The physiological and biomechanical effects of a short term, 8-week, eBike cycling intervention in stroke survivors

Adrienne Day (BSc)
20625197/CE

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University of Central Lancashire
School of Sport and Health Sciences

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STATEMENT OF ORIGINALITY

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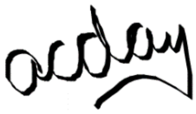
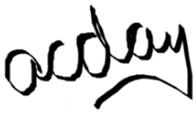
Signature: 

Apart from contributions by my supervisor, the work and its reported analysis in this thesis titled 'The physiological and biomechanical effects of a short term, 8 week, eBike cycling intervention in stroke survivors', represents original work and where others work has been acknowledged they have been cited.

Signature: 

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Adrienne Day (20625197/CE)

ABSTRACT

Background: Stroke is a global health concern that results in cognitive and motor impairments, leaving survivors with chronic disability and resultant cardiovascular deconditioning. Emergent evidence has supported the use of cardiovascular training, such as cycling, as an effective rehabilitation method. However, despite such studies survivors often find cycling difficult resulting in disengagement from cycling based rehab. The introduction of electric bikes (eBikes) has the potential to aid individuals in overcoming these barriers, by providing electrical assistance, and to the best of our knowledge the potential physiological and biomechanical improvements of an eBike intervention have not been assessed. Therefore, the aim of this study was to evaluate the use of eBikes within a stroke rehabilitation program and provide the initial evidence to encourage further investigation.

Methods: A mixed method intervention case study was utilised to assess physiological and biomechanical changes. Five participants who had suffered a stroke more than 3 months prior to the study with unilateral paresis, were recruited and successfully gained doctor's permission to take part. Assessments of ambulatory function, power balance and muscle activity were conducted either side of an 8 week eBike intervention in which participants maintained cycle diaries.

Results: Participants one, two and four completed the intervention period and attended post-intervention assessments. Participants three and five withdrew after falling from their eBike early on in the study. Clinically meaningful improvements (1SEM) in ambulatory function were observed in participants one (1.313 ± 0.120 ms^{-1}) and four (1.380 ± 0.043 ms^{-1}) along with reductions in blood pressure. Improvements between limb power balance was observed in participants two and four, whilst lower limb sEMG activity (%MVIC) became more efficient as muscle co-ordination altered. Significant differences ($P<0.05$) were additionally observed in muscle oxygenation during pre-intervention for participant one ($t(46) = 30.985$, $p>0.05$), four ($t(60) = 24.680$, $p<0.05$) and five ($t(60) = -62.024$, $p<0.05$) indicating higher tissue oxygenation in the paretic limb.

Conclusion: The initial findings of this research suggest that an eBike intervention can induce improvements in individuals who have suffered a stroke. The intervention encouraged the participants to become more physically active and demonstrated that eBike application can be successful in supporting and overcoming some stroke comorbidities. The results of this study give preliminary evidence in support of eBikes to increase activity after stroke and warrants further research.

Contents

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'I am grateful for all the moments that I have, and I'm moving forward one step at a time to the future'

It gives me immense pleasure to submit my final thesis and thank all those involved in its creation.

I would firstly like to extend my thanks and respect to all those who have provided me with guidance over the duration of my research masters. I am grateful to my director of studies Dr Howard Hurst and supervisory team Prof. Jim Richards and Dr. Louise Connell; whose expertise, guidance and support has made it possible for me to work on such an inspiring topic. I would like to express my deep gratitude to Dr Howard Hurst for finding time to talk through the study, respond to emails and for providing me with structured advice and direction throughout the year.

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GLOSSARY OF TERMS

Term	Definition
Aerobic exercise	Exercise of low to moderate intensity in the presence of oxygen for aerobic metabolism. Exercise designs to promote circulation by working the heart and lungs.
Cerebrovascular disease	Identifies conditions that affect blood vessels of the brain and cerebral circulation
Cycle dynamics	Measurements that provide an insight into performance and riding
Ergometry	Measurement of work done by the body; aimed to specify work of specific muscles or groups of muscles
eBike	Electrically assisted bicycle
Haemorrhagic stroke	Stroke caused by the rupture of a blood vessel
Heterogenous disease	A condition that has several aetiologies
Hemiparetic	Weakness or paralysis of one side of the body
hypertonicity	Abnormally high muscle tension
Ischemic stroke	Stroke caused by the blocking of a blood vessel
Moderate unilateral paresis	Weakness of one side of the body resultant of a stroke
Non paretic	Limb that is unaffected by the stroke
Paretic	Limb that is affected by the stroke
Rehabilitation	Help to relearn skills lost through stroke and regain independence whilst improving quality of life.
Self-directed	Support provided to encourage individuals to manage their own rehabilitation
Stroke	"A clinical syndrome typified by rapidly developing signs of focal or global disturbance of cerebral functions, lasting more than 24 hours or leading to death, with no apparent causes other than of vascular origin" caused by the "interruption of the blood supply to the brain" (Hatano, 1976)
Transient ischemic attack	Temporary loss of function which mimics an ischemic stroke but resolves after 24 hours

ABBREVIATIONS

Abbreviation	Definition
1SEM	1 standard error of the mean
BF	Bicep femoris
CLARHC	Collaborations for Leadership in Applied Health Research and Care
eBike	Electrically assisted bicycle
eTrike	Electrically assisted tricycle
GP	General practitioner
GC	Gastrocnemius (medial)
HRmax	Maximum heart rate
MMT	Manual muscle test
MVIC	Maximal voluntary contraction
NICE	National institute for health and care excellence
PA	Physical activity
RF	Rectus femoris
RPE	Rating of perceived exertion
SES	Socio-economic status
sEMG	Surface electromyography
SmO_2	Muscle oxygen saturation
TA	Tibialis anterior
TIA	Transient ischemic attack
WHO	World Health Organisation
W_{mean}	Mean power (watts)
W_{max}	Maximum power (watts)

CHAPTER 1 INTRODUCTION

1.1 BACKGROUND AND RATIONALE

Stroke is a heterogeneous condition affecting more than 100,000 people in the UK every year (Stroke Association, 2018). Its impact can be extensive and leaves individuals with lifelong acquired disability. The prolonged consequences of stroke means that only 20% of survivors are able to engage in exercise, resulting in further psychological and physiological decline (Joseph et al., 2017). Developments in stroke preventative research and a greater understanding of brain recovery has brought about a shift in stroke mortality resulting in a higher proportion of stroke sufferers surviving each year (Feigin et al., 2014).

Stroke rehabilitation is unique to each individual and common rehabilitation aims state the need for therapies to assist with regaining activity, preventing stroke and improving fitness. Evidence from controlled trials (Lin et al., 2012) and Cochrane reviews (Saunders et al., 2016) recognises the benefits of physical activity within stroke rehabilitation programs and although optimal time to aid recovery is unclear, a range of methods have been explored to safely integrate physical activity into rehabilitation programs. Methods such as; circuit classes (English & Hillier, 2010), repetitive task training (Thomas et al., 2017), and progressive resistance strength training (Lee et al., 2010).

Application of physical activity delivers positive results demonstrating that exercise can improve and reduce musculoskeletal impairments. Cycling has been identified as an appropriate method of physical activity that supports rehabilitation; as it encourages reversal of muscle weakness in hemiparetic stroke survivors (Kautz & Brown, 1998) and supports with limb asymmetries (Chapman et al., 2008). Furthermore cycling has been identified as a safe activity for rehabilitation as individuals are seated and do not experience as many of the postural disturbances they otherwise would walking (Brown et al., 2005). However, whilst cycling has been proven beneficial in aiding recovery its application can be limited, as Rahman et al. (2012) acknowledged. Stroke survivors can find cycle ergometers uncomfortable and difficult to use because of their cardiovascular deconditioning and therefore, the introduction of electric bikes (eBikes) into stroke care may assist in overcoming these some of the barriers to participation, by providing electrical assistance.

eBikes are bicycles integrated with a battery and motor that are designed to provide electrical support. They have been successfully used in active travel models to overcome barriers to exercise and remove aerobic fitness limitations (Langford et al., 2013) offering a suitable alternative to cycling. eBike research is still in its infancy and has been reviewed against some conditions like coronary heart disease (Hansen et al., 2018) and although limited studies have assessed physiological changes after an eBike intervention, those that have assessed their use do provided promising results (Höchsmann et al., 2018).

This thesis, therefore, aims to explore if any physiological or biomechanical changes are achievable as a result of an eBike intervention in stroke survivors. The pilot intervention case series will identify the possible application of eBikes and provide evidence to support further investigation.

CHAPTER 2 LITERATURE REVIEW

This review of literature, conducted in December 2019, provides an introduction into stroke and its impact on both the community and individuals life. The review will provide background information surrounding current stroke rehabilitation research and summarise the application of physical activity into post-stroke care. Finally, this review will provide context for cycling in stroke rehabilitation and introduce eBike technology.

2.1 DEFINITION OF STROKE

Stroke is a serious life-threatening condition that occurs when blood flow to the brain is reduced. The World Health Organisation (WHO) defines stroke as “a clinical syndrome” characterised by “rapidly developing signs” which affect cerebral function. It lasts more than 24 hours and can lead to death. With no apparent causes, other than of vascular origin, it occurs when blood supply to the brain is interrupted (Hatano, 1976). As a heterogeneous disease, stroke falls under the umbrella term of ‘Cerebrovascular disease’ and is subdivided into three different types, 1) transient ischaemic attack, 2) ischaemic or 3) haemorrhagic (See Figure 2.1). It has more than 150 known causes and leaves 80% of survivors with motor impairments that affect movement along with other speech, balance and emotional impairments (Amarenco et al., 2009).

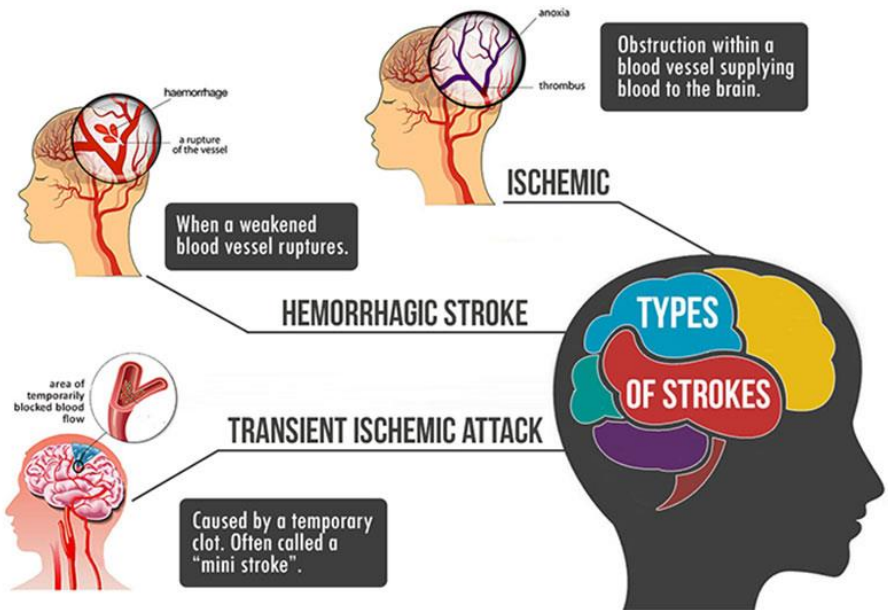


Figure 2.1: Info graphic detailing the types of stroke that individuals can experience, with a brief summary of how they are caused.

Taken from: https://www.kauveryhospital.com/blog/wp-content/uploads/2017/11/1.jpg (accessed 02.07.2019)

2.2 CLASSIFICATION AND PATHOPHYSIOLOGY OF STROKE

As detailed previously stroke is classified as a 'cerebrovascular disease' along with aneurysms and vascular dementia. The expansive term is used to define any disease of the brain that affects blood supply temporarily or permanently and encompasses a range of disorders that are assessed and characterised by their pathological processes. These characteristics are based on factors including severity, underlying cause, functional outcome and duration (Brown et al., 2006).

A transient ischaemic attack (TIA) usually described as a 'mini stroke' imitates an ischemic stroke, resulting in temporary dysfunction that affects about 46,000 people in the UK every year (Turner et al., 2016). TIA's occur when blood flow to the brain is disrupted and they emulate comparable symptoms to stroke. Unlike an ischaemic or haemorrhagic stroke (discussed below), a TIA lasts no longer than an hour and symptoms are resolved after 24 hours, leaving no permanent damage (National Collaborating Centre for Chronic Conditions, 2008). They are considered 'warnings' for stroke, as they have the same underlying mechanisms and researchers acknowledge that individuals who experience TIA's are at a heightened risk of secondary strokes (Khare, 2016).

