AALBORG UNIVERSITY
STUDENT REPORT

RehabNeuroLab
University of Victoria

Assessing Coordination of Advanced 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 | Introduction

This is introduction.

Stroke and spinal cord injuries are bad for people. Not in relation to causing deaths, because mentioning this in the introduction would imply that we tend to fix that problem. We do not.

Stroke and SCI are bad for people who like to walk. To have normal independent daily life. Then, people are send through rehabilitation. However, current rehabilitation are not very good at getting people good at going again. This is seen as a lot of people experience falls post rehabilitation. This is bad. Real bad.

What is the cause? We are not sure, but a plausible cause could be that current rehabilitation methods are not properly training people to be fit for independent daily life. Current rehabilitation methods for training people involves walking on treadmills. Walking is a fine way of training people to walk. However, it is bad at training them to walk outside clinical environments, out in real life. This has been proven. (add some references) Additionally, current rehabilitation methods for assessing peoples health and ability to walk properly could be flawed in that it is qualitative, meaning that it is subjected to changes from session to session, patients immediate feeling and energy level and the physicians personal experience.

Thus, it would be real nice to have a new way to train patients to gain good ability to walk. This would also involve them having good balance, strength and coordination of movements. Some kind of dynamic movement might be better training. Luckily such training exist. Martial arts involves dynamic movement. Some martial arts even involves dynamic movements on an advanced level. Karate is one such martial art. Additionally, is would be really cool to have some way to assess how well people are at performing karate, to investigate if they get better balance, strength and coordination over time.

Thus, this project will investigate the possibility to develop a system to assess the performance of the martial arts of karate (and maybe suggest that rehabilitation should begin to incorporate new methods for training people, and not just keep doing what it has done for the last 20 years.)

2 | Problem Analysis

2.1 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]

2.1.1 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]

2.1.2 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].

2.2 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]

2.2.1 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]

2.3 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 control of limbs. Many patients suffer from loss of the ability to walk properly, as a result of losing control of the lower limbs. A giant step toward regaining autonomy and independence in daily life is to train patients balance and ability to walk again.

Rehabilitation programs for both stroke and SCI patients often involves training gait and the sensory-motor (SM) system in the brain. Studies have shown that due to neural plasticity patients can regain lost functions with training [12, 10]. Rehabilitation training functions through repetition of specific gait tasks while utilizing feedback to achieve improvements in gait coordination, speed and strength [12]. The training is often conducted using treadmills, on which

the patient will attempt to walk while being supported by an unloading harness. This training method can consist of both explicit and implicit methods; the explicit method is where patients will 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]

An important aspect of rehabilitation is that when assigning training to patients of stroke or SCI, 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 stroke or SCI. Rehabilitation should be suited to each patient individually. [10]

2.4 Assessing Gait in Rehabilitation

During rehabilitation patients must be assessed to evaluate the progressing of the rehabilitation process. Several different methods for assessing patient gait abilities have been developed to evaluate on the rehabilitation progress.

2.4.1 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]

2.4.2 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.

2.4.3 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 [19], 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 [20, 21]. 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 [22, 23]. 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 [7, 18, 19]. This might suggest that current evaluation methods does not properly evaluate whether or not patients are fit for independent daily life.

2.4.4 New Methods for 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 [24, 25].

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. [26] 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. [26] Despite the outcomes reported in [26], 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. [26]

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 [24, 25]. 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. [24] 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 [24]. 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 [25]. 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 [27].

2.5 Problem definition

The previous chapter introduces the problem of patients suffering from complication of mobility caused by stroke or SCI and leads 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 an improvement to current rehabilitation methods.

1. 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. How is it possible to develop a wearable system to evaluate subjects Centre of Pressure when performing advanced dynamic movements.
3. How can a wearable system be developed which can measure Centre of Pressure and rotational forces of advanced dynamic movements to assess coordination control and balance.
4. How can a wearable system be developed which can be used to assess coordination control and balance of advanced dynamic movements.
5. Evaluating Centre of Pressure/Balance in subjects performing the karate kata Pinan Nidan. A proof of concept study.

3 | Methods

For this project reaction and pressure forces are collected from subjects performing the karate kata Pinan Nidan. A karate kata is a sequence of detailed choreographed 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. Pinan Nidan takes between 30 and 60 seconds to perform depending on the speed of movements. The kata consists of 13 stepping, 11 turning, 7 punching and 13 blocking movements. [28, 29, 30]

3.0.1 Subjects

For this project three healthy test subjects will be used; one who is a master at karate (+30 years of karate experience), one intermediate (3-5 years karate experience) and one novice (less than 1 year of karate experience). All subjects are able-bodied and have no neurological or muscular injuries. Subjects were prior to the test instructed about the purpose of the study and their role as test subjects.

