AALBORG UNIVERSITY
STUDENT REPORT

RehabNeuroLab
University of Victoria

Assessing Coordination of Dynamic Movements in Patients with Motor Dysfunction Following Stroke or Spinal Cord Injury

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Project group: 18gr9406

Simon Bruun and Oliver Thomsen Damsgaard

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1.1 Cardiovascular Diseases

Cardiovascular diseases (CVD) are the number one cause of death on a world wide scale. In 2015 CVDs was estimated to account for more than 31% of all deaths globally. [1] CVD are a collected term for a number of conditions revolving around diseases to the heart and system of blood vessels. According to the World Health Organisation (WHO) the top two causes of global deaths are the CVDs coronary artery disease and stroke. Of the two, stroke accounted for 10% of deaths in 2016. [2]

1.1.1 Stroke

A stroke is caused by either a blockage or rupture of blood vessels in the brain. As such stroke is divided into two subtypes; ischaemic stroke and haemorrhagic stroke. During a ischaemic stroke a blood vessel in the brain is blocked by blood cloths caught in narrow blood vessels. The narrowing of blood vessels are commonly caused by other conditions such as high cholesterol, high blood pressure, unhealthy lifestyle and ageing. If a blood vessel is blocked a part of the brain will be shot off from its blood supply. If not treated within minutes this can cause damage to brain cells in the cut-off area. [3, 4, 5] During an haemorrhagic stroke a blood vessel will rupture and blood will leak inside the brain. Depending on where in the brain the leak occurs the haemorrhagic stroke is either a intracerebral haemorrhage or and subarachnoid haemorrhage, intracerebral being inside the brain and subarachnoid occurring in the space between the brain and the cranium. In both types a rupture and leakage of blood can cause a sudden increase in pressure potentially causing damage to brain cells and can lead to sudden unconsciousness and death. The most common causes are high blood pressure, unhealthy lifestyle, diabetes and ageing. [3, 6, 5]

1.1.2 Stroke Complications

Complications following a stroke are common. In surviving patients 30-96% have been reported to experience post-stroke complications of both physical and psychological nature. Complications involve recurrent stroke and epileptic seizures, cardiac arrhythmias and failure, infections, problems in gastrointestinal and genitourinary systems, complication of immobility, dementia, pain and depression. [7] As so the consequences are many, however this study will focus on complications of mobility. Following a stroke complications related to movement are common. Depending on where in the brain the stroke occurs it can have a variety of outcomes that can affect the patients balance and motor control. Up to 38% of stroke patients have been reported to experience spasticity affecting the performance of dynamic muscle movements such as gait. Spasticity and motor control changes can occur following an upper motor neuron lesion. [7] Stroke patients are also at a higher risk of osteoporosis due to weakening of performing voluntary movements or movements as a whole if the patient experience hemiparesis [7].

1.2 Spinal Cord Injury

The spinal cord (SC) is part of the central nervous system (CNS) together with the brain. The SC is connecting the brain to the rest of the body by connecting to the peripheral nervous system (PNS). It is responsible for leading nerve impulses between the brain and body, to modulate movements, sensory inputs and visceral innervation. The SC extends from the brain just below the cranium down the spine to the lumbar vertebrae one and two (L1-L2). From L1-L2 to the end of the spine at the coccyx vertebrae or tailbone, bundles of nerve fibres extend further. The vertebrae bones encapsulates and protects the SC. However, trauma to the spine can cause trauma to the SC as well. [8]

The incidence for spinal cord injuries (SCI) ranges from 15 to 39 million a year in industrialized countries. Most traumatic causes are a result of traffic accidents, falls and violence. Causes for non-traumatic SCI are degenerative diseases and tumours. In prevalence of traumatic SCI, men outnumber women at a ratio of 3:1, while the prevalence is near equal in non-traumatic SCI. According to the National Spinal Cord Injury Statistical Center (NSCISC), the most frequent category for neurological damage is incomplete quadriplegia at 32.2% of cases. This is followed by complete paraplegia at 24.2%. Out of all SCI cases only 7.4% reach neurological recovery. [9]