Unlike TIA's cerebrovascular disturbances lasting longer than 24 hours are classified as stroke; ischaemic or haemorrhagic. Ischaemic strokes are accountable for 85% of strokes in the UK and transpire after a sudden reduction in cerebral blood flow, caused by blockage/clot in a major brain artery (Dirnagl et al., 1999). Within minutes of an ischaemic attack the reduction in blood flow is enough to alter cellular function and initiate a sequence of events that culminates in cell death. Brain tissues that is exposed to this massive reduction in blood flow undergoes necrotic cell damage whilst the surrounding tissue remains metabolically active but functionally dormant until treated (Woodruff et al., 2011). Clot busting medication can be administered to ischaemic stroke sufferers to dissolve and restore blood flow but unfortunately less than half of patients with major ischaemic stroke arrive within the optimal 4.5 hour window and are therefore not eligible for thrombolysis treatment (Musuka et al., 2015).

Unlike an ischaemic stroke, a haemorrhagic stroke is as a result of rapid blood accumulation within the brain and carries a lower chance of occurring (15%) but a higher risk of mortality (Andersen et al., 2010). There are two types of haemorrhagic stroke; 1) An intracerebral haemorrhage which occurs when a blood vessel inside the brain bursts, releasing blood into the surrounding tissue and 2) a subarachnoid haemorrhage which transpires from bleeding between the brain and surrounding tissue layer into the subarachnoid space (Qureshi et al., 2009). In both cases increased volumes of blood within the brain catastrophically disrupts normal bodily function and increases local pressure, resulting in life changing damage within minutes (Aronoski & Zhao, 2011). These spontaneous strokes can occasionally be treated in hospital but with such an increased risk of mortality most fatalities occur within two days of symptom onset.

2.3 INCIDENCE AND OCCURANCE OF STROKE

More than 100,000 individuals in the UK suffer a stroke, ischaemic or haemorrhagic, annually and it is estimated by the global burden of diseases, that stroke is the third most common cause of acquired disability leaving individuals with life-long limitations that affect daily living (Lozano et al., 2012; Bray et al., 2016). Current estimates suggest that 1 in 6 people will suffer a stroke in their lifetime and whilst 32,000 people suffer stroke related deaths. A steady decline in mortality over the past 20 years (See Figure 2.2) suggests that more people are surviving.

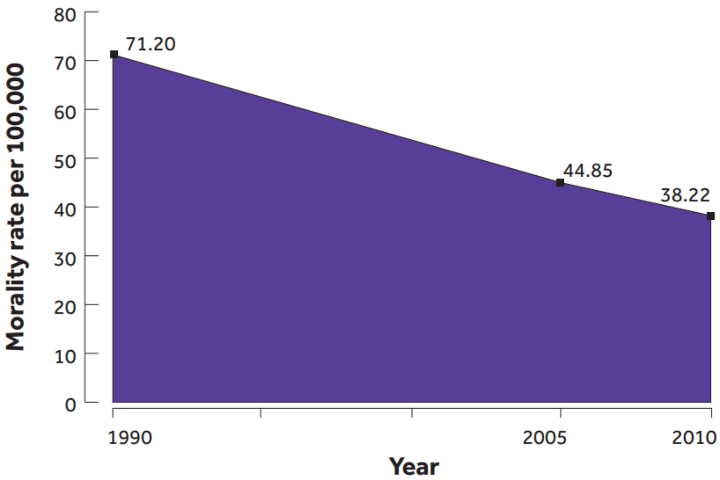


Figure 2.2: Graphical representation of reduction in mortality rate between 1990 and 2010. Taken from 'State of the Nation' produced by the Stroke Association (2018)

This well-documented reduction in mortality could either be an outcome of reduced disease occurrence or a decline in fatalities (Seminog et al., 2019) but nevertheless it recognises a shift towards better survivorship from stroke validated by the current 1.2 million stroke survivors population in the UK, that is projected to increase by 59% by 2035 (Feigin et al., 2014). Whilst improvements in treatment and early identification of stroke (Seminog et al., 2019) has improved initial survivorship, Mohan et al. (2011) identified that 25% of survivors are still at greater risk of experiencing another stroke within five years.

This combination of reduced mortality and increase in individuals' risk of secondary stroke demonstrates a need for new methods of rehabilitation that are accessible to everyone and prevent recurrence.

2.4 SOCIOECONOMIC IMPACT OF STROKE

Stroke has a global impact and although the elderly are placed at higher risk, it has elevated impact on individuals living in areas of lower socio-economic status (Addo et al., 2012). It is important to understand the effect of this socio-economic divide in stroke risk to assist with prevention and rehabilitation in order to provide everyone with equal opportunity to lead a healthy life. The extent to which socio-economic status (SES) influences mortality is complex, as its definition varies greatly. Income, education and area based deprivation are all used to some extent but a lack of standardisation for comparison can manifest inaccuracies as reflected by the work of Langagergaard et al. (2011). However studies that have explored the associations between SES and stroke clearly identify that individuals with lower SES suffer from higher incidence of stroke, with a worsened risk profile (van den Bos et al., 2002).

Engström et al. (2001) conducted research in Sweden to investigate whether stroke is related to socio-economic status. Through assessment of 18 areas that displayed substantial economic differences they provided evidence to suggest that age-adjusted risk factors like smoking, diabetes and being overweight were more prevalent in areas of low SES. This prevalence put individuals at significantly higher risk of stroke as they were less likely to meet physical activity guidelines and subsequently increased the likelihood of biological risk factors such as pre-stroke diabetes (Ashe et al., 2009; Howard & Thrift, 2018). Engström et al. (2001) findings supported a longitudinal study conducted by the World Health organisation (WHO), which confirmed that stroke occurrence is inversely proportional to SES. Further emphasising that strokes occurs in lower socio-economic areas at a significantly younger age (64 ±14.1 years) than those in the higher areas of living (72± 12.9) (Redon et al., 2011).

The effect SES has on stroke has been shown to effect more than just stroke occurrence. Weir et al. (2005) presented evidence linking socio-economic status to stroke severity, implying that a lower SES resulted in more severe strokes and subsequent disability (Kerr et al., 2011). It has also been reported that individuals from lower SES have less chance of receiving optimal care, unfair investigation and management distribution. This bias increases the risk of death between 30 days to 1 year after their first stroke (Langagergaard et al., 2011). This surmises that individuals from a lower socio-economic status are not only more at risk of their first incidence stroke but also a secondary, and increased risk of death.

Public Health England (2015) has recognised this increase in stroke occurrence in relation to SES and has identified that prominent health inequalities are most prevalent in the North of England. Cox et al. (2006) identified that England and Wales had the highest ratio of stroke difference in the 30-44 year age group where manual occupational class were identified to be 4.23 times more at risk of stroke compared to the non-manual class. Arrich et al. (2008) concluded this was not as a result of education and that the divide in risk and care ultimately increases the occurrence and placing pressure on specific hospitals and health services.

Combined with the knowledge that areas of lower SES are more at risk of secondary stroke and a reduction in readily available rehabilitation further evidences the need to develop methods of rehabilitation that minimise the likelihood of secondary stroke. This study will therefore investigate one form of rehabilitation that could be made accessible to all, regardless of SES and immediate care availability.

2.5 STROKE RISK FACTORS

Stroke can occur at any time and several risk factors, further to socioeconomic status, increase the risk of stroke. The Framingham stroke risk score (FSRS) was developed to predict stroke occurrence through scoring and combining stroke risk factors including; age, diabetes, cigarette smoking and prior cardiovascular disease. The specific algorithm predicts a 10 year probability of having a stroke and is repeatedly used in research to identify risk (Flueckiger et al., 2018). Each risk factor affects stroke differently and when combined may be responsible for stroke occurring at a younger age and in areas of lower SES (Hankey, 2006).

Age is acknowledged as the main risk factor in the Framingham stroke risk score and is identified by the stroke association as a non-modifiable risk. In the UK the elderly population are more at risk of stroke as a result of expected atherosclerosis and approximately 59% of strokes occur in this population (Feigin et al., 2014). The remaining 41% of strokes occurrence amongst the younger population (<65 years) but new work conducted by Feigin et al. (2014) reinforced the work of Andersen et al. (2010) to recognise that individuals are suffering strokes earlier in life. Feigin et al. (2014) projected that this sustain shift towards a younger population was a growing concern that would continue as cardiovascular risk factors and diabetes prevalence increased. Ultimately resulting in individuals suffering a stroke younger and living with the consequences.

Andersen et al. (2010) identified complex relationships between gender, age and first-time stroke. Through assessment of the effect of gender they acknowledged a five year difference (See Figure 2.3) between the age of first instance strokes for males (61.8 ± 12.8 years) and females (73.2 ± 14.5 years) concluding that the difference was an effect of lifestyle choices and consequential medical conditions. Men are more likely to experience pre-stroke diabetes, as men are more likely to experience diabetes, consume more alcohol (300%) and smoke more (3%) which places them more at risk at a younger age, whereas women are more likely to report age associated factors related to hypertension and atrial fibrillation (Andersen et al., 2010)

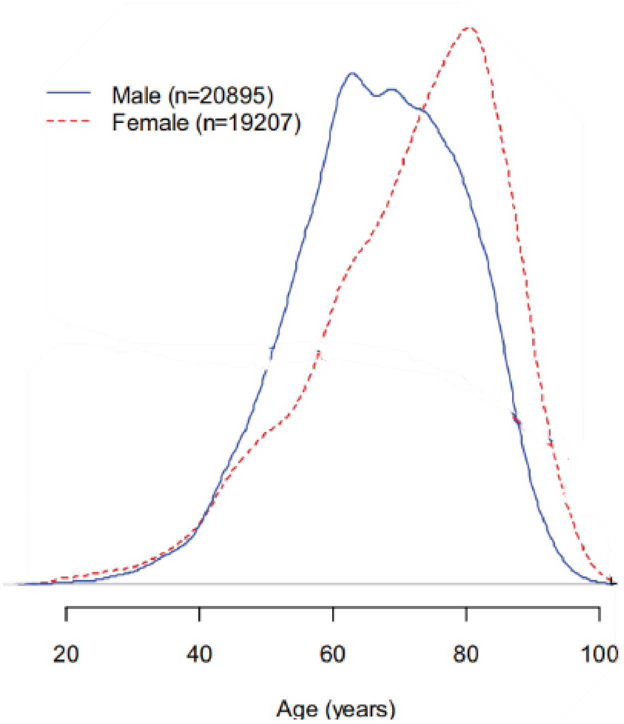


Figure 2.3: Age and gender comparison for first-ever ischemic stroke taken and edited from: Andersen et al. (2010)

Pre-Stroke functioning and disability also presents a gender dissimilarity. Women are more likely to be widowed or living in assisted housing before suffering their first stroke, resulting in a decrease in physical capability and worsened ramifications post-stroke. This supports the concept that stroke has a more severe impact on women, as they are less likely to survive their first stroke when it occurs at a later stage in life (Lai et al., 2005). Further to age related and pre-Stroke functioning factors; women can also experience a 160% increase in stroke risk as a result hormone changes during pregnancy and hormone altering contraceptive medication increasing the risk of venous thrombosis (Reeves et al., 2008; Roach et al., 2015).

Many medical conditions also effect an individual's pre-disposition to stroke mainly through medication or lack of condition control. High blood pressure, diabetes, atrial fibrillation and high cholesterol are all major risk factors of stroke which are more prevalent in areas of lower socio-economic status. Uncontrolled high blood pressure increases pressure around the vessels that can result in vessel perforation or the transport of blockages (Stroke Association, 2017) whilst Hjalmarsson et al. (2014) concluded that poor glycaemic control in diabetes and the resultant hyperglycaemia is a marker for increased stroke severity and poor survival. Additionally atrial fibrillation is a major risk factor for ischemic stroke, particularly in the elderly, and its prevalence is continuously rising and effecting approximately 10% of the elderly population (Stewart et al., 2004). Finally, although high cholesterol directly impacts blood pressure and atherosclerosis formation its association to stroke risk has divided the scientific community. Cheng et al. (2018) therefore conducted a meta-analysis reviewing seven cohort studies and concluded that although high cholesterol has no association with overall stroke risk, it does affect diet and BMI, which are known risk factors of stroke.

Several other lifestyle factors also increase the risk of stroke. These modifiable factors range from alcohol and drug use to stress. Each individual risk culminates into unique issues that attributes to stroke occurrence and a combination of various factors substantially increases stroke risk. Findings from a meta-analysis conducted by Larsson et al. (2016) concluded that light to moderate alcohol consumption reduces the risk of ischaemic stroke but heavy alcohol consumption increased the risk of all strokes, particularly haemorrhagic. Smoking and/or vaping is as concerning as alcohol consumption. In several case control studies the effect of smoking was identified as an independent risk factor for stroke and remained significant when other risk factors were adjusted for (Boden-Albala & Sacco, 2000). Its exposure is strongly associated with mechanisms for stroke that include carotid atherosclerosis, increasing cholesterol, increased platelet aggregability and again results in higher levels of haemorrhagic stroke (Shah & Cole, 2010).

