Assessment of Arm Activity Using Triaxial Accelerometry in Patients With a Stroke	Validity study	Accelerometers
West & Bernhardt 2011	Physical Activity in Hospitalised Stroke Patients	Systematic review	Video recording
Dobkin 2013	Wearable motion sensors to continuously measure real-world physical activities	Literature review	Accelerometers Gyroscopes Magnetometers GPS Goniometers EMG Video recording IPS
Shim et al. 2014	Comparison of Upper Extremity Motor Recovery of Stroke Patients with Actual Physical Activity in Their Daily Lives Measured with Accelerometers	Validity study	Accelerometers
Uswatte et al. 2006	Validity of Accelerometry for Monitoring Real-World Arm Activity in Patients With Subacute Stroke: Evidence From the Extremity Constraint-Induced Therapy Evaluation Trial	Validity study	Accelerometers
Alamäki et al. 2019	Wearable technology supported home rehabilitation services in rural areas: emphasis on monitoring structures and activities of functional capacity	Practice-based research	Accelerometers Gyroscopes Magnetometers GPS IPS
Block et al. 2016	Remote Physical Activity Monitoring in Neurological Disease: A Systematic Review	Systematic review	Pedometers Accelerometers
Gebruers et al. 2010	Monitoring of Physical Activity After Stroke: A Systematic Review of Accelerometry-Based Measures	Systematic review	Accelerometers
Gendle et al. 2012	Wheelchair-mounted accelerometers for measurement of physical activity	Validity study	Accelerometers
Kang et al. 2020	Real-time elderly activity monitoring system based on a tri-axial accelerometer	Validity study	Accelerometers

McCarthy & Grey 2015	Motion Sensor Use for Physical Activity Data: Methodological Considerations	Literature review	Pedometers Accelerometers
González-Villanueva et al. 2013	Design of a Wearable Sensing System for Human Motion Monitoring in Physical Rehabilitation	Validity study	Accelerometers
Van Remoortel et al. 2012	Validity of activity monitors in health and chronic disease: a systematic review	Systematic review	Accelerometers Pedometers
Tao et al. 2012	Gait Analysis Using Wearable Sensors	Systematic review	Accelerometers Magnetometers ETS EMG Gyroscopes Goniometers Smart textiles
Dowd et al. 2018	A systematic literature review of reviews on techniques for physical activity measurement in adults: a DEDIPAC study	Systematic review	Pedometers Accelerometers
Patel et al. 2012	A review of wearable sensors and systems with application in rehabilitation	Systematic review	Accelerometers Gyroscope Magnetometer Smart textiles
Cheng et al. 2020	Wearable Motion Sensor Device to Facilitate Rehabilitation in Patients With Shoulder Adhesive Capsulitis: Pilot Study to Assess Feasibility	Validity study	Accelerometers Gyroscopes
Petoom et al. 2015	Literature review on monitoring technologies and their outcomes in independently living elderly people.	Systematic review	Accelerometers Video recording
Swartz et al. 2014	Responsiveness of motion sensors to detect change in sedentary and physical activity behaviour	Validity study	Accelerometers
Spain et al. 2013	Body-worn motion sensors detect balance and gait deficits in people with multiple sclerosis who have normal walking speed	Validity study	Gyroscopes Accelerometers
Field et al. 2013	Physical Activity after Stroke: A Systematic Review and Meta-Analysis	Systematic review	Pedometers Accelerometers
Esfahani & Nussbaum 2018	Preferred Placement and Usability of a Smart Textile System vs. Inertial Measurement Units for Activity Monitoring	Validity study	Accelerometers Gyroscope Magnetometer Smart textiles

FIGURE 2. Original studies

7.5 Reliability and ethics

It is important that research follows the basic principles of conducting a research, such as having integrity and accuracy while conducting, analysing, presenting and evaluating the research. (Houser 2016, 534.) The concepts of reliability, validity and generalizability are associated to the whole research process. Validity in research means the level of integrity and application of the methods used in the research, and the precision of how accurately the findings reflect the data. Reliability describes the consistency within the used analytical procedures. Generalizability means that the research is repeatable by someone else and that the research has been done from an unbiased viewpoint. (Noble & Smith 2015, 34.) In this research, the original studies were chosen carefully to meet the set criteria and then analysed using general inductive approach to find the information to answer the research questions. All the phases in the process were handled with maintaining an unbiased view considering the topic, this demanded an ongoing process of self-reflection during the research process.