1.2.1 Complications of SCI

Any injury to the SC causing neurological damage can lead to serious dysfunction depending on where the injury happens. This can lead to loss of sensory sensation and motor control and dysfunction to bladder, bowel and cardiovascular functions. [8] As mentioned earlier, this project will focus on complications of mobility. Many SCI patients experience rehospitalization, depression and pain, following the injury. According to the NSCISC many patients are unsatisfied with their life in the years after injury. However, life satisfaction generally increase with years post injury. [9]

1.3 Rehabilitation

Patients suffering from neural damage caused by stroke or SCI will in many cases need to go through a rehabilitation process to regain or relearn lost functions [10, 11]. Currently many different methods for rehabilitation exist, many with focus on patients regaining the ability to control their limbs and balance, as a step toward regaining independence. An important aspect of rehabilitation is that when assigning training to patients of SCI or stroke, it is important to evaluate the state of the patient, as different patients will have different levels of dysfunction depending on the severity of the damage caused by SCI or stroke. Rehabilitation should be suited to each patient individually. [10]

1.3.1 Current stroke rehabilitation methods

Gait and balance rehabilitation of stroke patients focus on implementing the locomotion mechanisms, but also the brain, to achieve functional gait on various surfaces. Several studies have indirectly shown that cortical functions are involved in the gait cycle, where they are responsible for reacting and adapting the gait to uneven surfaces. [12]
As in cases of SCI, stroke rehabilitation also focuses on regaining the ability to walk, and therefore the rehabilitation process implements gait training. Stroke patients have the same possibility to exploit motor plasticity, in order to relearn previously known skills. [12]
There are many approaches to gait rehabilitation, where the most relevant in this case is the motor learning techniques. This method gives the patient an active role in the rehabilitation process, and there are multiple approved approaches within this technique. The overall thought behind this technique is to learn new and improve current skills by repetition of specific tasks and utilizing sensory feedback to achieve manipulation of the involved neural systems. [12]

1.3.2 Current SCI rehabilitation methods

The aim of rehabilitating patients suffering from either stroke or SCI, is to compensate for the abilities they have lost by training the intact parts of their sensory-motor (SM) system. This can be achieved by activating the intact parts of the SM system with sensory cues recruiting both spinal and supra spinal connections. [10]
This approach has been shown to work in animal studies, where neural systems in the spinal cord responsible for locomotion were trained independently of the connection to the brain. These methods have been used as the foundation for the current training protocols to train functional movements such as walking in patients with incomplete SCI, meaning the training should make use of the neural plasticity. [10]
Training the walking ability includes a treadmill on which the patient will attempt to walk while being supported by an unloading harness. The treadmill walking should activate locomotion movements through the input from load and stretch sensitive mechanoreceptors, resulting in improved coordination, speed and strength. This training method can consist of both explicit and implicit methods, where patients will either receive visual feedback to adjust the length of their steps in order to activate a cognitive process to adjust their gait. The implicit method will rely on resistance in order to train locomotion without the patient having to plan their step length. Another important aspect of rehabilitation of these individuals is their balance, and lately training of this ability has been shown to increase both speed and distance in walking tests. [10]

1.4 Assessing gait in rehabilitation

It is common for rehabilitation programs to focus on patients regaining their ability to walk following impairment of movement due to stroke or SCI. Walking is an important part of life and is a large factor for autonomy and independence in daily life. Several different methods for assessing patient gait abilities have been developed to evaluate on the rehabilitation progress.