Finally, Individuals who are at the highest risk of stroke are often not physically active, this impacts their weight, blood pressure and cholesterol level. Physical activity (PA) has been identified as a modifiable risk factor for stroke and is defined as bodily movement produced by muscles that results in energy expenditure (Caspersen et al., 1985). There is substantial evidence supporting the use of physical activity as a preventative measure for stroke identifying a reduction in premature death and cardiovascular disease (Boden-Albala & Sacco, 2000). Flueckiger et al. (2018) reported that moderate PA is sufficient in significantly reducing the risk of stroke and offers some protection. Physical activity is already considered to control blood pressure by reducing systolic pressure (Pedersen et al., 2009) and assist with diabetes management through glycaemic control (Thomas et al., 2006), both risk factors of stroke. Therefore, application of PA into stroke prevention and furthermore stroke rehabilitation appears to be a suitable method of reducing recurrence and this is discussed further on in the literature review.

2.6 IMMEDIATE SYMPTOMS OF STROKE

Stroke results in both motor and cognitive impairments determined by the location and severity of the stroke (Verstraeten et al., 2016). Signs and symptoms are unique and defined by arterial anatomy, not the type of stroke that is experienced. Rathore et al. (2002) evaluated 474 individuals to collect data displayed in Table 2.1 concluding that paresis, speech and sensory deficits were common amongst hospitalized stroke survivors and most likely amongst individuals who had suffered an ischemic stroke.

Table 2.1: Characteristics of stroke and their reported incidence (%) with mean range, amongst hospitalized stroke survivors

Characteristic	Overall incidence percentage (mean range)
Headache^	27.4 (23.4–31.4)
Gait disturbance^	10.8 (7.9–13.6)
Convulsions^	4.4 (2.6–6.3)
Speech deficit^^	24.0 (20.2–27.9)
Hemianopia (blindness over half the field of vision)^^	14.6 (11.4–17.7)
Diplopia (double vision)^^	5.5 (3.4–7.5)

(^symptom, ^^sign)

Rathore et al. (2002) pinpointed that although some of the signs and symptoms of stroke may be dramatic, more subtle signs, like loss of balance, dizziness and numbness are often missed and confused with other conditions. Although much smaller, these subtle signs are just as important and if they are left unnoticed a delay in medical care results in worsened long-term prognosis. This partially explains why the impact of stroke can be so extreme.

2.7 STROKE IMPACT

The long-term consequences of stroke can really impact an individual's quality of life, as two thirds of stroke survivors are left with chronic disability (Royal College of Physicians, 2016b) which can lead to cardiovascular deconditioning (Rahman et al., 2012). The long-term effects of stroke are classified by the World Health Organisation (WHO) in terms of pathology, impairment, activity limitations and participant restriction (See Figure 2.4: Brief summary of the international classification). As this study aims to investigate the biomechanical and physiological aspects of an eBike intervention strokes impact has been divided into physiological, psychological and biomechanical sections

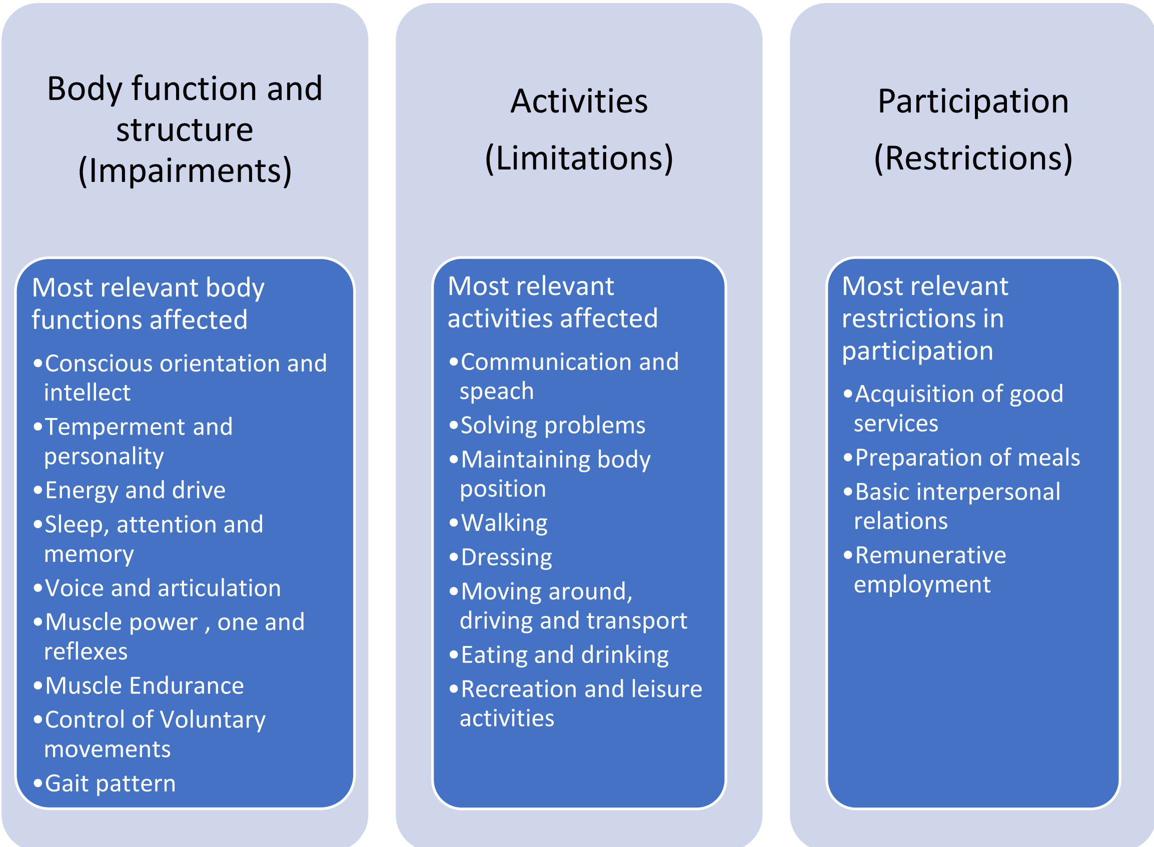


Figure 2.4: Brief summary of the impairments, limitations and restrictions after stroke that effect the health of an individual, taken from the 'International classification of function, disability and health framework' presented by the WHO.

2.7.1 PHYSIOLOGICAL IMPACT OF STROKE

As a result of functional decline after stroke, only 20% of survivors are able to engage in light to moderate intensity exercise (Joseph et al., 2017). The prolonged consequence of stroke can further affect an individual's physical capability and places them at an increased risk of cardiovascular disease. Specific application of aerobic exercise in rehabilitation could counteract this physical deconditioning and make some of the physiological morbidities associated with stroke more manageable. Brewer et al. (2012) reported that 90% of stroke survivors' quality of life is negatively affected by physiological changes that include fatigue, dysphagia, hemiparesis, tissue oxygenation and respiratory function. Changes that could be managed through suitable methods of rehabilitation.

Fatigue is a complex condition to outline in reference to stroke as it presents in both physiological and psychological conditions but is a common problem after stroke affecting up to 72% of survivors (Lerdal et al., 2009). de Groot et al. (2003) generated a definition of fatigue which provided a broad explanation to summarise the different aspects of fatigue, identifying fatigue as a feeling of physical tiredness with a lack of energy that is abnormal and/or problematic (Colle et al., 2006). A causal association between fatigue and cerebrovascular events is present (Winward et al., 2009) and fatigue is considered one of the greatest barriers to stroke recovery, decreasing quality of life and increasing the risk of death (Lerdal et al., 2009).

Stroke survivors report that they have poor stamina and fatigue more readily as an adjustment reaction to stroke and this can relate to poorer physical function (Barritt & Smithard, 2011) the chronic fatigue syndrome guidelines emphasises a need for individuals to be aware of their fatigue induced limitations and partake in graded exercise for aerobic training, pushing enough to promote recovery but not too much that fatigue is exaggerated.

In addition to fatigue other aspects of physiology are altered after stroke, most notable blood pressure and blood oxygen saturation. Elevation of post-stroke diastolic and systolic blood pressure occurs in about 75% of patients and as a consequence of the stroke; it is hypothesised that the change in blood pressure is an adaptive response to maintain cerebral flow due to disturbed autoregulation and/or damage to areas of the brain which regulate the autonomic nervous system (Wong & read, 2008; Fischer et al., 2014).

The identified increase in post-stroke blood pressure places individual at a higher risk of secondary stroke and can be controlled through medication in order to reduce re-occurrence. McManus & Liebeskind (2016) identified that measurement and management of blood pressure is one of the easiest way to predict and prevent stroke and whilst stroke is complex they concluded that elevations in blood pressure is associated with worsened outcomes despite debate surrounding whether it should be treated (Appleton et al., 2016).

Roffe et al. (2001) published the first article which aimed to investigate oxygenation differences between the paretic and non-paretic sides in hemiparetic stroke patients. Through utilising oximeters their early study identified no significant difference in blood oxygen saturation. However a more recent study conducted by MasoudiMotlagh et al. (2015) did identify a significant difference in levels of oxygenation between muscles in the paretic and non-paretic limbs; a difference that did not exist in the comparative healthy population. This observed difference indicates that the paretic muscles have a higher reliance on anaerobic metabolism, utilising glucose rather than oxygen for cellular respiration. MasoudiMotlagh et al. (2015) further suggested developments that could be made to focus on observed differences after physical therapy and application to lower limbs muscles.

Hypoxia is also reported post-stroke and very common amongst stroke survivors. Ferdinand & Roffe (2016) summarised that respiratory function could be a potential cause of this hypoxia directly associated with muscle weakness and significant reductions in respiratory values. Ventilation depends on a fully functioning neuromuscular system in order to maintain normal function. Breathing is typically activated voluntarily and automatically through the recruitment of the diaphragm and intercostal muscles however after stroke individuals develop inadequate respiratory function attributed to pulmonary muscle impairment. Teixeira-Salmela et al. (2005) identified that the lower abdomen muscle strength decreases after stroke producing significantly lower inspiratory and expiratory pressures when compared to control groups, as a result of an individual's functional decline. This impairment could also be as a result of damaged hemi-thorax and deterioration of respiratory muscles (Kim et al., 2014).

Respiratory function plays a key role in stroke recovery and is essential in reducing the effects of fatigue and long-term disability. When respiratory muscle function declines gaseous exchange is hampered, this manifests as a lower exercise tolerance and other commonly observed conditions like ankyloses; due to a lack of oxygen and increased metabolic demand (Polese et al., 2013; Kim et al., 2014). With application to this study reduction in respiratory muscle function and gaseous exchange limits an individual's ability to exercise and restricts suitable methods of rehabilitation. It is therefore important to identify suitable rehabilitative programs that support individual's pulmonary decline but also introduce low levels of aerobic exercise that can induce respiratory and functional improvements.

2.7.2 BIOMECHANICAL IMPACT OF STROKE

Those living with stroke can be left with physical deficiencies as a result of the initial brain lesion and additional disuse after the event metamorphose into mechanical deficits affecting movement and structure. Assessment of the biomechanical impact of stroke within this thesis will encompass function, motion and control of lower limbs.

Postural imbalances, paralysis and limb asymmetry are commonly observed in stroke survivors as a result of inappropriate muscle contraction, muscle spasticity, reduced range of movement and abnormal activation patterns (Brown & Kautz, 1998; Chen et al., 2005). These factors manifest into the muscle weakness, identified through EMG activation magnitude, and functional decline of not just the affected paretic limb, but also the non-paretic limb (Hsiao, 2001).

Postural control is defined as the ‘act of maintaining, achieving or restoring a state of balance’ (Pollock et al., 2000) and following a stroke postural imbalance affects eighty-three percent of survivors, diminishing ambulatory function (Hugues et al., 2017). One focus of rehabilitation is to reduce this imbalance and increase autonomy which can be challenging to address due to the heterogeneity of the individuals deficits as identified by Hugues et al. (2017). Some survivors struggle to recover postural control as they bear more weight on the non-paretic limb consequential of a postural sway and this asymmetry contributes to instability and musculoskeletal degeneration (Genthon et al., 2008). Due to a combination of these asymmetries and alterations in limb control survivors also report difficulty with balance.