8 THE RESEARCH RESULTS

8.1 Types of motion sensors

Different types of motion sensors that are suitable for measuring activity especially with rehabilitation patients are presented on the upcoming paragraphs. The last paragraph of this section presents also the environmental context, that is a measuring method for activity but does not typically include wearables. The reason why this method is listed here, is because it was mentioned in more than one studies that were chosen to be a part of this research and it could present an option for activity measuring in rehabilitation.

8.1.1 Accelerometers

Accelerometes are quite common in physical activity monitoring as they measure body movements in terms of acceleration (see Figure 3). The gathered information can be used to interpret the intensity of the activity over time. Accelerometers can be triaxial, biaxial or uniaxial depending on their sensitivity. Accelerometers can be categorized to three different types; piezoelectric, piezoresistive, and capacitive accelerometers. When it comes to accelerometer types, it is said that piezoresistive and capacitive types can provide dual acceleration components and have higher stability. (Tao, Liu, Zheng & 2012, 2257.) For gathering information the accelerometers usually use a piezoelectric sensor. The data is then stored to an internal memory which then can be downloaded to a smartphone or a computer. Accelemeter is beneficial when measuring activity as it can record continuously for days or weeks and in the patient's own environment. Accelerometers have been used in healthcare to monitor agitated behaviour in dementia patients and investigate the relation between physical activity and fatigue with Multiple Sclerosis patients. Recently the accelerometers have been used in clinical stroke research as a measure of physical activity. (Gebruers, Vanroy, Truijen, Engelborghs & De Deyn 2010, 289.)

It has to be noticed that when using accelerometers on activity monitoring that it does not distinguish between active and passive motions. Accelerometers measure the intensity and duration of movement but not the quality of movement. (Van Der Pas, Verbunt, Breukelaar, Woerden & Seelen 2011, 1437.) Actions with unusual combinations or low gravitational force may be misinterpreted. Some studies say that a wrist-worn accelerometer may not be suit able on the research of a patient with neurological impairments. Triaxial accelerometers that are placed posteriorly at the midline of the waist, use proprietary algorithms that detect walking speed and gait cycle, but also this tends to be inaccurate with patients that have impairments on walking and have slow walking speed. Multisensor systems would be the most accurate to measure activity and estimate the energy expenditure. Combinations of accelerometers can also detect postural imbalance and may help predict fall. Wheelchair activity and energy consumption monitoring also requires multiple sensors, on the chair and on each arm. (Dobkin 2013, 3-4.)

8.1.2 Pedometers

Pedometer is a simple and inexpensive, but also a low-tech solution for activity monitoring. Unlike the accelerometers, pedometers are not designed to capture the pattern, type or intensity of the physical activity. Pedometers detect the steps taken with acceptable accuracy, and they have showed evidence of reliability. (Tudor-Locke, Ainsworth, Thompson & Matthews 2002, 2047.) Walking is one of the most common forms of activity and is readily captured by a pedometer. The most simplest type of pedometer is one with the mechanism that has a spring-suspended lever arm with metal-on-metal contact. The mechanism uses a spring-suspended horizontal lever that moves up and down in response to the hip's vertical accelerations. This movement then opens and closes an electrical circuit and the lever arm makes an electrical contact (metal-on-metal) and then a step is registered. (Schneider, Crouter & Bassett 2004, 331.)

8.1.3 Gyroscopes

Gyroscopes measure the angurar velocity about each axis. In other words gyroscope senses turning around or twirling. In Huang and Onnela's research the gyroscope data outperformed accelerometer in correctly predicting walking, ascending and descending stairs. Usually when measuring activity, the accelerometer and gyroscope are used simultaneously because accelerometer measures linear speeding up of the movement and gyroscope measures the angular revolving speed. (Huang & Onnela 2019, 2-6.)

