

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

3rd semester Masters, Biomedical Engineering & Informatics - Autumn 2018

Project group: 18gr9406

Simon Bruun and Oliver Thomsen Damsgaard

Contents

1	Problem Analysis	1
1.1	Cardiovascular Diseases and Spinal Cord Injury	1
1.2	Spinal Cord Injury	2
1.3	Rehabilitation	2
1.4	Assessing gait in rehabilitation	4

1 | Problem Analysis

1.1 Cardiovascular Diseases and Spinal Cord Injury

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. 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]

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] 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 an ambulatory assistive device to increase their independence when it comes to getting around in their every day life. [10, 11] This need is caused by the previously mentioned effects both SCI and stroke can have on a patients ability to control their limbs and thereby also their balance.

1.3.1 Stroke

Gait and balance rehabilitation of stroke patients also focuses on implementing both 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 Spinal Cord Injury

The aim of rehabilitating patients suffering from both stroke and 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]

1.3.3 Balance and Gait Training

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. [13]

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. [13]

Despite the outcomes reported in [13], 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.

[13]

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 [14, 15]. 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. [14] 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 [14]. 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 [15]. 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 [16].

1.4 Assessing gait in rehabilitation

Several different methods for assessing patients gait abilities have been developed to evaluate on the rehabilitation progress. Many of these outcome measures are also used in studies on the development of new technologies and methods. According to the Italian Robotic Neurorehabilitation Research Group (IRNRG) there are six outcome measures which are used more commonly in research studies. These six are: Functional Ambulation Category (FAC), the 10-m Walking Test, the Motricity Index, the 6-Minute Walking Test, the Rivermead Mobility Index and the Berg Balance Scale (BBS). [10]

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. [17]

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 [18]. 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 newer studies. Here, studies have used wearable systems to measure upper limb kinematics and trunk posture, to evaluate on movement performance. [19] 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 and pressure forces and EMG depending on what system is implemented. Here, measuring forces applied to the feet can be done with simple force sensors based on either resistive, piezoelectric or capacitive designs, and often includes an implementation of these in shoes or insoles. [20] A study by Muro et al. [20] 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. [20]

A study by Hurwitz et al. [21], 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.

Bibliography

- [1] WHO. *WHO: Cardiovascular 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] 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.
- [14] Meng Ding. “Tai Chi for Stroke Rehabilitation”. In: *American Journal of Physical Medicine & Rehabilitation* 91.12 (2012), pp. 1091–1096.
- [15] 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).
- [16] 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.
- [17] E. Costamagna et al. “A generalisable methodology for stability assessment of walking aid users”. In: *Medical Engineering and Physics* 47 (2017), pp. 167–175.

Bibliography

- [18] 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.
- [19] 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.
- [20] 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.
- [21] 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.