Studies presented by Horstman et al. (2008) and Prado-Medeiros et al. (2012) share commonalities in reporting that movement and strength asymmetry deficits are present in stroke survivors. However, they present conflicting evidence surrounding the root cause of muscle weakness. In 2008, Horstman et al reported that muscle strength was significantly reduced in the stroke survivors affected side as an effect of muscle mass type 2 fibre atrophy. However, Prado-Medeiros et al. (2012) later provided evidence to suggest that there was no difference in muscle volume and the paretic limb did not show atrophy when compared to controls, possibly due to the presence of intramuscular fat: indicating a disturbance in central activation over muscle atrophy. Their contrasting evidence indicates some confusion surrounding the root cause of such weakness but does agree that a more significant reduction in muscle strength is apparent on the paretic side of stroke survivors.

In 2009, Seki et al. quantified muscle activity differences whilst assessing the suitability of an adapted cycle wheelchair (c-w/c) for severe hemiplegia sufferers. The comparative study collected surface electromyography (sEMG) data from various lower limb muscles to ascertain muscle activation differences between the healthy and paretic limbs (See Table 2.2).

Table 2.2: Identified differences in mean muscle activity between healthy and paretic limbs in stroke survivors where R-EMG identifies the rectified EMG summarised from Seki et al. (2009)

MVIC baseline (R-EMG/sec)	Healthy limb (mean and SD)	Paretic limb (mean and SD)
Gluteus Maximus (GM)	11.70 (3.60)	7.97 (1.96)
Rectus Femoris (RF)	28.78 (7.78)	5.83 (1.32)
Medial Hamstring (Ham)	26.67 (4.71)	6.85 (1.89)
Tibialis Anterior (TA)	28.07 (7.47)	4.57 (1.06)
Soleus (Sol)	23.0 (3.54)	4.88 (0.67)

Seki et al. (2009) was able to identify that that sEMG activity from flexors and extensors in the lower limb were almost silent during a maximal voluntary contraction in the paretic limb concluding that total flexion and extension was not enough to induce reliable sEMG signals. However, this was used to ascertain that the muscle activation of the Rectus Femoris (RF) and Tibialis Anterior (TA) were significantly larger in the affected leg during cycling when compared to the isometric contraction. Periodic muscle activity was also identified in several muscles, even on the paretic side indicating muscle activation occurred, but maybe not at the most efficient points of the pedal cycle. These findings, coupled with data presented by (da Silva et al., 2016) identifies a clear difference in activation patterns between healthy individuals and stroke survivors. Chen et al. (2005) also conducted research to assess asymmetrical cycling movement's patterns and identified a low symmetry within cerebrovascular accident subjects, implying asymmetric muscle activity was a result of phasic differences in muscle activation within the paretic limb, attributed to poor motor control.

2.7.3 PSCYHOLOGICAL IMPACT OF STROKE

Suffering from a stroke doesn't just affect an individual's physical wellbeing, but also their psychological wellbeing. It is reported that all patients suffering from a stroke are likely to suffer from some degree of cognitive loss and up to 50% of individuals will display symptoms of a psychological or emotional disorder (Hildebrand, 2014). In the last decade depression and mood disturbances after stroke has been acknowledged as an equally important comorbidity, affecting up to 63% of stroke survivors, influencing recovery and increasing stroke reoccurrence (Gottlieb et al., 2002).

Individuals experience changes in emotion, behaviour and information processing. Nys et al. (2007) acknowledged this in early stage stroke recovering identifying that 60-70% of survivors demonstrate disorders in abstract reasoning, verbal memory and/or language with no identifiable difference in lesion size or type of stroke (Carson et al., 2000). This change in cognition is stressful and sometimes more challenging to overcome than physical deficits resulting in a longer-term impact on mental wellbeing, sleep and communication.

The occurrence of sleep apnea and mild to moderate insomnia is a common complication amongst acute stroke survivors as a result of brain damage affecting up to 50% of stroke survivors, its occurrence aggravates functional and mental disabilities and usually worsens the effect of neuropsychiatric disturbances like depression and anxiety (Kaneko et al., 2003; Pincherle et al., 2017).

2.8 CURRENT STROKE TREATMENT

In the UK over 80,000 individuals are hospitalised annually suffering a stroke and dependent on classifications defined by the National Institutes of Health Stroke Scale (NIHSS), all disabling strokes are considered for immediate treatment by specialist units (Zerna et al., 2018). Whilst survivors remain in hospital, they are under the care of specialist stroke units and received rehabilitation and early interventions to optimise recovery.

When care is transferred from in-hospital care back home, it is administered 'as long as it continues to be of benefit' (Stroke Association, 2019). Survivors are managed by an early supported discharge scheme and receive reviews at 6 weeks, 6 months and then annually after their stroke to monitor improvements. The Transfer of care back home can be one of the hardest times for survivors who report they feel unsupported and abandoned when they leave hospital, with over 30% of survivor's rating their care at home as poor and many feeling they have been left with restricted support that lacks long term supported rehabilitation (Stroke Association, 2016).

This identified lack of long-term continuous post-stroke support is unexpected given that risk of recurrent stroke is prevalent; 26% within the first 5 years of first stroke, increasing to 39% by 10 years (Mohan et al., 2011). Furthermore acknowledged methods of rehabilitation for stroke care, identifying forms of muscle training, aerobic exercise and repetitive task training are available and can be implemented to improve individual's quality of life (National Collaborating Centre for Chronic Conditions, 2008). Although the effectiveness of these interventions can vary, the application of these methods has the potential to provide the required support to improve long term supported rehabilitation.

Therefore, the combined requirement for long term rehabilitation and need to address patient concerns identifies a requirement for continued support and provides opportunity to develop self-managed methods of rehabilitation. One such method may be the use of eBikes. With the rapid development of eBikes and their application in health research (Cooper et al., 2018), their use may have potential applications in stroke rehabilitation (Hansen et al., 2018).

2.9 DEVELOPMENT OF STROKE REHABILIATION AND TREATMENT METHODS

Recovery from stroke is complex and individually unique. The process depends largely on the location and size of the stroke and primarily focuses on relearning previously obtainable skills whilst promoting independence. Traditionally, physical rehabilitation ended within several months of stroke occurrence, as it was believed that the most substantial functional gains were up to this point. This previous lack of knowledge about brain recovery and adaptation following injury resulted in higher mortality rates and long-term disability. Through recent research healthcare professionals now have a greater understanding of recovery and adaptation following injury and although an 'optimum' time for recovery has not been defined, 'aggressive rehabilitation' beyond the initial hospitalisation period reflects furthers improvements. As a result of these developments in stroke treatments, changes in stroke care have been introduced and summarised by three major rehabilitation goals originally set out by Gordon et al. (2004); 1) regain pre-Stroke level of activity, 2) prevent recurrent strokes and 3) improve aerobic fitness.

The ultimate goal for stroke rehabilitation is the same for all professionals, assist in achieving a level of independence and assist the individual in returning home to supported rehabilitation (Kollen et al., 2006a; Royal College of Physicians., 2016a). Guidelines recommend that stroke survivors who have suffered mild to moderate disability are offered early discharge to continue their rehabilitative care from home, reducing dependency on hospital care whilst maintaining the recommended care intensity. Although these early discharge programs are not suitable for all survivors, they do provide individuals with an opportunity to take responsibility for their own rehabilitation whilst being provided the expertise and care they would receive as an inpatient (The National Institute for Health and Care Excellence, 2010) and has been proven to increase the likelihood of regaining independence.

Physical activity post-stroke has been implemented into rehabilitation programs like the early discharge program and has been successful in preventing stroke occurrence and promoting rehabilitation (Damush et al., 2007), achieving all three goals set out by Gordon et al. (2004). Moreover although the optimal dose and time to aid recovery is unclear, studies have explored a variety of methods to safely integrate physical activity into rehabilitation for stroke survivors.

Goal setting has been utilised in many home based rehabilitation programs and Levack et al. (2015) concluded that application may not improve health related quality of life; so focus should instead should be placed on supported self-management approaches. Jones et al. (2016) provided encouraging proof that concluded that administration of self-management programmes are feasible but unfortunately a lack of consistency and identified difficulties when implementing self-managed rehabilitation trails into stroke rehabilitation must be considered when planning an intervention (Royal College of Physicians, 2016a) and key principles need further development.

It is the general consensus that cardiovascular and strength training are the most effective methods in rehabilitation, utilising activities such as; circuit classes (Park & Kim, 2016) repetitive task training (French et al., 2007), treadmill (Mehrholz et al., 2017), progressive resistance strength training (Lee et al., 2010). Survivors both early and late on in their rehabilitative journeys benefit from interventions which have cardiorespiratory focus whilst repetitive task and specific task training is stated in the national clinical guidelines of stroke (Royal College of Physicians, 2016a) to improve balance and walking function. This knowledge combined with recommendations made by the Royal College of Physicians (2016a), that stroke survivors should receive functional task-specific training and lower limb strengthening exercises, supports the application of physical activity and furthermore application of activities such as cycling.

2.10 STROKE AND EXERCISE

Stroke has a detrimental effect on an individual’s ability to exercise. Not only do sufferers experience the physiological and psychological barriers, stated above, which limit their participation, but their profound physical deconditioning worsens their disability and places them at higher risk of a cardiovascular event as a result of reduced central neural drive. Oja et al. (2011) provided evidence to suggest that aerobic exercise provides a positive relationship with health supporting the idea that stroke survivors who participate in exercise programmes can achieve better balance and motor ability reducing musculoskeletal impairments. Physical activity programs have already been implemented without adverse effects and a Cochrane review by Saunders et al. (2016) identified 58 trials which tested different forms of fitness training summarising that cardiorespiratory fitness training can improve exercise ability and balance

Little research has been conducted to identify the adverse effects of exercise post –stroke and assessment of dropout rates in participants taken from a large clinical trial in stroke by Duncan et al. (2003) conclude only a small percentage (8%) of participants withdraw from physical activity research and even fewer (3%) as a result of a secondary stroke. These identified predictive values are below the national average proposed for stroke re-occurrence (25%) and provides evidence to suggest that participation in exercise post-stroke does not increase the risk of secondary stroke, as some may fear. In addition many modifiable risk factors associated with stroke; hypertension, diabetes and obesity are often treated with exercise; supporting its application into rehabilitation (Xing et al., 2018).

Participation in exercise, such as cycling, has been implemented into rehabilitation to improve functional ambulation and quality of life in stroke patients. Vanroy et al. (2017) collected objective and self-reported measures for an active cycling intervention in subacute survivors and although significant changes were identified it highlighted the need for quantitative data collection. Furthermore Janssen et al. (2008) presented data utilising electrical stimulation (ES) in combination with a cycling ergometer as part of a 6 week training block, identifying significant aerobic capacity improvements ($p=0.039$, 13.8%) in chronic stroke survivors.

Leg cycle training is already considered one of the most effective methods for aerobic exercise in the ‘sub-acute’ stage of stroke, 7 days to 6 months after the initial event (Stoller et al., 2012) and positive outcomes have been found from the application of cycling in rehabilitation providing encouraging results. Cycling is an engaging way of meeting recommended levels of physical activity (Bjørnarå et al., 2017) and encourages muscular weakness reversal in hemiparetic stroke survivors through a coupled pedalling action (Kautz & Brown, 1998) assisting with rehabilitation of identified limb asymmetries. In addition, the repetitive motor task encourages adaptation of the neuromuscular system, in turn improving the efficiency of muscle activation (Chapman et al., 2008) and providing passive movement.

Cycling shares similar kinematic patterns with walking as both are cyclical movements that require alternative flexion and extension movements of the hip, knee and ankle. Raasch & Zajac (1999) specified that cycling and walking share the same sensorimotor control mechanism generated by the same neural network and therefore can play a vital role in regaining walking ability and related balance deficits. Furthermore, cycling encourages a larger range of movement around these joints, maintaining motion necessary for ambulation and proving an effective training method for stroke recovery (Lin et al., 2012).

Whilst cycling exercise has been proven to be beneficial to improve cardiovascular fitness, cycling can be limited in patients with balance issues (Janssen et al., 2008) and Rahman et al. (2012) acknowledged that stroke patients found cycle ergometers unnatural and difficult to use, due to their limited range of movement, spasticity and cardiovascular fitness. Movement and spasticity limitations could nonetheless be overcome through modifications such as foot straps and trike configurations as suggested by Blumenstein et al. (2014) but an individual's cardiovascular deconditioning is considered more challenging to support. One development which may help to address these challenges is the increase in availability of electrically assisted bicycles (eBikes) which may help in overcoming the effects of physical deconditioning through supplemented electrical support.

