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# Literature Review

## Stroke Mechanisms and Effects

Stroke, also known as Cerebrovascular Accident, is the leading cause of disability in the UK according to the Stroke Association (2018). Stroke is classified by 2 mechanisms: Haemorrhagic Stroke and Ischaemic Stroke. Haemorrhagic Stroke occurs when an artery in the brain ruptures, often as a result of high blood pressure. Ischaemic Stroke occurs due to the blockage of an artery in the brain, usually caused by a blood clot or fatty deposits. Both mechanisms lead to cell damage or cell death in the affected region of the brain because of a lack of oxygen (Moskowitz et al, 2010).

The symptoms of Stroke are wide ranging and dependant on which region of the brain has been affected and the severity of the Stroke. Different regions of the brain control different behaviour, as shown by figure 1.1.1:

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| Figure 1.1.1: Different regions of the brain associated with control of different behaviour (Stroke Association, 2018) |

Common symptoms include motor impairment along one side of the body (known as hemiplegia), impairment to speech, difficulties swallowing and impairment to memory. It was found in a study by Sommerfeld et al (2004) that up to 80% of Stroke patients initially experience motor difficulties. Lawrence et al (2001) performed a community-based study on first-time Stroke patients in which 77.4% of the Stroke patients suffered from upper limb impairment.

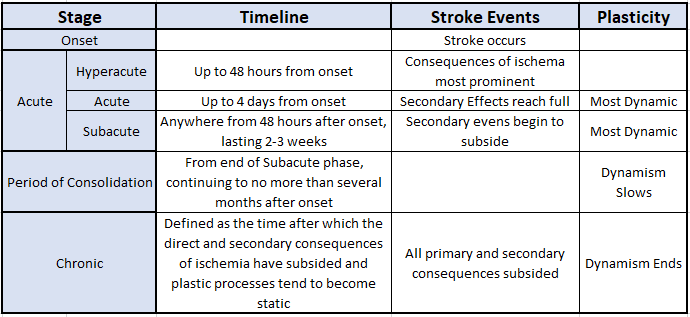
Stroke has a significant negative impact on a patient’s quality of life. Regular activities such as walking, eating, and manipulating objects become difficult or impossible. This often leads to dependency on care and assistance from others. Aside from the personal impact on the patient, Stroke has financial implications for society. Xu et al (2018) estimated the mean cost of health and social care per Stroke patient to be £46039. This figure is in close agreement with the Stroke Association (2017), who estimated that in 2015 the mean cost of health and social care per Stroke patient was £45409.

## Stroke Recovery

### Neural Recovery

Since Stroke is a neurological issue, it follows that Stroke recovery must exploit neurological mechanisms. Cerebral plasticity (otherwise known as neurofunctional plasticity) is the ability of the brain to “reorganise during ontogeny, learning or following damage” (Duffau, 2006). It is this ability of the brain to reorganise that provides the mechanism for Stroke recovery, though this is not yet fully understood according to Kreisel et al (2007).

Without the intervention of rehabilitation, there does remain some natural motor recovery after Stroke. The timeline for natural motor recovery after Stroke is summarised in the following table:



It can be seen from the above table that the neurofunctional plasticity of the brain is most dynamic after the Hyperacute phase, but then the dynamism slows. Once the patient has reached the Chronic stage, the plastic processes become static and motor deficits remain unchanged after this point Kreisel et al (2007) .

### Physiotherapy

The use of physiotherapy is an accepted element for the rehabilitation of Stroke patients. Physiotherapy is traditionally applied by trained physiotherapists, though there has been a rise in the use of robots for post-Stroke physiotherapy in recent years. There is little agreement on the effectiveness of different rehabilitation strategies. 2 main rehabilitation strategies are in widespread use according to Morreale et al (2016) and Coleman et al (2017). Proprioceptive Neuromuscular Facilitation (PNF) involves stretching and contracting a targeted muscle group, as shown by figure 1.2.2.1:

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|  |
| Figure 1.2.2.1: Proprioceptive Neuromuscular Facilitation (PNF) (Marek et al, 2005) |

Cognitive Therapeutic Exercise (CTE) involves high level cognitive training through task-based activity (Lee et al, 2015). Robotic rehabilitation devices mainly use the CTE strategy due to the ease of integrating tasks using computer game or virtual reality technologies.

Van Peppen et al (2004) performed a systematic review which showed that physical rehabilitation is more effective when performed intensively and early after Stroke. This is corroborated by Morreale et al (2016), who observed that early intervention was a factor on the effectiveness of rehabilitation. Indeed, these findings make sense when considering the neurofunctional plasticity of the brain is most dynamic earl after onset, as shown in table above. Morreale et al (2016) also stated, however, that “the optimal schedule and content of rehabilitation in the acute phase of care is still undefined”. It is generally agreed that early intervention of physical rehabilitation is important for recovery, but there is little evidence to support the existence of an optimal rehabilitation strategy. Kreisel et al (2007) agree, stating that “mechanisms that support or modulate recovery are not yet fully understood”.