3.1 Instrumentation

For this project data will be acquired using gyroscopes and force sensors. The gyroscopes are provided through the use of the Shimmer3 device from Shimmer Sensing (Dublin, Ireland)). Force sensors are from Interlink Electronics Inc. (California, USA) of the 400 Series.

The Shimmer3 device is a nine degree of freedom (DoF) Inertial Measurement Unit (IMU) possessing four 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 gyroscope module of the device will be used. The gyroscope 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. [31] Communication between the Shimmer3 devices and the computer is through Bluetooth (Bluetooth SIG, Washington, USA). The computer will be running MATLAB (MathWorks, Inc. Massachusetts, USA) 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. Two Shimmer3 devices will be used for this project.

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 square area of 38mm × 38mm. [32] A total of six sensors will be used with three sensors under each foot. An Arduino Uno will be used for handling recording and saving the data from the FSRs. The Arduino Uno is mounted on a breadboard, and connected to six jack stick plugs, an microSD card reader and batteries for power supply (see figure 3.1). The FSRs are connected to the Arduino through 3.5mm jack sticks. Data collection is initiated by pressing a designated record button. When recording is active a LED on the board will light up. Data from the FSRs will be stored on a microSD card and be processed offline with MATLAB.

The system setup as a whole for both the gyroscope and FSR parts can be seen illustrated in a block diagram on figure 3.1.

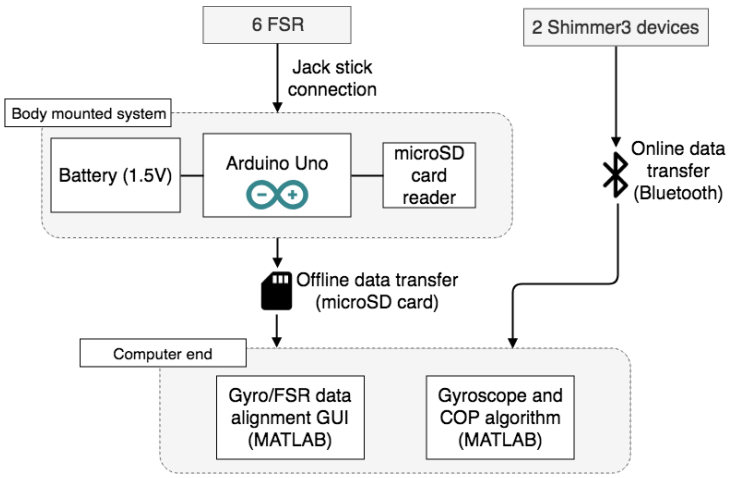

Figure 3.1: Block diagram of the system. The left side is of the pressure sensing part utilizing the FSRs. On the right side is the Shimmer3 devices (gyroscopes). All data is collected and processed on a computer using MATLAB.

3.1.1 Instrumentation placement

During data acquisition the subjects will be wearing the instruments presented earlier in section 3.1. The Shimmer3 devices will be placed, one on each leg, lateral distal to the knees of the subject.

The FSRs will be placed on the sole of each foot of the subject. One FSR 406 is placed at the lateral eminence of the sole. Of the two FSR 402 sensors, one will be placed under the heel and the other medial eminence of the sole. The placement of FSRs can be seen on figure 3.2.