2.11 EBIKES

An electric bike (eBike) is an electrically assisted pedal cycle with an integrated battery and motor. With growing interest in the use of eBikes in urban transport, researchers and practitioners are highlighting the method of active travel as a means of overcoming physical deconditioning and commonly associated barriers to cycling (Popovich et al., 2014). eBikes are designed to provide individuals with supplemented electrical support whilst actively pedalling encouraging them to achieve higher speeds with less effort thus making activities such as hill climbing much easier by removing possible aerobic fitness constraints (Langford et al., 2013). In the UK eBikes are restricted to a maximum power output of 250 watts and cannot provide additional power when travelling more than 25 km/h (Fishman & Cherry, 2016). They are becoming increasingly popular as individuals seek a cost-effective, safe and eco-friendly mode of transportation and as a result of this are being reviewed for transport models and rehabilitation.

However, questions have been raised as to the health benefits of eBikes. Bourne et al. (2018) conducted a systematic review of 16 studies exploring the health benefits of electrically assisted cycling. They aimed to identify the intensity of physical activity associated with eBike usage, changes in health through eBike application and comparisons between eBiking and conventional cycling. It was broadly reported that electrical assistance is associated with lessened levels of lower limb muscle activation, reduced cardiovascular effort and lowers perception of effort (Sperlich et al., 2012; Theurel et al., 2012).

However, Gojanovic et al. (2011) documented that even at the highest level of electrical support, individuals using eBikes were achieving moderate exercise and meeting between 55-65 percentage heart rate maximum (%HRmax) recommended by the American college of sports medicine (2010) to improve health. These findings are supported by the work of Sperlich et al. (2012) who reported that mean heart rate when cycling with electrical assistance was lower (105 ± 20 Beats.min^{-1}) than without (133 ± 19 Beats.min^{-1}), but both were still within the recommended levels for aerobic exercise. Simons et al. (2009) also evaluated the effort intensity and concluded that eBikes elevated heart rate to 67% of maximal capacity, within a suitable training range. Therefore, the use of eBikes is indicative in achieving the aerobic training zones required to improve cardiovascular fitness. The reduced heart rate and perceived effort may facilitate more frequent, prolonged cycling and a more enjoyable form of exercise (Langford et al., 2017). Therefore eBikes could be offered as a suitable alternative to conventional cycling and this thesis explores its application on stroke survivors.

2.12 EBIKES AND REHABILITATION

eBike rehabilitation research is still in its infancy and although there is evidence suggesting that eBike implementation could bring about positive changes to individual's fitness there have been few studies conducted on its scientific application to rehabilitation. To date most of the published literature focuses on safety implications of eBikes and their integration into urban planning. This is surprising given that cycling has been identified as a suitable modality to improving cognitive health and wellbeing. Hence the application of eBikes, which could remove additional fitness limitations and expose individuals to a stimulating environment, could be implemented as a safe and functional activity that is accessible to individuals suffering from cardiovascular, cardiorespiratory and cerebrovascular diseases.

eBike use has been applied and reviewed against some limited conditions; diabetes and heart conditions and although few assess the physical changes after an intervention Blumenstein et al. (2014) provided some of the first evidence optimizing eBikes for youths with disabilities, working with a group affected by cerebral palsy. The neurodevelopment disorder has relatable symptoms to stroke, as it effects an individual's ability to maintain balance and co-ordinate muscles. Blumenstein et al. (2014) demonstrated that eBikes could be adapted for individuals needs and moreover provide ongoing adjustment to support participation. This research was effective in identifying modifications that would suitably assist individuals with disabilities become more active to optimize the effect of an integrated eBike therapy.

Hansen et al. (2018) examined the use of eBikes within rehabilitation of individual's participants suffering from coronary artery disease. They indicated that eBiking provided high enough intensity of exercise to be suggested as an exercise modality to stimulate outdoor physical activity. The study compared differences between the levels of electrical support proving the concept that eBikes could be used for rehabilitation by eliciting that electrical assistance achieved exercise intensity (METS – metabolic equivalents) within the range of international aerobic recommendations (3- 6METS) proposed to prevent further coronary heart disease. Issues surrounding the research by Hansen et al. (2018) have since been addressed in a randomised 4 week pilot study conducted by Höchsmann et al. (2018). Höchsmann et al. reported an increase in oxygen uptake (6%) following a 4-week eBike trial when assessing a group of physically inactive individuals compared to conventional cycling (4%) and detailed a maximum power increased after the 4-week intervention. This has been further developed by Cooper et al. (2018) who explored the feasibility of eBiking to improve the health of individuals with type 2 diabetes. Cooper et al. (2018) recorded better fitness test results at follow up and showed that eBiking elevated heart rate to 67-69% of heart rate maximum for a flat circuit concluding that eBiking could elicit improvements in cardio-metabolic risk factors. And also demonstrated that a 20-week eBike intervention could produce results that advocate eBike implementation in rehabilitation and health treatment. This provides verification that eBike interventions are appropriate for reducing cardiac risk factors and improving quality of life, highlighting their potential scope for implementation in stroke rehabilitation. Supporting the application of eBikes for stroke survivors to help manage their condition.

New research conducted by Boland (2019) specifically explored the use of eBikes within stroke rehabilitative care. The study investigated barriers and enablers prior to loaning the eBike, and after a 3 month intervention; highlighting components from the 'capability', 'opportunity', 'motivation' and 'behaviour' (COM-B) model used to assess behavioural change interventions. The study identified challenges in relation to liability and time scale but proposed suitable, stroke specific, eBike adaptations that should be considered. It was not the aim of research by Boland (2019) to conclude that eBikes should or should not be implemented into stroke rehabilitation, but it did provide information regarding barriers that should be considered whilst developing future research into eBike application and development.

CHAPTER 3 AIMS AND OBJECTIVES

Through assessment of current stroke and eBike research, eBike cycling has not been applied in a stroke rehabilitation capacity or directly used to assess physiological and biomechanical changes. Although research has been conducted to evaluate the implications of eBike use in stroke survivors (Boland, 2019). Similar studies encompassing cycling interventions and disability have provided evidence which encourages the application of cycling and more specifically eBike rehabilitation. Therefore, the aim of this thesis was to summarise the benefits of eBike application in stroke and assess physiological and biomechanical changes following an 8-week eBike intervention. Providing an overview of the use of eBikes in stroke survivors to inform future research and rehabilitation practices.

3.1 HYPOTHESIS

It was hypothesised that muscle activity, ambulatory function and strength will improve as a result of an 8-week eBike aerobic training intervention in stroke survivors. Identified through:

- Clinically important differences in ambulatory speed when performing the 10 metre walk test (10MWT) as muscle co-ordination improves and the paretic limb strengthens.
- Improvements in a cycle ergometry task as participants will cycle with more power (W) and at a higher cadence indicating improvements in cardiovascular fitness.
- Recording lower resting heart rate and blood pressure at post intervention.
- Higher confidence ratings when using an eBike over the intervention period.
- Increased cycling distances and/or for longer periods of times during the intervention.

CHAPTER 4 METHOD

Results for this thesis were written up as individual case studies. This method was selected as it provided an opportunity to apply general concepts to individual improvements and because it was not possible to regulate improvements. Furthermore, assessment through individual case studies meant that specific improvements could be identified and discussed in more depth.

4.1 PARTICIPANTS

The study was approved by the University of Central Lancashire (UCLan) ethics committee (STEMH 968) and supported by I-cycles limited in partnership with the Collaborations for leadership in applied health research and care (CLAHRC, RS/17/06). Verbal and written consent was obtained from all participants prior to commencement of the study.

Participants were recruited through opportune sampling of stroke groups, sports associations and support networks in the North West of England; they represented stroke survivors who had suffered a stroke more than three months prior to the study. Participants were provided with information sheets (Appendix Figure 1), consent forms (Appendix Figure 2) and GP permission forms (Appendix Figure 3). Initially 29 individuals registered interest for the trial and 18 met the inclusion criteria (listed below):

- 18+ years of age
- Have a one sided weakness
- Suffered stroke more than 3 months ago
- Understanding of basic English
- Able to store a bike

Of these 29 individuals only 5 individuals were able to gain GP permission and take part in the study. These participants were firstly met by a member of the research team and an I-cycles representative to assess their suitability for the study and establish eBike modifications that could be made to support their involvement.

These participants were subsequently invited to the University of Central Lancashire (UCLan) physiology laboratory for the pre-intervention assessments; their descriptive values are discussed within each case review and presented below (See Table 4.1). Each participant completed repeated 10 metre walk tests (10MWT), maximal voluntary isometric contractions and a cycle single ergometry task. Following the initial data collection participants were then provided with a modified eBike and prescribed an 8 week cycling intervention. The participants were contacted biweekly to ascertain engagement and identify further modifications. This was conducted as a short telephone call and no data was collected. To conclude the study, participants returned to the university to repeat the Pre-intervention tests.

It was each participant's intention to use the eBike for the 8 week intervention, however some participants withdrew from the study in the early stages. Data collected from all these participants was still included in the final findings and each individual case study is discussed within the results section.

Table 4.1: Participant descriptive values collected at pre-intervention.

Participant number	Mass (kg)	Stature (m)	Age (years)	Time since stroke (months)	Affected side	Diastolic Blood pressure (mmHg)	Systolic Blood pressure (mmHg)	Resting Heart rate (Beats.min^{-1})
One	96.3	1.82	78	108	L	91	123	68
Two	94.6	1.83	51	102	R	97	145	75
Three	87.8	1.77	69	36	R	78	147	47
Four	118.5	1.85	59	7	L	91	130	81
Five	87.6	1.86	47	122	R	87	135	63

4.2 DESCRIPTIVE VALUES

Stature was measured to the nearest centimetre using a stadiometer (Harpenden Avery Ltd., Birmingham, UK). Mass was recorded to the nearest 0.1kg using digital scan scales (Omron Karada., Omron, UK) and blood pressure with resting heart rate (RHR) were measured using a blood pressure monitor (Omron basic M2., Omron, UK) placed above the brachial artery on the left arm.

4.3 AMBULATION ASSESSMENT

Kwakkel et al. (2017) recommended a set of standardised predefined tests to be used in every stroke recovery and rehabilitation trial to make studies more comparable. The 10 metre walk test was identified as a measure to assess independent ambulation and endorsed by the Royal College of Physicians (2016a). The measure highly correlates (absolute Spearman ρ=0.61 to 0.87) with the postural assessment scale for stroke patients (PASS) (An et al., 2015) and defined as statically significant in stroke assessment by Collen et al. (1990) supported by An et al. (2015). The method is also regularly used in stroke assessment studies such as one conducted by Paul et al. (2016).

Participants were asked to walk 10 metres from a standing position at a self-selected speed using a preferred aid, for example: a walking stick or frame (Vos-Vromans et al., 2005). Time was recorded using a stopwatch for the 10 metre distance once the participant's foot crossed taped lines marked at 0m and 10m. Three repeated measures were completed, recording the time achieved (s). Mean, standard deviation and speed (ms^{-1}) was calculated from these three repeated measures at pre and post intervention. In addition, Individuals stroke was visually assessed during the ambulatory assessment against the functional ambulation categories defined by Kollen et al. (2006b) and identified in the table below (Table 4.2).

Table 4.2: Functional ambulation categories used to classify individuals stroke severity.

Score	**Category**	**Guidance**
0	Non-functional (unable)	Person cannot walk or requires help of 2 or more people
1	Dependent, level 2	Person requires firm, continuous support from 1 person to help with carrying weight and with balance
2	Dependent, level 1	Person needs continuous or intermittent support from 1 person to help with balance or coordination
3	Dependent on supervision	Person requires verbal supervision or stand-by help from 1 person without physical contact
4	Independent on level ground	Person can walk independently on level ground but requires help on stairs, slopes, or uneven surfaces
5	Independent	Person can walk independently anywhere

4.4 CYCLE ERGOMETRY

Participants took part in an exercise test that was performed on a Wattbike Pro (Wattbike Pro; Wattbike Ltd., Nottingham, United Kingdom). The Wattbike's pedals were replaced with Garmin vector pedals (Garmin., Schaffhausen, Switzerland) and fitted with a KEO cleat and adjustable toe clip so that the participant could wear their own shoes. The pedals recorded power output (W_{mean} and W_{max}) and cadence (revs.min^{-1}) during each revolution. They were additionally used to compare power balance (%) between the left and right limbs and power phases (°) during the crank cycle. These measures described where in the pedal stroke the participant starts and stops applying a driving force and indicates the region where the most power is applied. The pedals were paired wirelessly with a Garmin Edge 510 cycle computer mounted to the handlebars through which data was uploaded to Garmin connect for interpretation.

A decision was made to use the vector pedals to record power, rather than Wattbike, because of their ability to store data via the headset and upload to garmin connect. This made repeated collection easy to manage and view. Although no direct comparison has been made between the wattbike power metres and the Vector pedals, research has been published by Novak & Dascombe (2016) which concluded that there was no significant difference in power output between the Vector pedals and an SRM device, this was supported by Nimmerichter et al. (2017) who concluded there was no significant difference in power output between devices in a laboratory setting ($p=0.245$). Thus, providing reproducible results across a range of power outputs. However the vector pedals have been reported to overestimate at higher power outputs (Whittle et al., 2018) and should be treated with caution.