1.4.1 Measuring Gait In a Clinical Environment

Recent technological improvements makes it possible to perform advanced gait analysis (GA) while examining 3D kinematics and EMG in a clinical setting. This method provides the clinician with an advanced insight in the patients current abilities and gives the possibility of measuring and quantizing any changes that might occur during a rehabilitation process. [10]

The method of using 3D kinematics takes place in a laboratory with the use of cameras, surface electromyography (sEMG), force platforms and stereophotogrammetry equipment to provide the needed data to perform GA. The system provides recordings for qualitative analysis, as well as quantitative measures of muscle activation, contact forces with the ground and body position during gait. These measures are used to evaluate the gait cycle with regards to step length, cadence, swing time, rotation and power in the joints for the individual subject. [10]
An attempt to quantify the quality of gait with a single parameter was made with the Normalcy Index (NI), where the algorithm measures deviation of a patients gait pattern from the gait of healthy individuals through Principal Component Analysis (PCA). The mean pattern is based on some of the features obtained with GA. This method has been proven to be an effective tool to examine changes in gait over time. [10] Further advances in the quantification of the many features is the gait deviation index, the gait profile score and the movement deviation profile. All of these methods take different approaches to finding the deviation between healthy gait and the measured variables from the advanced clinical set-up described briefly above. [10]
Other approaches exist to measure improvement during rehabilitation. One study calculated the combined centre of pressure of the patient and a walking frame (WF) as a combined system, by measuring reaction forces of both the patient and the WF along with cameras capturing the placement of the feet relative to the WF. This gave the possibility to calculate the weight supported through the frame and the stability of both patient and WF. [13]

1.4.2 Measuring Gait Outside a Clinical Environment

Methods of measuring gait and other dynamic activities outside clinical environments are becoming more accessible and favourable over measurement methods bound to clinical environments. Rehabilitation and assessment in clinical environments rarely translate well to real life situations [14]. Such systems are most functional if they are wearable by the patient or test subject.

Wearable systems to analyse and monitor body dynamics are attracting an increased interest in research, where accelerometers and inertial measurement units (IMU) are the most used in newer studies. Here, studies have used wearable systems to measure upper limb kinematics and trunk posture, to evaluate on movement performance. [15] Wearable systems can also be used for assessing gait by implementing multiple sensors placed on the subjects lower limbs, measuring variables such as acceleration, gyroscopic, pressure forces and EMG depending on which system is implemented. Here, measuring forces applied to the feet can be done with force sensors based on either resistive, piezoelectric or capacitive designs, and often includes an implementation of these in shoes or insoles. [16] A study by Muro et al. [16] has been

shown that the implementation into insoles reflects the measurements obtained from clinical motion analysis laboratories.
Inertial measurement units (IMU) can also be implemented in wearable devices. These consist of gyroscopes measuring the rotational inertia used to measure changes in direction, as well as accelerometers measuring the acceleration in three axes giving the opportunity to measure changes in balance or sudden knocks such as those experienced by the sensor while walking. [16]

A study by Hurwitz et al. [17], examined the importance of accelerometer position, age and walking speed on the accuracy of accelerometer based measurement of gait. It was found that the device location did not affect measures such as speed, cadence and single limb support time. Gait asymmetry and variability was shown to be affected by age and walking speed.

1.4.3 Shortcomings of current rehabilitation

It is known that clinical trials and training translates poorly to daily life outside clinical environments, however still current rehabilitation mainly perform training in clinical environments, or train tasks which poorly portrait normal daily life. [14] This is a problem since both stroke and SCI patients experience a greater risk of falls. The prevention of patients falling should be prioritized in rehabilitation as falls can lead to loss of independence and serious injury. Despite the consequences, studies have shown that 30-39% of stroke patients fall at least once during a rehabilitative process, and of these patients 42% experience multiple falls. [7, 18] According to a study by Wannapakhe et. al [**Wannapakhe2015**], out of a group of 100 SCI patients, 45 experienced falls during a six month period post rehabilitation. Apart from the immediate risks and dangers to patients falling, falls can also further extend the rehabilitation period and worsen the rehabilitation of both motor and cognitive functions [19, 20]. This is a problem since strength recovery is usually greatest in the first 100 days following injury [8].