8.1.4 Global Positioning System (GPS)

GPS, the Global Positioning System, is typically used in navigation systems. This technology can also be used to collect spatial-temporal data and used as sensors for observing and measuring activities of people. GPS measures the location and motion of a GPS device and the person that carries it rather than a physical property. The sensor output is in the form of a track log with 3-dimensional spatial location coordinates and a time stamp. (Van der Spek, Van Schaick, De Bois & De Haan 2009, 3034.)

8.1.5 Magnetometers

Magnetometer is a sensor that measures magnetic fields and the magnetization of materials. Magnetometer also measures the direction, strength and relative change of a magnetic field at given location. The magnetometer sensor is usually based on the electromagnetic property of earth. Magnetometer is highly sensitive to the movement of the body and it is very suitable for different monitoring in healthcare, for example measuring breathing from the chest movement. (Milici, Lázaro, Villarino & Magnarosa 2018, 2145-2148.)

8.1.6 Electromagnetic Tracking System (ETS)

The electromagnetic tracking system is a kind of 3D measurement device based on Faraday's law of magnetic induction. In the ETS, the controlled magnetic fields are generated by a fixed transmitter and then detected by receivers attached on the moving object. This means that the positions and orientations of the object in relation to the transmitter can be calculated. This kind of technology has been applied to bioengineering, but also for gait analysis and activity monitoring. (Tao, Liu, Zheng & 2012, 2259.)

8.1.7 Electromyography (EMG)

Electromyography (EMG) measures muscle activation, the surface electromyography (sEMG) uses gelled electrodes placed on the skin that monitor muscle movement. (Leone, Rescio, Caroppo & Siciliano 2015, 456.) They are widely used in medical diagnosis, rehabilitation and human-computer interaction. When comparing EMG with other sensors, EMG can directly indicate the body's electrophysiological responses to different activities. EMG detects which muscles are recruited for an action, generates information about the behavior being performed and determines the effort required to perform such behavior. EMG also has the advantage of distinguishing between passive and active activities. (Xi, Tang & Luo 2018, 1-2.) Real-time and minimally invasive surface electromyograpghy has been proven to have good detection time, sensitivity and specificity. This method has been used in healthcare for fall risk detection in elderly patients. (Leone, Rescio, Caroppo & Siciliano 2015, 456.)

8.1.8 Goniometers

Goniometer measures the joint's angular range of motion, monitoring joint angles through wearable systems enables human posture and gesture to be reconstructed as a support for physical rehabilitation. While there now is digital goniometers, they are often used on smart textiles in sensing purposes. (Tognetti et al. 2014, 1.) There are also inductive and optical fibre goniometers. Goniometer with an inductive sensor for the measurement of human motion is a potential tool in activity measuring. Also, a type of optical fibre goniometer has been developed to be applied in human joint movement monitoring. (Tao, Liu, Zheng & 2012, 2257.)

8.1.9 Insole Pressure Sensors (IPS)

The insole pressure sensor (IPS) measures the pressure distribution at the foot, which is widely used to estimate gait parameters such as step count, duration of the gait cycle, swing duration, stance duration and foot–ground interaction events. There are different available variants of IPS that are based on optoelectric sensors, force-sensing sensors, piezoelectric sensors and capacitive sensors. IPSs are typically placed inside the shoe and measure the pressure between it and the foot, which sometimes might lead to non-zero pressure readings even when the foot is in swing phase. The advantages of using IPS are cost factor, wearability, and unconstrained movement that allows natural gait in both indoor and outdoor environments. (Prasanth et al. 2021, 11-13.)

8.1.10 Smart textiles

Textile based deformation sensors can be produced by coating a thin layer of piezoresistive material on conventional fabrics. Smart textiles can be formed from a superficially attached electronic components to a substitution of fibers and yarns with sensing properties in normal fabrics, all the way to electronic components made out of fabric materials. For example, printing carbon-based polymers onto stretchable fabrics, such as Lycra®, can provide a perfect sensing fabric because of the compliant qualities and piezoresistive behaviour of the polymer. The main features of textile sensors are flexibility and the preservation of the mechanical properties of the garments on which they are applied. Compared with other wearable sensors, the sensing fabric is more flexible and comfortable in measuring human posture and movement. (Tao, Liu, Zheng & 2012, 2260.) This kind of sensor technology has been used for knee-sensing garment and for the detection of torso movements. (Tognetti et al. 2014, 2.)