## Stroke Prevalence

PREVIOUS STATS

Stroke can occur in people of any age, but it is shown by the Stroke Association (2018) that the likelihood of an individual having a Stroke increases with age. According to the Office of National Statistics (2018) the population of the UK is aging, with 26.5% of the population projected to be aged 65 or older by 2041, as shown by figure 1.3.1:

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| Figure 1.3.1: Aging population in the UK (Office of National Statistics, 2018) |

This ‘greying’ of the population is common across most Western Societies due to falling birth-rates and an increased life expectancy.

Observing the projected trend, it is reasonable to expect that the total number of Strokes will increase. This will, of course, increase the demand and financial costs upon the NHS and rehabilitation services. The anticipated increase in demand upon rehabilitation services compounds with the research showing that early and intensive physical rehabilitation is an important factor in recovery. It is reasonable to state that the demand will far exceed the supply.

## Robotic Rehabilitation of Stroke Patients

In recent years there has been an increase in interest and research into the use of robots for rehabilitation of Stroke patients. This is mainly because of the increased demand upon medical and rehabilitation services due the greying of the population identified in section 1.3. According to Maciejasz et el (2014) and Culmer (2007), rehabilitation robots are categorised by their mechanical structure as either an end-effector based device or an exo-skeleton based device.

DESIGN PARAMETERS

### 1.4.1 High Level Control Strategies

### 1.4.2 Accounting for Interaction Forces

The case of a robotic physiotherapy device interacting with a human patient should be considered as a coupled mechanical system (Maciejasz et el, 2014). This means that the use of a force control strategy or a position control strategy alone is insufficient, since interaction forces with the patient are not accounted for and are thus inherently unsafe. Further to this, failure to account for interaction forces raises the possibility of controller instability. Hogan and Buerger (2004) demonstrated this instability by showing that the Rough-Hurwitz stability criterion were met when considering an example system in isolation but were not met when considering the same system in a coupled mechanism.

In order to account for interaction forces, the majority of rehabilitation robotic devices use Impedance Control or Admittance Control as the low-level control strategy. Impedance Control and Admittance Control involve modulating the dynamic behaviour of the robot alongside position or force control, according to Hogan (1984), by specifying the robot’s position and force relationship using virtual mass, spring and damping characteristics which are heuristically determined (Richardson, 2001). Richardson (2001) explains this using figure 1.4.2.1:

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| Figure 1.4.2.1: The external force changing the desired position (Richardson, 2001) |

Essentially, the desired position changes due to the application of an external force in a predictable manner defined by the mass, spring and damping characteristics.

A physical system which accepts force inputs and produces position outputs is defined as an admittance. A physical system which accepts position inputs and produces force outputs is defined as an impedance (Ott et al, 2010) (Hogan,1984). The end effector of a mechanically coupled robot is subject to physical constraints, so it acts as either an admittance or an impedance. If the environment acts as an admittance, the end effector must act as an impedance according to Hogan (1984). Conversely, if the environment acts as an impedance, the end effector must act as an admittance.

### 1.4.3 Admittance Control

Admittance control is a strategy whereby the force exerted on the end effector is measured, and the robot provides the corresponding displacement (Maciejasz et el, 2014). This means that the controller is acting as an admittance and the environment is acting as an impedance. As such, an Admittance control strategy is based around an inner loop position controller, as shown by the block diagram in figure 1.4.3.1:

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| Figure 1.4.3.1: A block diagram for a generic Admittance Controller (Richardson, 2001) |

According to Culmer et al (2010), the control signal can be simply defined as shown by equation number:

|  |  |
| --- | --- |
|  | Eqn number |

Where:

### 1.4.4 Impedance Control

Impedance control is a strategy whereby the motion of the end effector is measured, and the robot provides the corresponding force-feedback (Maciejasz et el, 2014). This means that the controller is acting as an impedance and the environment is acting as an admittance. An Impedance control strategy is based around an inner loop force controller, as shown by the block diagram in figure 1.4.4.1:

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|  |
| Figure 1.4.4.1: A block diagram for a generic Impedance Controller (Richardson, 2001) |

According to Culmer et al (2010), the control signal can be simply defined as shown by equation number:

|  |  |
| --- | --- |
|  | Eqn number |

Where:

### 1.4.5 Selecting Impedance Control or Admittance Control

It is agreed by A LOT OF PEOPLE [13] that the advantages and disadvantages of Impedance and Admittance control systems are opposite, which makes sense considering that the definition of a mechanical Impedance is opposite to the definition of a mechanical Admittance.

When to select which controller?

## MIT-MANUS

## MEMOS (Lit Review 49)

## MIME

## ARM-Guide

## EEULRebot System (lit review 52)

## iPAM

## Myoelectrically Controlled Robotic System (Lit Review 47)

## RUPERT

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