In addition, current rehabilitation programs still use qualitative methods for evaluating patients progress. These methods rely on the physician to evaluate how well the patient performs [**ANPT_SCI2018**, **ANPT_Stroke2018**]. This is a problem since qualitative evaluations are prone to changes from session to session depending on many factors which are not accounted for, like the patients level of energy or the physicians personal experience. This could be a problem since patients are observed to experience falls post rehabilitation [**Wannapakhe2015**, 7, 18]. This might suggest that current evaluation methods does not properly evaluate whether or not patients are fit for independent daily life.

1.4.4 Balance and Gait Training

In contrast to current rehabilitation methods, mainly focusing on simple gait training, a rhythmic movement, newer approaches have begun to use dual-task training, incorporating cognitive tasks as well. Similarly, training involving advanced movements have suggested to improve balance for both stroke and Parkinson's disease patients [21, 22].

Studies have shown that dual-task mobility training helps improve balance and gait compared to groups that performed single-task training in stroke patients. The dual-task approach was designed to make the patient walk on a treadmill while performing either a cognitive or motor task at the same time. [23] The walking/motor dual-task method proved to be significantly better at improving speed, stride length and cadence for both dual-task and single-task tests. Combining walking and cognitive tasks improved the patients cadence and dynamic gait index, which describes balance while walking, in single-task tests. It was also found that combining balance and cognitive or motor tasks improved a number of balance measures significantly compared to single-task training. [23] Despite the outcomes reported in [23], the conclusion is that more studies are needed in order to support that dual-task training improves performance in dual-task tests. The review study shows that a dual-task approach improves single-task tests compared to the single-task training. [23]

A similar approach can be seen in studies where Tai Chi was used as a rehabilitation method for stroke and Parkinson's disease patients, implementing the aspect of thought and simultaneous movement into the training [21, 22]. This use of martial arts training resulted in multiple studies finding significantly higher improvement in balance compared to the control groups, while gait measures did not improve significantly with the implementation of Tai Chi training. [21] These findings can not lead to a final conclusion due to the number of trials and sample size, but the results indicate that martial arts could help increase balance in stroke patients [21]. It was also found that Tai Chi helps to reduce the number of falls for people suffering from balance problems after both stroke and Parkinson's disease, while in this study it did not result in a significant difference between balance measures compared with regular treatment [22]. It has also been found that Pilates training improves both static and dynamic balance in older adults compared to the control group that only did their normal daily activities [24].

1.5 Problem definition

Following the previous chapter the work leads us from the problem of patients suffering from complication of mobility caused by stroke or SCI, to the current rehabilitating methods used to train patients to regain mobility. However, these methods are not standardised and evaluations of patient performance is subjected to physicians personal experience and patients immediate feeling. Additionally, most evaluations occur in clinical environments when performing simple movement tasks, which translate poorly to real life.

It can be discussed whether or not current rehabilitation training with single-task training of simple movements is properly prepares patients to live independent daily lives post rehabilitation. This project propose that training involving advanced dynamic movements can further improve on patients strength and balance, better preparing them for daily life, when compared to traditional simple movement training. However, there exist no suitable system to evaluate advanced dynamic movements. Thus a new system is needed to have a way to measure and assess patients ability to perform advanced dynamic movements to determine if this type of training is better than that currently used in rehabilitation.

How is it possible to develop a wearable system to measure performance of advanced dynamic movements to evaluate a subjects performance in relation to balance, coordination and sequence of execution.

2 | Methods

2.1 Subjects

For this project two test subjects will be used; one who is a master at Karate, and one who is novice. Both subjects are able-bodied and to the authors best knowledge healthy. Both subjects were prior to the test instructed about the purpose of the study and their role as test subjects. Both the master and novice were instructed to perform the karate kata Pinan Nidan as best they are able to. The novice further received detailed instruction on how to perform the kata, as the novice has never before done karate.