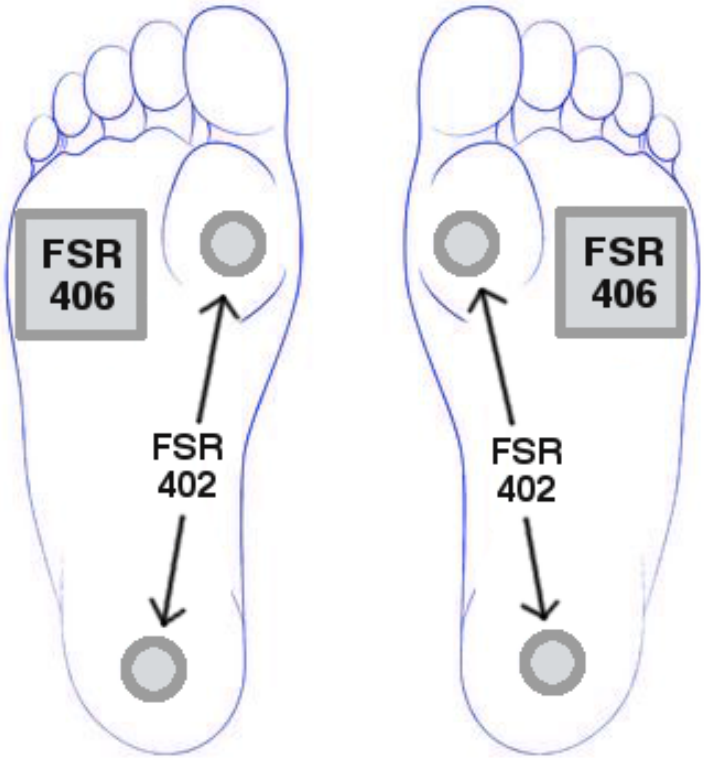

Figure 3.2: The placement of the FSR 402s and 406 under the foot of subjects.

The Arduino-setup will be placed at the lower back of the subject and handle data collection. Collected data will be stored on an microSD card for offline analysis with MATLAB. An illustration of device placement on a subject can be seen in figure 3.3.

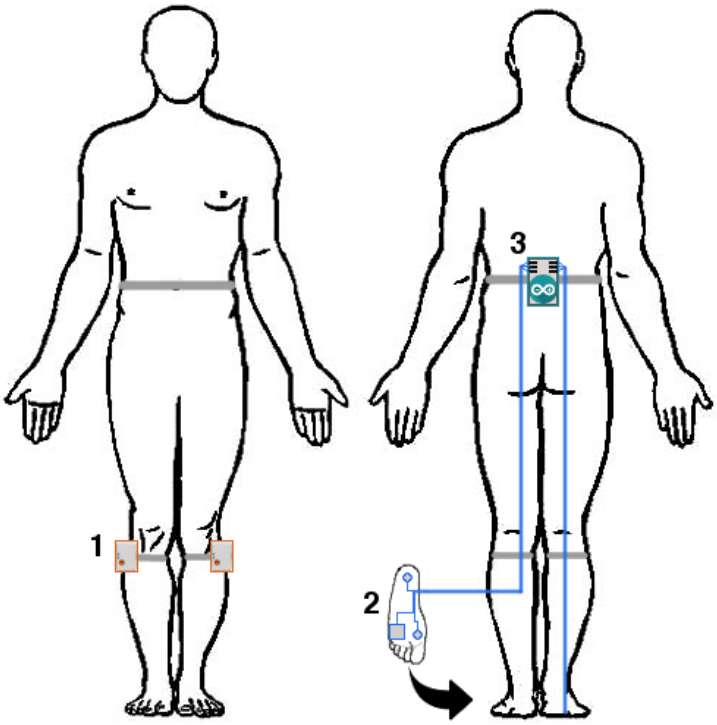

Figure 3.3: The placement of the Shimmer3 IMU devices (1), FSRs under to feet (2) and Arduino-setup (3) on a test subject.

3.2 Data Acquisition

Data acquisition from both the FSR sensors and the Shimmer3 devices are set to have a sample frequency of 100Hz. This sample rate is used by others performing similar measurements [33, 34, 35]. Additionally, the sample rate is decided to be the same so it is possible to match the two data streams to each other, so it is possible to compare measured pressure forces under the feet while matching it to movement of the body. A simple graphical user interface (GUI) have been developed to match the data. This manual approach is favourable for this project as it were determined that it would be more time consuming to develop an algorithm to automatically match data streams. It would also go beyond the scope for the project.

Data from the Shimmer3 devices are send and saved directly to MATLAB via Bluetooth and stored in $n \times 3$ matrices, one for each leg.

For saving acquired data from the FSR sensors an Arduino program have been written to arrange measurements into an $n \times 6$ matrix. Each column corresponds with the channel input for each FSR. See figure 3.4 for the numbering of FSRs and channels. Rows in the matrix are time steps. The data is saved to a *.txt*-file on the microSD card.