A variety of methods were used to assess cycling performance during a self-paced cycle timed to a maximum of 5 minutes on a Wattbike Pro, which was set to level 3 air resistance (Wang et al., 2018). Participants cycled in their own gym wear and shoes and were asked to aim for a Borg scale rating of 13 (Yates et al., 2004) identified by Borg as 'somewhat hard', in line with physical activity recommendations made by Billinger et al. (2014) for stroke survivors. Pedals fitted to the Wattbike measured power balance, mean power (W_{mean}) and at which angle during each revolution positive power was applied (power phase).

Wireless near-infrared muscle oxygenation monitors (MOXY, MOXY., USA) were attached bilaterally with an elastic adhesive bandage onto the mid central muscle belly of the vastus lateralis, one third of its length from the insertion point to assess localised muscle oxygenation.

The selection of this position was so not to interfere with sEMG sensors. Muscle oxygenation (SmO_2) values collected from the MOXY infrared device every two seconds for the duration of the cycle to ascertain differences in muscle oxygenation between the paretic and non-paretic limbs. Assessment was only conducted during the pre-intervention assessment and final data from the MOXY device was trimmed to represent the middle two minutes of the cycle.

Participants also wore a smart heart monitor (Vivosmart, Garmin, USA) on their wrist throughout the cycle. Sartor et al. (2018) concluded that strapless heart rate monitors, such as the wrist-worn optical heart rate monitors used in the present study, generated 'acceptably close' results in healthy populations over a range of activities when compared to a traditional chest strap monitors. Sartor et al. (2018) developed this further to identify that the use of an optical heart rate monitor produced close results (±2.4 $Beats.min^{-1}$) to chest straps for cardiac patients partaking in walking and sedentary activities. Application of the heart rate monitor was primarily utilized to establish if the participant was achieving an aerobic training zone of 50 -80% of age calculated maximal heart rate as identified by Gordon et al. (2004) derived from the equation for percentage heart rate maximum (%HRMax) (Tanaka et al. (2001).

$$(209 - 0.7 \times age)$$

The heart rate monitor was furthermore used to identify a safe termination point for exercise, recommended as 85% HRMax (American college of sports medicine, 2010). Information from the pedals and heart rate monitor were transmitted to the Garmin edge 510 head unit and uploaded to Garmin connect. a web-based software application, through USB connection to a UCLan windows PC.

4.5 SURFACE ELECTROMYOGRAPHY

Surface electromyography (sEMG) was recorded bilaterally for the cycle test and maximum voluntary isometric contractions (MVIC) using wireless electrodes (Trigno, Delsys Inc., Boston, MA) at an upsampled rate of 2000Hz.

Measurements were taken bilaterally from four lower limb muscles suggested by da Silva et al. (2016) during the cycle exercise test. Electrodes were placed on the Tibialis Anterior (TA), Rectus Femoris (RF), Medial Gastrocnemius (GC) and Bicep Femoris (BF) in line with SENIAM guidelines. The area of placement was shaven, lightly abraded and cleaned using alcohol wipes to lower skin impedance in preparation for electrode attachment (Hurst et al., 2017). The electrodes were attached using pre-cut double-sided adhesive tape.

Data acquisition software (EMGworks version 4.5.4, Delsys Inc. Boston, MA), was used to create a measurement protocol which collected data at 2000Hz in 30 second intervals over the 5-minute cycle (or until the participant stopped). Raw data was exported from EMGworks into analysis software (Visual 3D v6.01.36, c-motion inc., Gaitherburg, MD USA) where it was processed using a metric mean offset, bandpass filtered (40 - 400hz) and full wave rectified. Events were marked to indicate top dead centre for both the left and right pedal cycles (Figure 4.1), this was defined by the angular velocity of the bicep femoris in the X Axis. Rectified EMG signals (rEMG) were normalised against maximum sEMG amplitude collected for each muscle during repeated maximum voluntary isometric contractions (MVIC).

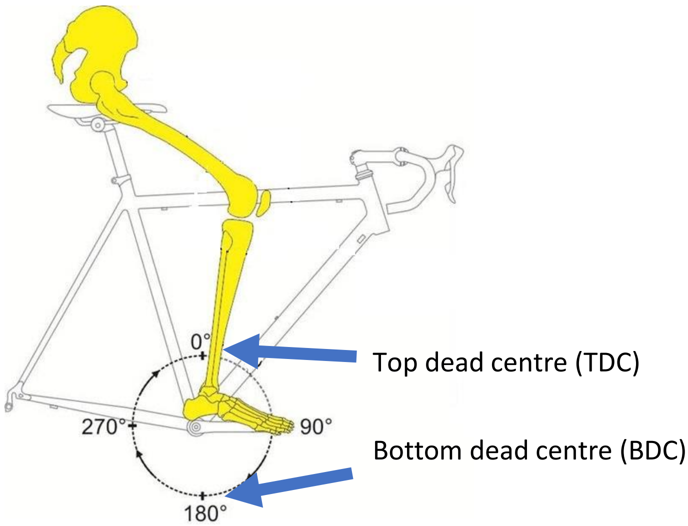


Figure 4.1: Top dead centre (0°) and bottom dead centre (180°) of the pedal cycle used to identify events markers for analysis of sEMG. Image taken and edited from: Bini et al., (2014) accessed 08/04/2019

4.6 MAXIMUM VOLUNTARY ISOMETRIC CONTRACTION

sEMG data was collection for maximum voluntary Isometric contractions (MVIC) for knee flexion and extension as suggested by Lee et al. (2010). Testing commenced on the non-paretic side whilst the participant was seated in an upright position; their hip and knee joints were positioned at 90° of flexion. The participant was required to push unidirectionally for six seconds against a core zone resistance Theraband (23 – 57kg) looped around the shank and front two legs of the chair. The Participant completed four repetitions with a ten second rest interval between each. This method was repeated for the flexion movement after a two-minute rest, where the resistance band was placed around the participants heel and front two legs of a chair which the researcher as sat on (See Figure 4.2). Surface electromyography (sEMG) data was collected during these MVIC tasks from the same muscles identified for the cycle ergometry and analysed with a metric mean offset, bandpass filtered (40 - 400hz) and full wave rectification before identifying the metric maximum (Appendix Figure 6).

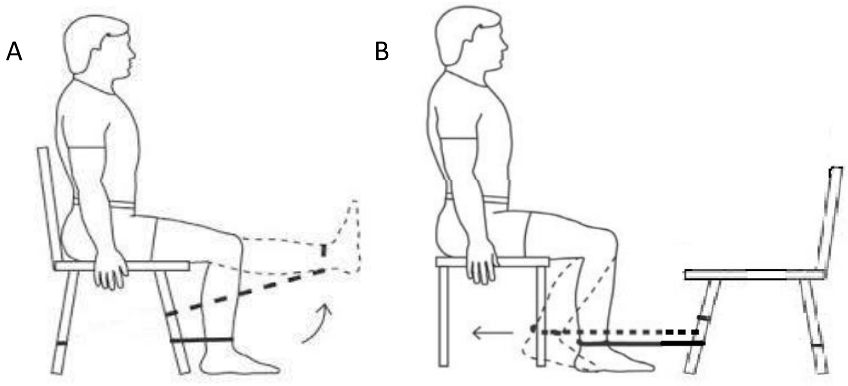


Figure 4.2: Resistance band flexion and extension method used to create a manual muscle test for maximum voluntary isometric contraction. Image adapted from https://tbdev.performancehealthdev.com/media/theraband/instructions/Resistance_Band-Tubing_Instruction_Manual (1).pdf (accessed 16/05/2019)

Application of Manual muscle testing (MMT) appeared to be a highly valued and reliable alternative to using a Cybex isokinetic dynamometer (Lin et al., 2008) to obtain maximal voluntary contractions. Lin et al. (2008) identified no significant difference in electromyographic amplitude and median frequency when comparing MMT to Cybex testing. Application of comparable elastic tubing resistance has also induced similar muscle activity displaying reciprocal EMG patterns (Jakobsen et al., 2012). This supported our decision to opt for a more comfortable alternative, utilising a Theraband to apply resistance during knee flexion and extension.

4.7 INTERVENTION

Participants were provided with a modified eBike for an 8 week intervention, as Billinger et al. (2012) reported positive findings for physical function after stroke for this intervention period. As a result of fatigue, physical deconditioning and increased risk of exertion related cardiovascular events following stroke, participants were informed of the recommended aerobic training frequency of ≥3 days a week for 20 to 60 minutes Billinger et al. (2014)

Self-administered cycling diaries were provided to the participants and used to identify average heart rate, number of calories burnt and the length of the cycle (Appendix Figure 4). The diary was additionally used to assess socioeconomic characteristics of the participant in line with the CLARHC. The participants provided with an optical heart rate monitor in conjunction with the cycle diary. The application of these unobtrusive monitors allowed participants to monitor their exercise intensity during the intervention and record required information into the diary.

4.8 EBIKE MODIFICATIONS

The eBikes that were provided to the participants were suitably adapted to promote their involvement in the study. A list of possible modifications was discussed with the participants and fitted (See Table 4.3) to individuals' bikes (See Figure 4.3). Participants were provided with safety equipment (helmets and locks) and contact details for the eBike provider. The eBike provider arranged delivery and collection of the eBikes to the participant's residence, they were also on hand to deal with any bike repairs.

Table 4.3: eBike modifications available to the participants and offered by Icycles Ltd.

Modifications
Velcro glove to attach the hand to the handlebar
All levers (brake and gear) on the same side of the bike
Handlebar mounted rear view mirror
Pedal strap to hold the foot in place
Pedal boot (replace the pedal with a fixed boot) See Figure 4.3A)
eTrike (1 front and 2 rear wheels) See Figure 4.3B)

Figure 4.3: eBike modifications provided to some participants. A) Boot attachment with ankle support. Image taken from Boland (2019). B) eTrike.

4.9 STATISTICAL ANALYSIS

Heart rate, Blood pressure and other anthropometric measures were reported at pre and post intervention, although no statistical test was conducted to compare these. Individual paired samples T test were generated using SPSS (IBM SPSS statistics 25.0.0.2) to compare tissue oxygenation levels between the two limbs at pre-intervention to ascertain statistical differences between limbs.

Mean and standard deviation was calculated from three repeated 10m walk tests taken at pre and post intervention. Ambulatory function was then assessed for clinically important differences (CIDs) calculated using the '1 Standard Error of the mean' (1SEM) method proposed by Den Oudsten et al. (2013). 1SEM values were calculated using SPSS (See Appendix 4). This method was selected to identify minimal changes in mean ambulatory function that would be of benefit to the individuals.

sEMG activation will be presented graphically and displayed as a percentage of the maximum voluntary isometric contraction (MVIC) in the Y axis. The X axis will characterise phases of the crank cycle whereby 0% will identify top dead centre (0°), 50% will identify bottom dead centre (180°) and 100% will identify the return to top dead centre (0°).

CHAPTER 5 CASE REVIEWS

5.1 PARTICIPANT ONE CASE REVIEW

5.1.1 CLINICAL DESCRIPTION

Participant one was a 78 year old male with a mass of 96.3kg and stature of 1.82m who suffered from left side deficiencies following a stroke that affected his right thalamus and third cranial nerves. He had his stroke 108 months prior to volunteering for the study and suffered from double vision in his left eye. He used a walking stick and rated as 5, 'person can walk independently anywhere' in the functional ambulation categories classification (Kollen et al., 2006b). The participant could drive a car and was independent in daily activities, he had social support from his wife and prior to his stroke enjoyed an active lifestyle where he would regularly cycle. The participant wanted to start cycling again and showed interest in the study as he had researched eBikes and felt that the electrical assistance would encourage him to start cycling again.

5.1.2 INTERVENTION AND ADHERANCE

The participant was provided with a two-wheeled eBike with a rear-view mirror attached to the handlebar; this supported his double vision and reduced the need for turning his head, which he felt would impair his balance. No other modifications were made to the bike. Whilst testing the eBike the participant was comfortable cycling around the car park and only utilised the lowest level of assistance available on the eBike. The participant completed 2 cycles on the eBike but did not use the watch or record information in the cycle diary. The participant was then unable to continue using the eBike after receiving medication for a different condition which reduced his balance.