8.1.11 Environmental context

Activity monitoring can be done in an environmental context (see Figure 3), for example using video monitoring and analysing. This method can be very home-centered with the help of video-based activity recognition techniques. The continuous monitoring of daily activities and gait can point out early symptoms of some diseases and help in the diagnose making process. For example, there is a method called motion estimation method which analyzes the sit-to-stand motion from monocular videos. The sit-to-stand movement involves hip and knee flexion-extension, and ankle plantar flexion-dorsiflexion is analyzed by using a 2D human body model that considers the projections of body segments on the sagittal plane. (Ke et al. 2013, 119.)

Types of wearable sensors to assess physical activity

WEARABLE SENSOR	MEASURING METHOD
Accelerometer	Accelerations/decelerations, velocity and displacement of a body segment in x, y, z axes.
Pedometer	A spring-suspended horizontal lever moves up and down in response to the vertical accelerations.
Gyroscope	Angular velocity and rotation.
Global positioning system (GPS)	Location primarily outdoors; may calculate speed and distance of continuous walking.
Magnetometer	Directional vectors of spatial orientation.
Electromagnetic Tracking System (ETS)	Positions and orientations of the object in relation to the transmitter.
Electromyography	Dry electrodes for surface EMG of timing and amount of muscle group activation.
Goniometer	Joint angular range of motion.
Insole Pressure Sensors (IPS)	Piezoelectrode for distribution of weight on sole to define stance in the gait cycle.
Smart textiles	Fiberoptic or deformable textile across a joint detects angular change.
Environmental context	Ambient sound, light, motion-activated photo or video.

FIGURE 3. Types of wearable motion sensors (modified from Dobkin 2013, 3)

9 SENSOR SYSTEMS AND TECHNICAL DEMANDS

9.1 Sensor systems

The wearable, wireless motion sensor data that is analyzed by activity pattern-recognition algorithms can describe the quantity, quality and type of mobility-related activities. (Dobkin 2013, 1.) The system needed when enabling remote monitoring with wearable devices is formed of three components; hardware for sensing and data collection of physiology and movement, communication hardware and software to transfer the gathered data to a remote center and also data-analysis for clinically relevant information. The sensor system is made out of many components, such as the sensor system unit or multiples of them, communication modules and signal processing units. (Alamäki et al 2019, 18.) Wearable systems should be unobtrusive, affordable, easy-to-use and interoperable among various computing systems. There should be a minimum number of sensors, while still maintaining the most important clinical information. The equipment should have more processing capacities, be more lightweight and smaller in size to gain higher usability. (Alamäki et al. 2019, 16-17)

There are multiple things that need to be considered when introducing new technology and implementing new systems for rehabilitation use, for example to measure gait. First, requirements for a good system include that the system should be able to measure everywhere. When measuring gait, over a hundred gait cycles are needed to ensure that the collection represents the real-life condition. The reporting from the system should help immediate clinical decision-making and the reporting should also keep the patient involved and by that enhance empowerment. The immediate reporting is a key factor to attain acceptance within rehabilitation professionals. The system should serve for assessment and also for treatment and the outcome of the system must be problem specific and clinically relevant. The system should also be expandable because of rehabilitation is multifactorial entity and the system should also be validated because rehabilitation is evidence-based. (Alamäki et al. 2019, 16-17)

The sensor systems in practice must meet the many needs of complex design requirements, from aesthetic, privacy, signal processing and data transmission, annotation and scalability to technology acceptability of users. For motion sensing it is especially important that the algorithms of speed and accuracy of feature detection and classifier, turn a sequence of inertial signals into a recognizable movement pattern to measure clinically important details of activity, such as gait. (Dobkin 2013, 2-3.)