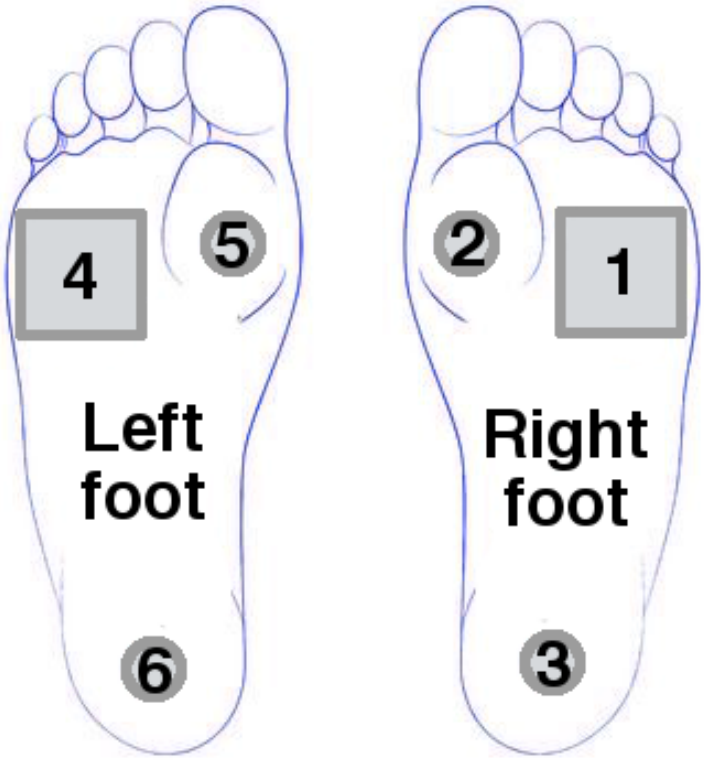

Figure 3.4: The numbering of each FSR sensor according to the channel they are recorded to in the Arduino program.

3.3 Data Analysis / Processing

This section covers processing and analysis of acquired data. All data processing is performed using MATLAB.

3.3.1 Filtering

The spectral density of gyroscope data have been analysed to investigate frequencies of interest. From the Fourier transform (FT) of gyroscope data (see figure 3.5) it can be observed that frequencies over 10Hz contain very little information. To avoid possible noise and artefacts a low pass third order Butterworth filter have been implemented with a cut off frequency at 25Hz.

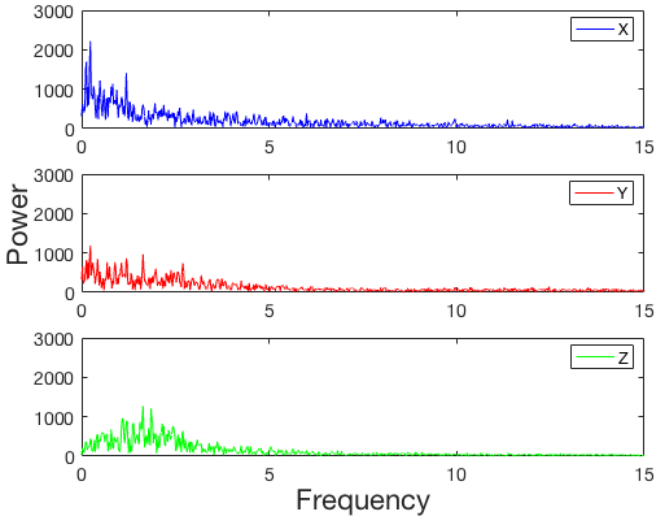

Figure 3.5: The power spectral density of gyroscope data from the left leg of one subject.

3.3.2 Data Alignment

Because the measurements from the FSRs are run on an Arduino, and the gyroscopes run through a Shimmer Sensing developed script for MATLAB, the timing for the measurements are run differently. In order to analyse FSR data to the corresponding time for gyroscope data a data alignment GUI have been developed in MATLAB. The implemented alignment program is a simple GUI which creates a plot where different channels from the six FSRs and six DoFs from the gyroscopes (three for each on each leg) can be shown or hidden. Additionally each channel can be translated left or right. This enables to align data from the FSRs to the gyroscopes, based on a spike in measurements caused by a small jump subjects will be asked to perform before and after performance of Pinan Nidan. An example of the alignment GUI can be seen in figure 3.6.

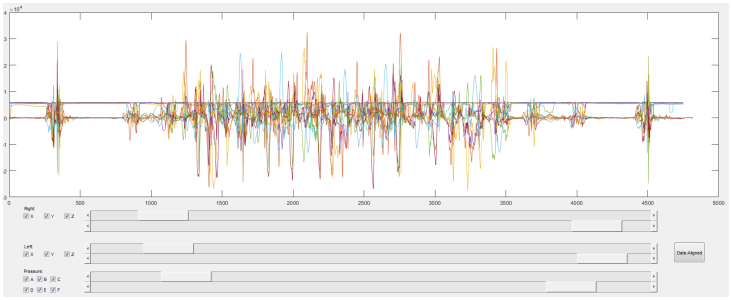

Figure 3.6: The alignment GUI showing a selected number of channels from the FSRs and gyroscopes. All channels can be translated in order to align timestamps for the FSR measurements to timestamps for the gyroscopes.