5.1.3 RESULTS

The participant had high blood pressure at both pre and post-intervention (pre: 123/91 mmHg, post 128/93 mmHg). His resting heart rate was higher post-intervention (77 Beats.min^{-1}) compared to pre (67 Beats.min^{-1}), this could have been an effect of new medication that was prescribed during the intervention. Anticipatory rise was accounted for as the participant as measurements were taken in a seated position, in a quiet lab. The participant exerted on average more power (88W_{mean}) at post-intervention but was unable to complete the full 5-minute cycle, achieving just 2:08.9 minutes on the bike, this may have been a result of the learning effect, or the participant performed at a high rate of perceived exertion. Cadence was higher post-intervention (70 revs.min^{-1}) and average heart rate was lower (75 Beats.min^{-1}). All cycling performance data is presented below in Table 5.1.

Table 5.1: Participant One's cycling performance data at pre and post intervention

Outcome measure	Pre-intervention	Post-intervention
Mean heart rate (Beats.min^{-1}).	126 (82% max HR)	75 (49% max HR)
Maximum heart rate (Beats.min^{-1}).	137	90
Mean power (W_{mean})	65	88
Maximum power (W_{max})	159	152
Mean cadence (revs.min^{-1})	63	70
Maximum cadence (revs.min^{-1})	84	82
Percentage left balance	42	50
Percentage right balance	58	50
Left power phase (°)	15 – 193 (178)	17 – 198 (181)
Right power phase (°)	8 – 197 (189)	14 – 195 (181)
Left peak power phase (°)	70 – 118 (48)	72 – 122 (40)
Right peak power phase (°)	70 – 122 (52)	73 – 125 (43)

The participant displayed expected left limb deficiencies during the cycle ergometry task, identified through the differences between the left and right side % power balance (See Figure 5.1). At post-intervention the participants power phase equalised exerting balanced power through the paretic and non-paretic limbs. In addition to this, the participants power peak power phases were longer in the right (non-paretic) limb at both pre and post-intervention (See Table 5.1).

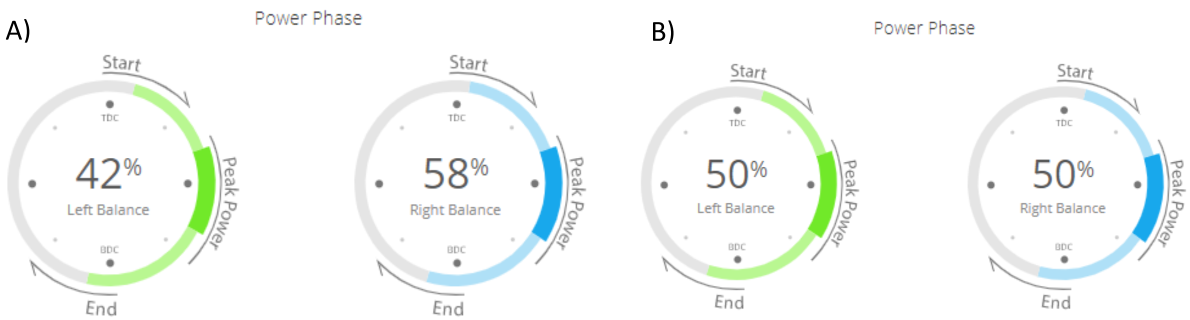


Figure 5.1: Participant One's between limb power phases comparison, including peak power phases taken at: A) Pre intervention, B) Post intervention

Pre and post-intervention cycling sEMG signals were normalised to maximum sEMG values obtained during manual MVIC as explained in the statistical analysis above and presented as %MVIC. The graphs below represent the sEMG muscle electrical activity throughout the crank cycle (Figures 5.2 and 5.3)

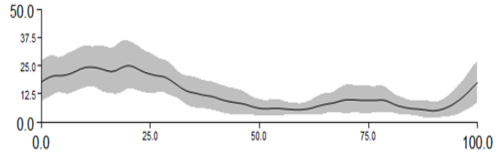
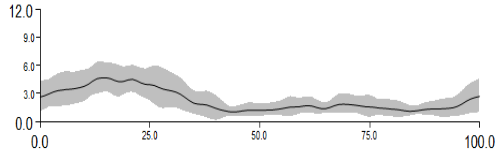
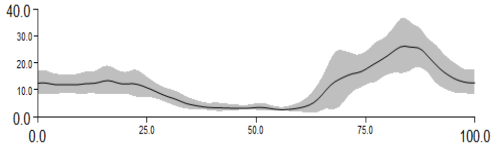
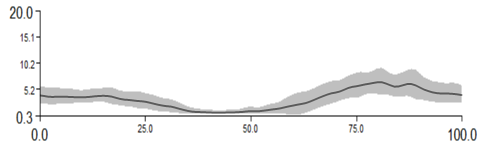
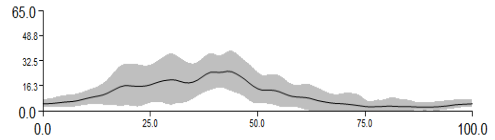
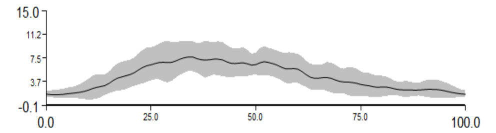
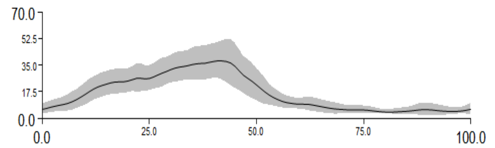
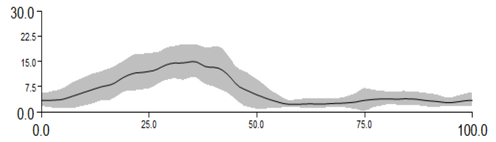
	Pre-intervention	Post-intervention
Tibialis anterior (TA)		
Rectus femoris (RF)		
Gastrocnemius (GC)		
Bicep femoris (BF)		

Figure 5.2: Participant one's, Pre and Post intervention left limb comparisons of mean and standard deviation sEMG. Normalised to % MVIC over the duration of the pedal cycle. Where 0 is top dead centre and 50 is bottom dead centre on the X axis (Appendix figure 12).

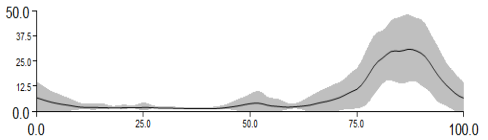
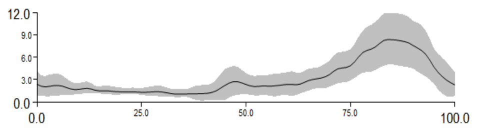
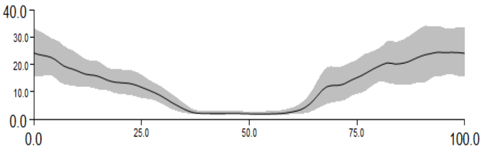
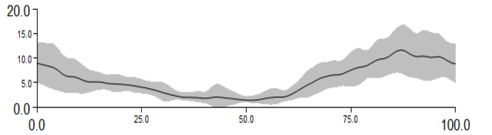
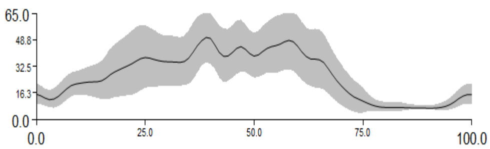
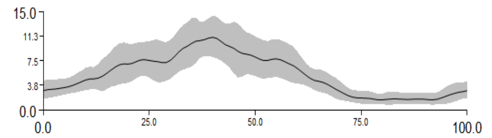
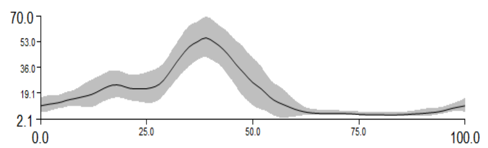
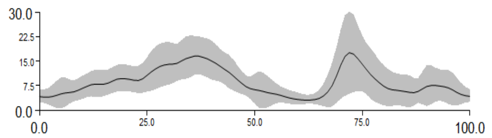
	Pre-intervention	Post-intervention
Tibialis anterior (TA)		
Rectus femoris (RF)		
Gastrocnemius (GC)		
Bicep femoris (BF)		

Figure 5.3: Participant one, Pre and Post intervention right limb comparisons of t mean and standard deviation sEMG. Normalised to % MVIC over the duration of the pedal cycle. Where 0 is top dead centre and 50 is bottom dead centre on the X axis (Appendix figure 13).

The participant was comfortable completing the 10 metre walk test (10MWT) without the use of his walking stick and he completed the 10MWT at pre-intervention in a mean time of 8.616± 0.854s travelling at an average speed of 1.167 ± 0.111 ms^{-1}. At post-intervention participant one's mean time improved by 0.959s (7.656 ± 0.688s) resulting in a post-intervention mean speed of 1.313 ± 0.120 ms^{-1}. This positive improvement exceeded the clinically important difference (CID) for mean time (0.493s) and mean speed (0.064 ms^{-1}) calculated using 1SEM. This improvement also exceeded the minimal clinical difference of 0.160 ms^{-1} identified by Tilson et al. (2010).

A paired samples T-test was additionally conducted to compare differences in tissues oxygenation between the paretic (left) limb and non-paretic (right) limb. There was a significant difference in SmO_2 between the paretic (31.29 ± 11.20 SmO_2) and non-paretic (19.08 ± 11.39 SmO_2) limbs; $t(46) = 30.985$, $p<0.05$. These results suggest that SmO_2 levels are higher in the paretic limb (Appendix Figure 7).

5.1.1 CASE DISCUSSION

Participant one completed pre and post-intervention testing, but he was unsuccessful in completing the intervention as he experienced balance and co-ordination concerns as a result of a newly prescribed medication. The participant did not wish to withdraw from the study, as he had been recommended by his doctor that the side effects of this new medication were only temporary, but unfortunately this was not the case. The participant was enthusiastic about taking part in the trial and excited to be able to access an electric bike for his rehabilitation and during a brief informal discussion the participant planned to purchase an electric bike of his own, so that he could become active as he felt it supported his disabilities.

Results identified that the participant suffered from high blood pressure, which is supported by the findings of Appleton et al. (2016) who concluded that high blood pressure is present in 75% of stroke survivors. This elevation placed the participant at a higher risk of stroke recurrence (Ishitsuka et al., 2014) and although no reduction in blood pressure was recorded after the intervention results matched baseline readings recorded by Moore et al. (2015). Dynamic exercise is normally successful in significantly reducing both diastolic and systolic blood pressure (Cornelissen & Smart, 2013) and it was hypothesised that this decrease would have been observed through use of the eBike, but as the participant was unable to complete the intervention this cannot be confirmed.

Participant one had higher resting heart rate at post-intervention compared to pre-intervention. Resting heart rate in this study was conducted after sitting still and recorded concurrently to blood pressure and values were within ranges proposed by Ofori et al. (2019) but the hypothesised reduction was not observed. This increase in heart rate could be a response to starting new medication and treatment, that he was unwilling to disclose specific details about. Alternatively this could have been a physiological response to anticipatory rise as the participant was aware of the protocol and subconsciously prepared his body for exercise (Kent, 2007), although unlikely as it was accounted for during data collection.

Assessment of ambulatory function identified clinically important changes in walking time and average speed. He was able to ambulate comfortably without the use of an aid and at higher average walking speeds that those reported for maximum pace by Salbach et al. (2001) (1.05±0.47 ms-1) and Yang et al. (2014) (0.68 ± 0.36 ms-1) identifying a higher a level of ambulation than subacute stroke patients, potentially as a result of longer rehabilitation. He documented improvements in walking speed beyond the minimum clinically important difference (0.16 ms-1) stated by Tilson et al. (2010) for subacute and severe gait speed impairments, supporting the theory that the participants stroke was not as severe as the comparative studies. It can be concluded that these improvements in ambulatory function were not a result of using the eBike, as the participant did not complete the intervention. In this instance it is possible to suggest that the improvements were a result of familiarisation to the protocol, an explanation supported by Zondervan et al. (2016) who identified that repetition of baseline assessments accounts for some learning effects that can misrepresent improvements. This could be addressed in future research by conducting familiarisation sessions prior to pre-intervention, reducing the magnitude of effect in final data collection.

It is understood that stroke survivors experience strength and power deficits in the paretic limb as a result of muscle weakness which affects their functional ability. Results collected from this participant identify a difference in peak power balance supporting work done by Hunnicutt et al. (2016) which states that individuals who suffer from post-stroke hemiparesis have issues generating force compared to their age matched health individuals. Muscle training can improve and potentially restore muscle power generation and these results further detect that % power balance difference between the left and right limbs reduced, reflecting an increase in power in the paretic limb. Conclusions made by both Hunnicutt et al. (2016) and Aaron et al. (2017) support the relationship between paretic muscle function and gait speed and this identified increase in paretic limb power could explain the increase in walking speed noted earlier.