Continuous monitoring is enabled by data transmission from sensors to cellphone and Internet. Remote access to laboratory-quality data about the measurements of walking speed, gait symmetry and smoothness of movement and exercise, opens new chances to engage patients in personalized therapies with feedback about the performance. The sensing systems may be come as common as cell phones for healthcare in the future, because of the progressively falling cost of miniaturized wearable gyroscopes and accelerometers and other physiologic sensors, but also due to inexpensive data transmission. Neurorehabilitation could develop these mobile health platforms for daily care to improve physical functioning. (Dobkin 2013, 1.)

9.2 Technical demands for a working system in rehabilitation use

9.2.1 Sensors and platforms

The number, type and position of sensors depend on the specific body metrics sought. It has to be decided what kind of design of sensors is used, for example piezoelectric or capacitive microelectro-mechanical-system accelerometer. The aesthetic appearance of the sensors, and the ease of use and reproducibility of placement are important. It has to be determined what kind of raw signal structure will be used and it's sensitivity to events. With platforms there has to be interoperability by using common software, communication, data processing and confidentiality protocols. The platform must be based on open source and publically available standards. There also has to be end-to-end system reliability. (Dobkin 2013, 3.)

9.2.2 Data transmission

A choice has to be made which kind of wireless standard is going to be used, for example is it going to be Bluetooth, Zigbee, Wi-Fi or some else standard. The costs of data transmission needs to be considered also. It has to be decided in what frequency the data is sampled and with what band-width. The power consumed in data transmission has to be noticed, an energy source is needed. The data transmission has to have data time stamping and error checking. There has to be in consideration what kind of storage capacity is needed for the data and the data must be secured at each stage of collection, transfer and storage. (Dobkin 2013, 3.)

9.2.3 Signal processing

In signal processing it is important that data is temporally fused synchronously from multiple sensors and body sites. Analytic algorithms must be used and the features of signal assessed, for example peak frequency, signal energy, axis correlation and standard deviation. It has to be decided what kind of classifier model is used, for example support vector machine, decision tree, neural networks or spectrum analysis. There has to be possible to integrate multiple layers of the classifier, for example activity and sensor location. Artifaction recognition is extremely important in signal processing to examine the outliers. Speed of processing is also important to create real-time data. Machine-Learning analysis can be utilized also in signal processing. (Dobkin 2013, 3.)

9.2.4 Resolution of data

When thinking of the resolution of the data, software is needed that interprets data from the sensors and other sources of information that will provide new insights to healths states. The data should be normalized for matched population and be sensitive to individual's daily functioning. There has to be discerning trajectory of change and clinically meaningful gains and declines. The data should also be visualized in reports. (Dobkin 2013, 3.)

9.2.5 Data accessibility, privacy and security

The gathered data in healthcare should be available to common databases, such as Kanta or Research Electronic Data Capture database. The data should also be in annotated raw data repository for data mining and research purposes. The gathered data should be securely encrypted. The handling and storaging of data should always follow the requirements of healthcare legislation. (Dobkin 2013, 3.)

10 BENEFITS OF USING WEARABLE MOTION SENSING TECHNOLOGY IN REHABILITATION

The use of activity trackers can be useful when defining patient's mobilization needs, monitoring post-acute patient parameters and increasing the patient's intrinsic motivation. Studies have shown that when patient's have worn wearable activity trackers, there has been a significant relationship between the number of steps taken, in the length of the hospital stay and dismissal disposition. Studies also show that activity monitoring can be a major inspiration for patient's behaviour change. (Wolk et al. 2017, 5.)

There is a global aim for this kind of technology use to lower the long-term costs of more personalized care and to reduce healthcare disparities, especially for patients with chronic diseases. This kind of long-term management capability is especially important in neurological rehabilitation. In the future, it is possible to find remarkable opportunities in rehabilitation by using this kind of technology. At some point, the prevailing clinical instruments that are used for outcome assessment might be replaced with these new low-cost portable sensors. (Dobkin 2013, 2.) Wearable motions sensors could serve as a primary indicator in assessing of effectiveness of rehabilitation interventions. The objective, performance-level tracking via wearables across clinical episodes of care for decision-making is in the future of rehabilitative care. (Lang, Barth, Holleran, Konrad & Bland 2020, 5.)