3.3.3 Calculation of movement scores

For calculating a movement score four separate scores will be calculated; COP, length, span and frequency distribution. COP is a calculation of the estimated COP for a test subject on a plane. The length is calculated on the path of the moving COP during recording. Span is a calculation of the area in which the COP has travelled. Frequency distribution is a measure for the gyroscope frequencies measured during recordings.

Calculation of Centre of Pressure

The COP (check for prior use of abbreviation) calculation consists of two simple equations to find the displacement of balance in the X and Y directions. To ensure the calculated values are unrelated to the weight of the test subject, but solely describes the displacement of balance, each calculation of the pressure distribution will be divided by the overall pressure placed on all sensors. The COPx equation finds the distribution of weight between the two feet, whereas the COPy equation describes the distribution between the sensors on the front and back of the foot. The COP measure is used in calculations of the length and span measures. In addition to the displacement of these sensors in relation to each other and to compensate for the number of sensors on the front and back of the foot, a weight (W) will be added to the pressure readings (P). The COP calculations for X and Y directions follow equation (3.3.3) and equation (3.3.3):

$$COP_x(i) = \frac{\sum_{i=1}^{3} P_i W_i - \sum_{i=4}^{6} P_i W_i}{\sum_{i=1}^{6} P_i W_i} \tag{3.1}$$

$$COP_y(i) = \frac{\sum(P_3W_3 + P_6W_6) - \sum(P_1W_1 + P_2W_2 + P_4W_4 + P_5W_5)}{\sum_{i=1}^{6} P_i W_i} \tag{3.2}$$

Calculation of length score

The length of the COP outcomes was calculated and divided by the length (L) of the recorded data, so the outcome measure described the mean COP change between each sample. To ensure this measure had an effect on the final score it was multiplied by a factor of 10. The length was calculated individually for X and Y directions for later use in score calculation (see equation (**??**)).

$$Length_{x,y} = \frac{\sum_{i=1}^{L-1} \sqrt{(COP_{x,y}(i+1) - COP_{x,y}(i))^2}}{L} * 10 \tag{3.3}$$

Calculation of span score

Calculation of the span describes the span between the outer most points of the COP changes, giving an area in which the COP travels. The span is calculated by taking the absolute value of

the difference between maximum and minimum observed values of COP. This is calculated for both the X and Y directions. In the same manner as the length measure is scaled by a factor of 10, the span measure is divided by 10 to decrease the effect of the span in relation to the other measures. Span is calculated as shown in equation (**??**):

$$Span_{x,y} = \frac{\left|max(COP_{x,y}) - min(COP_{x,y})\right|}{10} \tag{3.4}$$

Calculation of frequency distribution

As described in section 3.3.1 on filtering, it is shown that the power spectrum of the gyroscope data provided very little information above 10Hz. Thus, the frequencies have been divided into two categories: low and high. Here, low frequencies is defined as 2/3 of the frequency spectrum from 0 to 5Hz, and are an expression for stable movements. High frequencies are defined as the last 1/3 of the frequency spectrum from 0 to 5Hz, and are an expression for less stable movements. This separation of low and high frequencies, relative to the frequency band of acquired data, is based on when the frequency distribution deviated less than 5% of the mean for individual subject. The frequency distribution is calculated by the difference between the power at frequencies in the low and high category, divided by the total power of frequencies between 0 and 5Hz, as shown in equation (3.5):

$$Distribution = \frac{LowFreq - HighFreq}{LowFreq + HighFreq} \tag{3.5}$$

3.3.4 Calculation of performance score

Each movement score; length, span and frequency distribution is used to calculate a final performance score for each subject. The performance score is calculated by dividing length by span, and multiplying by one subtracted with the frequency distribution, as seen in equation (3.6). The best performance score is produced by short lengths in relation to larger spans. The performance score is better the lower the value.

$$Score = \frac{Length}{Span} * (1 - FrequencyDistribution) \tag{3.6}$$

3.4 System test

This section covers the test of the system, prior to conducting the experiment for the project.

3.4.1 Method of test for gyroscopes

The authors assess that a test of the gyroscopes is not necessary, as the Shimmer3 devices will be calibrated using the built in function of Shimmer Sensing's program, Consensys, to ensure the devices are working as expected.

3.4.2 Method of test for Force Sensitive Resistors

The FSRs will be tested by placing a 1kg weight covering a surface area of $1cm^2$ applied in the middle of both types of FSRs. This is done to test if any of the sensors are broken or deviate compared to the other FSRs.

3.4.3 Test results for Force Sensitive Resistors

A weight of 1kg were applied to each FSR in order from FSR channel 1 to 6. The weight were applied for approximately five seconds to each FSR in the middle of the sensor area. Results of the test of the FSRs is shown in figure 3.7.