2.2 Experiment protocol

For this project reaction and pressure forces is collected from subjects performing the karate kata Pinan Nidan. A karate kata is a sequence of detailed patterns of movements. Many different types of kata exist, each practice visualisation, balance and basic technique through repetition of movements. Different katas have different sequences of movements, some are more difficult than others where jumps and kicks are part of the movements. For this projects data acquisition the kata Pinan Nidan is chosen. Pinan Nidan consists of a series of movements involving steps, turning and hand strikes, where the performers' feet are on the ground at most times. It is the first kata of the Wado-Ryu system and is taught to new students as it is seen as an easier kata for beginners. [**Mccarthy1987**, **Dojo2018**] Therefore it should be possible to quickly teach a complete newcomer to karate through Pinan Nidan and have an adequate performance of the kata to compare to the movements of a master of the kata.

During performance of the Pinan Nidan kata, subjects will be wearing three Shimmer3 devices, located on the head, chest and waist [MAYBE]. Subjects will also be wearing shoes with FSR installed and a belt mounted Arduino Uno for data collection from the FSRs.

2.3 Experiment Materials / Instrumentation / Apparatus / Devices we use for measuring

For this project data will be acquired using accelerometers, gyroscopes and force sensors. The accelerometer and/or gyroscopes is provided through the use of the Shimmer3 device from ShimmerSensing. Force sensors are from Interlink Electronics of the 400 Series.

The Shimmer3 device is a nine degree of freedom (DoF) Inertial Measurement Unit (IMU) possessing five different types of sensors; accelerometer, gyroscope, magnetometer and altimeter. The Shimmer3 is capable of being configured to enable or disable specific sensors depending on which is needed. For this project only the accelerometer and gyroscope modules of the device will be used. The Shimmer3 device has two accelerometers, a wide range and a low noise. The wide range accelerometer is of the component LSM303DLHC. It has a three dimensional digital linear acceleration sensor with a range of $\pm$2g / $\pm$4g / $\pm$8g / $\pm$16g, and sensitivity of 1000 Least Significant Bit (LSB) per g at $\pm$2g. The LSM303DLHC also features a magnometer. [**LSM303DLHC**, **ShimmerSensing2016**] The low noice accelerometer is a KXRB5-2042 with a range of $\pm$2g. The sensitivity is 600$\pm$18 mV/g. [**ShimmerSensing2016**] The gyroscope in the Shimmer3 device is a MPU-9150, with a range of $\pm$250 / $\pm$500 / $\pm$1000 / $\pm$2000 degrees per second (dps). The gyroscope has sensitivity of 131 LSB/dps at $\pm$250dps. [**ShimmerSensing2016**] Communication between the Shimmer3 devices and the computer is through Bluetooth. The computer will be running MATLAB and the *Shimmer MATLAB Instrument Driver Library* to collect the streamed data from the Shimmer3 device. The Shimmer3 device has dimensions of 51mm x 34mm x 41mm and is easy to place nearly anywhere on the body with elastic straps with snap clips. Three Shimmer3 devices will be used for this project.

SHIMMER3 DEVICE BODY POSITION PLACEMENT: One device will be mounted on the head of the subject, one at the chest and one at the waist.

The force sensors used in this project are Force Sensing Resistors (FSR) from Interlink Electronics, models 402 and 406. The FSR 402 is a 13mm diameter circle single-zone resistor capable of force detection in a range from 20g to 2kg. The FSR 406 is similar but covers a larger area of 38mm in a square. [**IE400**] A total of six sensors will be used with three sensors under each foot. The FSRs will be installed in a pair of shoes for subjects to use during data acquisition, to ensure the same placement of sensors. One FSR 406 is placed under the heel and two FSR 402 sensors are placed under the front of the foot at the left and right side of the anterior lateral eminence of the sole. One Arduino Uno will be placed at the back of the hip of the subject to handle data collection. Collected data will be stored on an SD card for later analysis with MATLAB.

2.4 Data Acquisition

how do we record

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