Wearables represent a possibility to be used for rehabilitation and assessment at different points in the healthcare continuum, from acute care setting to sub-acute care setting and ultimately in the patient's home environment. (Alamäki et al. 2019, 9.) Some may think that this level of monitoring could be viewed as an invasion of privacy, but disabled persons are likely content about the accessibility of rehabilitation supervision in their home context with low costs. In the best scenario, teleneurology and tele-rehabilitation could interface with wearable sensor technology to add compliance with medical recommendations and complement home-based care. (Dobkin 2013, 6.)

The wireless activity monitoring that shows the quality, type and quantity of physical activities, offers a great potential for neurorehabilitation and neurologic patient care and clinical trials. (Dobkin 2013, 7). Ultimately, the optimal use of activity measuring wearable motion sensors would facilitate ongoing assessment of the patient's activity and enable frequent recommendations about how to progress exercise and train skills from remotely located professionals. Then these sensors would alter the rehabilitee's behaviour by offering feedback and personal activity that encourages self-efficacy. In long-term rehabilitation efforts, both patients and caregivers would benefit from remote monitoring. (Dobkin 2013, 5.)

11 CHALLENGES OF USING WEARABLE MOTION SENSING TECHNOLOGY IN REHABILITATION

There is a common problem in healthcare considering the limited uptake and non-use of e-health interventions. (Wentink et al. 2018, 620). Rehabilitation professionals have many competing priorities in today's busy clinical environment, that create a pressure considering limited time and energy to trial new technology, including wearable device systems. For rehabilitation professionals to charge and program the wearable devices, process and share the monitoring results with the patient and other health professionals is unrealistic, unless it can be completed quickly during a patient treatment session. This is why the wearable device systems technology must fit in seamlessly, minimizing disruption to busy clinical settings, for the possibility to be widely implemented into rehabilitation care. (Lang et al. 2020, 3-5.) When implementing such devices, there has to be a real need for using these devices, to get clinically meaningful additional data. The implementing process into everyday rehabilitation practice needs commitment and support from the management and from the organization. (Alamäki et al. 2019, 41.)

The use of smart sensoring devices in monitoring purposes is still underused even though they have been proven to be accurate and have clinical utility and usage. Rehabilitation processes could be extended or replaced with this kind of monitoring. The remote rehabilitation has been developed from the beginning of the 2000s, and the use of it is still low. (Alamäki et al. 2019, 11.) One barrier for implementing wearable sensors into clinical setting is that the wearable sensor technology that is directly marketed to consumers is the most accessible technology, and those sensors might have questionable accuracy in rehabilitation setting. People who need rehabilitation services often do not move normally, the algorithms programmed on the devices are typically for normal gait speed, so the wearable sensor might be inaccurate in identifying or quantifying the movements. It must be noted that the problem is not on the verification of the sensor itself. Studies have shown that there is a wide variability in the accuracy of these devices with people who walk with slower speed or have interruptions in continuous walking and who use assistive devices, such as a walker. Some consumer grade devices exist that have the ability to prove strong reliability and accuracy across varied levels of abilities, such as variable gait speed. When the wearable device has the ability to monitor variable abilities, the potential to integrate these devices into clinical practice grows exponentially. (Lang et al. 2020, 6.)

Most research-grade wearable devices work in conjunction with software systems that require a separate computer program to set-up, download and examine the data. For this to be executable in a clinical setting, every rehabilitation professional should have the access to this kind of computer program. The cost of these devices for multiple patients and for multiple limbs of the same patient, could be expensive. The cost of the program and the devices might make this technology unreachable for some clinics. Current systems also need training to use them, how to use the device itself and the system. In some systems the graphs that the system makes based on the activity analysis are not very patient-friendly. Wearable device systems would need to be less expensive, continuously streamed and on an accessible consumer-based platform, if wanted to have the clinically important information derived from the sensors more widely utilized by patients and clinicians. The compatibility with the wearable device and electronic medical record is one key factor for the overall usability in clinical settings, that the monitoring can contribute the quality and effectiveness of rehabilitation services. The measures and variables gathered from the device should be thoroughly vetted, since scores obtained may be used to make diagnostic and rehabilitation management decisions. If the devices and the system will not work as intended even a small amount of the time, eventually rehabilitation professionals and the patients will become frustrated and discontinue the use. (Lang et al. 2020, 6-12.)