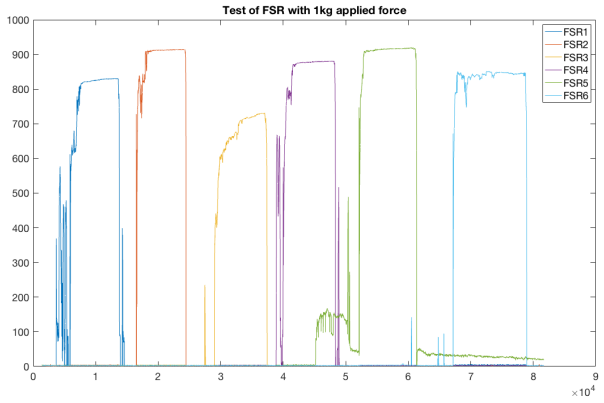

Figure 3.7: The result of the test of the six FSRs.

As it can be seen from the results none of the sensors are broken, however FSR number 3 (FSR#3), located at the heel of the right foot, returns a lower resistance when applied a 1kg weight compared to the other FSRs.

This could prove a problem if data were to be compared between individual FSRs, however the output for each FSR sensors will be used for estimation of a point for the subjects COP, which will be used to compare COP between subjects. Thus, the FSR#3 measurement will not have an effect as long as FSR#3 have the same deviance for every subject.

3.4.4 System test

The system as a whole will be tested with a walk sequence. The sequence will involve periods of no movement, movement by walking and turning and a light jump to mark the beginning and end of the sequence. The test walk sequence is as follows:

- 5 second pause
- Light jump
- 5 second pause
- Walk five steps
- 180 degree turn
- Walk five steps
- 5 second pause
- Light jump
- 5 second pause

Following the system test the acquired data will be qualitatively evaluated to ensure everything works as intended.

3.4.5 Test results for System test

Result of the system test as a whole were successful, despite lower readings from FSR#3. Acquired data were plotted for each FSR channel so the recorded output could be viewed alongside a video recording of the test walk sequence. At each step FSRs were reacting and returning values consistent with what would be expected when pressure were either applied to or removed from the sensors. It is concluded that, as the lower resistance returned from FSR#3 will be consistent for all data collection, the *"error"* will be present in each data set and therefore should not have any effect on comparison between subjects.

3.5 Protocol

3.5.1 Aim

The experiment aims to measure the ground reaction forces during the performance of the karate kata Pinan Nidan. At the same time gyroscopic sensors will measure the rotational forces of the legs for later use in data analysis.

3.5.2 Design

Before the experiment

- The data file “DATA.txt" on the microSD card for the Arduino will be emptied and the microSD card will then be placed in the Arduino-setup.

- Subjects have knowledge and various amounts of experience with the kata Pinan Nidan prior to the experiment. No subject needs instruction of performance of the kata.
- The subject is instructed that before recordings of the kata they will stand still for five seconds, do a small jump and stand still for five seconds. This small sequence is to be performed both before and after performance of the kata.

Initial part

1. The person responsible for the test will mount the force sensors underneath the feet of the subject according to the labelling on the sensors. These sensors will be placed as following on both feet:
    - One FSR406 sensor on the lateral eminence of the sole
    - One FSR402 sensor on the medial eminence of the sole
    - One FSR402 sensor at the heel
2. The distance between the sensors will be measured for later use.
3. 1 Shimmer3 device (gyroscopes) will be mounted lateral distal to the knee. One sensor on each leg.
4. The Arduino-setup will be mounted around the waist, and the system will be placed at the lower back.
5. Elastic straps will be mounted right above the knee to ensure the cables for the force sensors stays in place, and to mount the Shimmer3 devices.
6. The force sensors will be plugged into the Arduino-setup according to the numbering on both the system and the sensor cables.
7. Shimmer3 devices will be connected to MATLAB.
8. The subject will practice one round of Pinan Nidan to warm up.
9. The subject stands ready to begin performing Pinan Nidan with recordings.

Data acquisition part

1. Recording from the Shimmer3 devices will be initiated in MATLAB.
2. The Arduino system will be powered up and recording started by pressing the designated “Record” button until the red LED lights up.
3. Subject will be asked to stand still for 5 seconds then do a small jump, stand still for 5 seconds, do another small jump and then stand still for 5 seconds before moving on.
4. After this initial movement, the subject will be asked to perform the Pinan Nidan.