One risk that needs to be considered when harnessing wearable technologies in medicine is data processing and data storage, since both can be nowadays outsourced to the cloud. The problem is about the privacy and data security from the cloud provider and the client's perspective. When thinking from the provider's viewpoint, the client's data and applications must be protected and the security of the infrastructure addressed. From the client's viewpoint, the access to the data and services in the cloud must be restricted. (Alamäki et al. 2019, 24.) One challenge of using technology in care is the technological acceptance of the older generations. The oldest generation of patients is not used to using technology and this might increase the feeling of less aptitude in life management, while also the sense of security is extremely important part in life management. (Alamäki et al. 2019, 43.)

12 CONCLUSIONS

12.1 About the research process

The goal in this thesis was to find out what kind of different wearable motion sensors exist to measure the physical activity of a rehabilitation patient, what is needed technically to these sensor systems to work and also pointing out the benefits and challenges of the use of this kind of technology in rehabilitation. Through an integrative literature research I was able to find multiple sensor types that would be suitable for that matter and also answer the other research questions stated. The integrative literature review itself as a method has been proven to be reliable, as one way to enhance the research's reliability is to use different kinds of original studies, material and theories on the research. Integrative literature review is known for that it allows the use of different kind of material in the research. In this thesis the original studies varied from different research methods, from systematic literature reviews to validity studies. (Tutkimuksen toteuttaminen, 2010.) This research has generalizability and transferability, as the research was made with transparency and using proved methods for searching and analysing the data in the research process. The use of well-known methods in the research process increases the generalizability of the research. (Gerrish & Lacey 2013, 18.)

12.2 Personal development process

I got inspired of this topic during my career in rehabilitation and from the interest towards technology. There has been trials of some kind considering the activity monitoring of rehabilitation patients which I have participated also, but the variety of the different wearable motion sensors offer a lot of opportunities to utilize them into rehabilitation. I also wanted to compile up-to-date information about rehabilitation and stroke rehabilitation, that my partner organization can benefit from, for example in training new nurses. From executing this thesis, I have learned a lot about what is needed from the sensor system to work in rehabilitation setting and why different wearables might fit to that purpose better than others. The thesis writing process taught me to think and evaluate the overall research process more carefully and help me to become a better research writer and a critical thinker. It is said that critical thinking is an important and essential ability for nurses, and I'm glad that the research process has also developed my skills as a nurse. (Cui, Li, Geng, Hui & Jin 2018, 45-47.) All the studies I have done during this degree programme has grown me step by step towards this thesis process, while developing my skills as a healthcare professional at the same time. To understand this bigger picture behind wearable sensors in rehabilitation, it has helped me to grow to the next level in my career, to the role of Master of Health Care.

12.3 Future development ideas

From executing this thesis, it became obvious that wearable sensors are becoming utilized more and more in rehabilitation, because of the amount of available articles considering the topic was surprising. This research could be utilized when thinking of which method to use in activity monitoring amongst rehabilitation patients, the next step could be clinical trials on different wearable motion sensors, which of them is the most suitable on stroke patient's activity monitoring during rehabilitation. The multiple sensor systems that were mentioned in some of the original studies also generate opportunities on trials with hemiplegic patients, for example using one accelerometer on a wheelchair, one on the plegic arm and one on the non-affected arm, doing this kind of trial would generate a lot of data of activity for analysis and the activity monitoring would probably be very accurate. Overall it would be important to start utilizing e-health interventions more in rehabilitation, and seize all the opportunities they provide to help the tele-rehabilitation and through that to the accessibility of rehabilitation. During these unconventional pandemic times the importance of using different methods in healthcare that provide remote services have become more significant than ever, it has to be noted that by utilizing the tele-rehabilitation in rehabilitation services it is possible to reduce the costs of healthcare and give more personalized care to patients. (Alamäki et al. 2019, 6-7.)

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