5. When the subject is done with the Pinan Nidan, they will be asked to perform a 5 second pause, small jump and 5 second pause again.
6. The recording is stopped by pressing the “Record” button until the red LED turns off. The Arduino-setup will be shut off and the microSD card removed from the setup to extract the data to a computer.
7. After data is transferred to the computer, the microSD card is inserted to the Arduino-setup, and the process continues from step 1 in “Data acquisition part”.

The subject will perform Pinan Nidan four times in total, one for practice and three were data is acquired.

Removal of the system

1. After the data acquisition the subject will be asked to stand still and the Shimmer datastream will be stopped.
2. At the same time the “Record” button on the Arduino will be pressed until the red LED turns of.
3. The Arduino-system will be turned off and all the sensors and the Arduino will be removed from the subject.

3.5.3 Participants and statistical considerations

The included three participants are selected based on their experience with the kata Pinan Nidan. This includes a master (+30 years of karate experience), intermediate (3-5 years of karate experience) and novice (less than 1 year of karate experience) The number of participants is chosen as the study doesn’t aim to find a statistical significant difference between the subjects, but rather aim to examine if there’s a way to determine the stability of the subjects during the Pinan Nidan.

The time for the experiment will be 45-60 minutes.

4 | Results

This is the results section

Here results will be presented, with numbers and maybe some graphs or plots of the numbers.

results for COP

results for movements scores

maybe some statistics results

5 | Discussion

number of test subjects are few. Not too much of a problem since we only aim to prove that a system such as this would be able to work.

FSR#3 broke. This does of course make flaws in our data acquisition, since the FSRs were all old and used prior to our study. This is a problem according to Hall et al. [**Hall2008**]. But we do not use the FSRs for very long and, as state in the test section, FSR data is not used to compare between FSR outputs, but only used for calculating COP for subjects. Additionally, the "error" in FSR#3 is consistent for all data acquired and should therefore not have an effect in our study. This does however mean that our study cannot be used to compare to other studies.

use gyroscopes to determine rotation speed of movements and rotations

inclusion of accelerometers to measure movement acceleration and velocities not in rotational axes.

discussion on result results

further/future discussion points and/or what should be studied next:

a more in-depth report should be done on the effects of martial arts training in rehabilitation. This could be tested with our system, a similar or more developed one. Additionally, comparison should be made between rehabilitation evaluations done with a system like ours and the older currently used methods for assessing progress in rehab. a study like that would be a step to determining if rehab training should be changed and as well if assessing methods for rehab training should be changed.

combine this easily wearable system with kinetic/kinematics movement analysis (marker analysis of human movement) to have a better way of evaluating this type of system than qualitatively looking at measurements and compare with regular video footage.

6 | Conclusion

short presentation of the aim of the project, followed by the findings. Stroke and SCI patients are not too good after rehab. Karate might make them better. Our findings say that karate might be able to improve on stroke or SCI patients, as our results show that balance, accuracy and speed of movement is improved with experience in karate.

nothing can be concluded from this study as it has included too few subjects to really prove anything. It can however pave the way for the development of newer method to use in rehabilitation of

Bibliography

[1] WHO. *WHO: Cardivascular Disease*. 2017.

[2] WHO. *WHO: Mortality burden*. 2018.

[3] Judith MacKay and George A. Mensah. "Types of cardiovascular disease". In: *The Atlas of Heart Disease and Stroke* (2004), pp. 18–19.

[4] Dagmara Hering and Maciej Piskunowicz. "Hypertension and Brain Damage 7: Ischaemic Stroke Subtypes". In: (2016), pp. 75–89.

[5] Internet Stroke Center. *What is a Stroke*. 2018.

[6] Dagmara Hering and Maciej Piskunowicz. "Hypertension and Brain Damage 8: Haemorrhagic Stroke". In: (2016), pp. 91–97.

[7] Ajay Bhalla et al. *Management of Post-Stroke Complications*. Ed. by Ajay Bhalla and Jonathan Birns. Vol. 5. 2. Springer, 2016, p. 379.

[8] Norbert Weidner, Rüdiger Rupp, and Keith E. Tansey. *Neurological aspects of spinal cord injury*. 2017, pp. 1–770.

[9] NSCISC. *SCI Model Systems: 2017 Annual Statistical Report*. Tech. rep. Birmingham, Alabama: NSCISC, 2017, p. 120.

[10] Giorgio Sandrini et al. *Advanced Technologies for the Rehabilitation of Gait and Balance Disorders*. Vol. 19. 2018.

[11] Kathleen M. Michael, Jerilyn K. Allen, and Richard F. MacKo. "Reduced ambulatory activity after stroke: The role of balance, gait, and cardiovascular fitness". In: *Archives of Physical Medicine and Rehabilitation* 86.8 (2005), pp. 1552–1556.

[12] Bermejo-Bosch et al. Belda-Lois J, Mena-Del Horno S. "Rehabilitation of gait after stroke: a review towards a top-down approach". In: 66.December (2011).

[13] E. Costamagna et al. "A generalisable methodology for stability assessment of walking aid users". In: *Medical Engineering and Physics* 47 (2017), pp. 167–175.

[14] Angelo Basteris et al. "Training modalities in robot-mediated upper limb rehabilitation in stroke: A framework for classification based on a systematic review". In: *Journal of NeuroEngineering and Rehabilitation* 11.1 (2014), pp. 1–15.

[15] Qi Wang et al. "Interactive wearable systems for upper body rehabilitation: A systematic review". In: *Journal of NeuroEngineering and Rehabilitation* 14.1 (2017), pp. 1–21.

[16] Alvaro Muro-de-la Herran, Begoña García-Zapirain, and Amaia Méndez-Zorrilla. "Gait analysis methods: An overview of wearable and non-wearable systems, highlighting clinical applications". In: *Sensors (Switzerland)* 14.2 (2014), pp. 3362–3394.

[17] Silvia Del Din et al. "Measuring gait with an accelerometer-based wearable: Influence of device location, testing protocol and age". In: *Physiological Measurement* 37.10 (2016), pp. 1785–1797.

[18] H. Carl Hanger, Kate L. Wills, and Tim Wilkinson. “Classification of falls in stroke rehabilitation - Not all falls are the same”. In: *Clinical Rehabilitation* 28.2 (2014), pp. 183–195.

[19] Jirabhorn Wannapakhe et al. “Medical complications and falls in patients with spinal cord injury during the immediate phase after completing a rehabilitation program”. In: *The Journal of Spinal Cord Medicine* 38.1 (2015), pp. 84–90.

[20] Jennifer S. Wong et al. “The Impact of Falls on Motor and Cognitive Recovery after Discharge from In-Patient Stroke Rehabilitation”. In: *Journal of Stroke and Cerebrovascular Diseases* 25.7 (2016), pp. 1613–1621.

[21] Jannette M. Blennerhassett et al. “Changes in balance and walking from stroke rehabilitation to the community: A follow-up observational study”. In: *Archives of Physical Medicine and Rehabilitation* 93.10 (2012), pp. 1782–1787.

[22] ANPT. *Spinal Cord Injury EDGE Recommendations*. 2018.

[23] ANPT. *StrokEDGE II Documents Recommendations*. 2018.

[24] Meng Ding. “Tai Chi for Stroke Rehabilitation”. In: *American Journal of Physical Medicine & Rehabilitation* 91.12 (2012), pp. 1091–1096.

[25] Stanley John Winser et al. “Does Tai Chi improve balance and reduce falls incidence in neurological disorders? A systematic review and meta-analysis”. In: *Clinical Rehabilitation* (2018).

[26] Ying He et al. “Dual-task training effects on motor and cognitive functional abilities in individuals with stroke: a systematic review”. In: *Clinical Rehabilitation* 32.7 (2018), pp. 865–877.

[27] Noemi Moreno-Segura et al. “The effects of the Pilates training method on balance and falls of older adults: a systematic review and meta-analysis of randomized controlled trials”. In: *Journal of Aging and Physical Activity* c (2017), pp. 1–21.

[28] Pat McCarthy. *Classical Kata of Okinawan Karate*. Ed. by Mike Lee. 3rd ed. Ohara Publications, Inc., 1987, p. 255.

[29] Seiken Ryu. “Kata - Pinan Nidan Summary”. In: ().

[30] The Digi Dojo. *Pinan Nidan*.

[31] Shimmer Sensing. *Shimmer3 Wireless Sensor Platform*. 2016.

[32] Interlink Electronics. *Datasheet: FSR 400 Series*. 2017.

[33] G. J. Verkerke et al. “Determining the centre of pressure during walking and running using an instrumented treadmill”. In: *Journal of Biomechanics* 38.9 (2005), pp. 1881–1885.

[34] Seonjeong Byun et al. “Test-retest reliability and concurrent validity of a single tri-axial accelerometer-based gait analysis in older adults with normal cognition”. In: *PLoS ONE* 11.7 (2016), pp. 1–13.

[35] Kashif I.K. Sherwani, Munna Khan, and Neelesh Kumar. “Assessment of postural stability using centre of Pressure and knee progression during dynamic gait”. In: *12th IEEE International Conference Electronics, Energy, Environment, Communication, Computer, Control: (E3-C3), INDICON 2015* (2016), pp. 1–5.