Assessment of the cycle ergometry task detailed a decrease in mean and maximum heart rate (Beats.min-1) at post-intervention. During this assessment the participant terminated the cycle after 2:09.0 minutes because he was exhausted and assessment of his mean heart rate identified that he was unable to achieve an aerobic training zone identified by Gordon et al. (2004) (50 - 80%). The participant had made us aware that he had felt more fatigued since starting his new treatment and this combined with a lack of participation in the intervention may have resulted further cardiorespiratory decline identified by Billinger et al. (2014).

Through assessment of muscle co-ordination and activation, participant one recorded overall lower %MVIC magnitudes during post-intervention as a result of higher sEMG amplitudes in all muscles during the MVIC, demonstrating increased activation levels during post-intervention assessment. These identified increases in sEMG amplitude have the potential to identify an increase in magnitude of muscle force which would complement a change in power balance, but without identifying a maximal voluntary isometric contraction force value its relationship is complicated and it shouldn't be inferred that sEMG amplitude, in this instance, increased because of increased strength (Roberts & Gabaldón, 2008) although this could be explored in future research.

Analysis of sEMG activation patterns was successful in identifying muscle co-ordination of paired muscles (rectus femoris with bicep femoris and tibialis anterior with gastrocnemius) typical of a healthy participants (Alves-Pinto et al., 2016) during pre-intervention. A favourable change in activation pattern was also observed during post-intervention, further refining co-activation detailed at pre-intervention. Identification of this co-activation is unusual in stroke survivors who often simultaneously activate paired muscles (Dyer et al., 2011) but is helpful in maintaining control of the knee and hip joints which could transpire into higher ambulatory function (Ma et al., 2017).

Whilst assessment of co-activation of these muscles is important it is equally important to note changes in activation patterns of the individual muscles. The tibialis anterior muscle is typically recruited biphasically, displaying peak activity during both upwards and downwards phases of the pedal cycle (Chapman et al., 2008). During the pre-intervention assessment the left tibialis anterior was most active during the downwards (0-25%) phase of crank cycle and not the upcycle contrary to identified activation of the right limb which demonstrated the expected activation (da Silva et al., 2016). Therefore, signifying incorrectly timed activation in the paretic limb, a documented characteristic of stroke (Seki et al., 2009). Activation of the right tibialis was typical of the phasic recruitment identified by da Silva et al. (2016) for experienced cyclists and clearly display a short timed burst during the upcycle (75-100% crank cycle). Assessment of the post-intervention signals indicate a reduction in the length of activation of the tibialis anterior in the paretic limb suggesting a learned control of the muscle and potential reduction in muscular spasticity (Ma et al., 2017) contributing to increased power output.

The participant displayed characteristics typical of normal activation for the rectus femoris and this was most refined on the right side. Whilst cycling, the rectus femoris produces two distinctive and similar bursts during the first and last 25% (between 0-90^{o} and 270 - 0^{o} See Figure 5.3) of the crank cycle, active primarily during hip flexion and extension (da Silva et al., 2016). Both assessments of the right limb clearly show this. Evaluation of the left shows that the muscle is most active during the last 25% of the pre-intervention generating substantially larger magnitudes. Post-intervention analysis revealed a much lesser difference suggesting that over the 8-week intervention the paretic rectus femoris became more co-ordinated. As we were unable to ascertain that muscle strength increased over the intervention it is possible to suggest that an increase in ambulatory function and power balance could be a result of this more refined muscle activation required for walking (Hugues et al., 2017). However, as the participant did not complete the cycling intervention, a lesser difference is not a result of the eBike use.

Previous findings suggest the gastrocnemius muscle is recruited either during the downstroke (0-50%) (Gregor et al., 1991) or upstroke (50-100%) (Ericson et al., 1985). Chapman et al. (2006) identified inconsistencies with these methods and identified that the muscle is active during both phases of the pedal cycle with period of inactivity at top and bottom centre as the muscle contributes to flexion of the knee. sEMG activation pattern obtained from the pre-intervention assessment identified that the paretic and non-paretic gastrocnemius muscles was most active between 0-75% of the crank cycle indicative of activation of the gastrocnemius lateralis concluding that the muscle is active throughout the crank cycle and silent at top dead centre in support of findings. At post-intervention the paretic gastrocnemius was increasingly active throughout the crank cycle whilst the non-paretic activation pattern remained relatively unchanged. It is important to note, however that the non-paretic %MVIC was comparatively higher that the paretic identifying a higher level of activation.

Finally assessment of the bicep femoris identified the expected level of activation, during the upwards phase of the cycle (270 - 0^{o} of the crank cycle) (Roy et al., 2018). Muscle activation was more sustained typical of an unskilled cyclist (Ma et al., 2017) and this remained constant at post-intervention. There is a clear difference in activation between the pre and post non-paretic bicep femoris but high variability in sEMG activity. This points towards possible crosstalk of nearby muscles. sEMG sensors placement was done correctly in accordance to SENIAM guidelines reducing the chance of sensor misplacement.

This participant exhibited physiological and biomechanical symptoms of stroke which changed over the 8-week intervention, despite not using the eBike. The participant was retained in the study to assess the case study results and to ascertain the entire impact of the eBike intervention providing us with an opportunity to reflect upon the impact of post-stroke conditions in the trial.

Notable changes were observed in the muscle activity of paretic rectus femoris and gastrocnemius and the non-paretic bicep femoris which could equate to improvements in ambulatory function. These improvements cannot be interrelated to the eBike intervention but could be associated with a learning response. At post intervention the participant would have been more aware of the protocol at hand and this would result in a higher performance. Future research could adjust for this by including a familiarisation session prior to the pre intervention assessment. Furthermore, the participant developed new medical concerns during the trial and the impact of these on results was not wholly assessed. Extra care should therefore be taken to identify the impact that medication can have on results.

5.2 PARTICIPANT TWO CASE REVIEW

5.2.1 CLINICAL DESCRIPTION

Participant two was a 51 year old male who had a mass of 94.6kg and stature of 1.83m. He had severe right-side deficiencies following a stroke 102 months prior to the study. The participant initially suffered a left side ischemic stroke and whilst recovering suffered an additional left side haemorrhagic stroke. The combination of both strokes left the participant with a speech impediment (aphasia) and hypertonicity in his right side. The participant's mobility was hampered as a result of permanent right foot inversion and poor ankle mobility and he therefore relied on the use of a walking aid to ambulate. The participant was classified as 2 on the functional ambulatory category classification requiring 'intermittent support from 1 person to help with balance' and relied on his wife for support with daily activities. Prior to suffering his stroke, the participant was working a respectable fulltime job and he regularly ventured out on his motorbike.

5.2.2 INTERVENTION AND ADHERANCE

The participant was provided with a three-wheeled eTrike with a right-side boot attachment with ankle support. The boot attachment replaced the pedal and assisted with supporting the participant's paretic foot in a fixed position throughout the cycle, so that he would not slip off the pedal and onto the chain or frame (See Figure 4.3a). Despite hypertonicity on his right side, the participant was able to place his right hand on the handlebar but primarily steered and controlled the bike with his left hand/arm. The participant completed both pre and post-intervention assessment and regularly used his eTrike during the intervention period (Appendix Figure 8).

5.2.1 RESULTS

The participant cycled a total of 18 times over the 8-week intervention, completing a total distance of 45.7 miles (See Figure 5.5). The participants' confidence and rate of perceived exertion varied throughout the intervention but in general his confidence remained above 8 and RPE remained above 11 (See Figure 5.4).

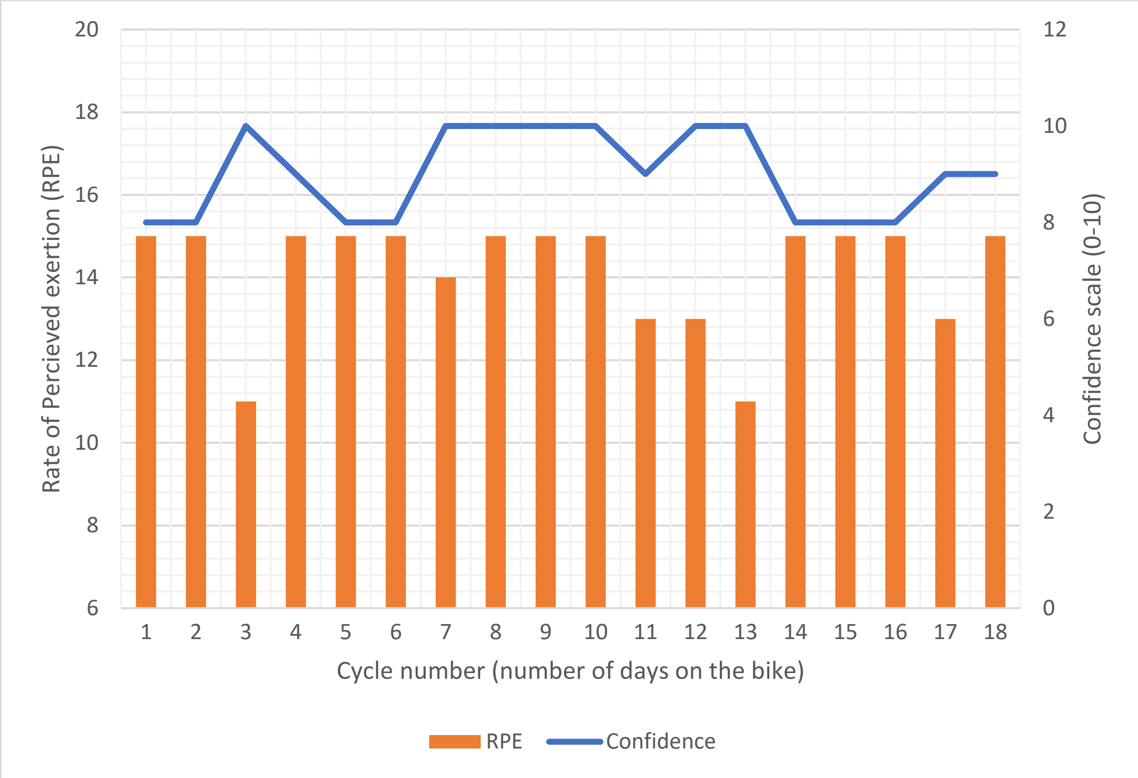


Figure 5.4: Participant Two's self-reported confidence and Rate of Perceived Exertion (RPE) over the duration of the intervention. Reported as days cycled.

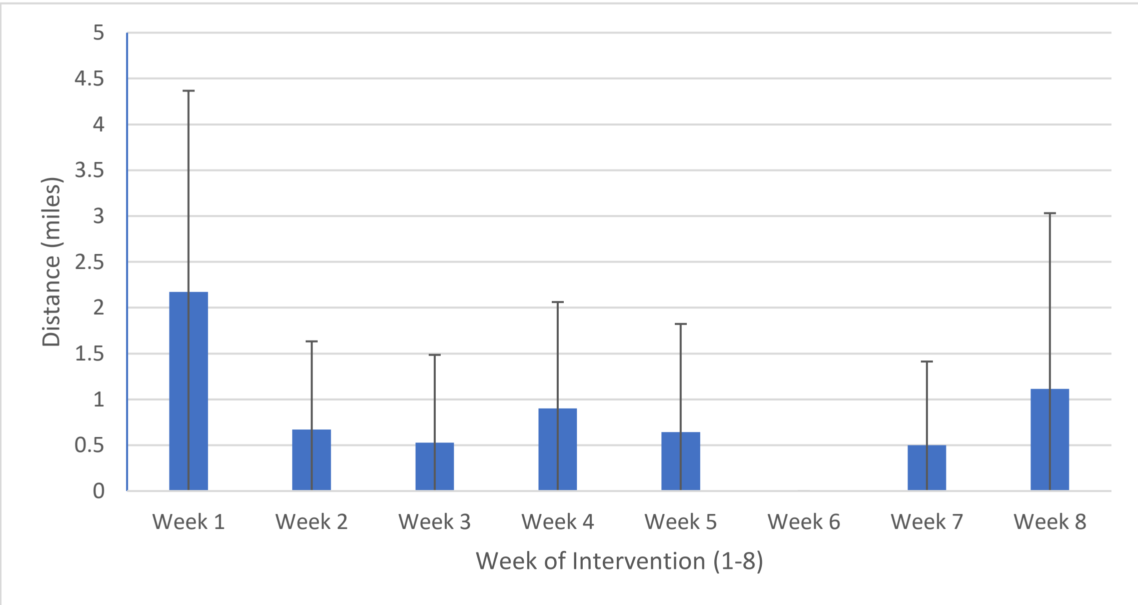


Figure 5.5: Participant Two's weekly recorded cycling distance (mean with standard deviation), taken from the cycle diary collected recorded throughout the intervention

All rides during the intervention were used for exercise and despite the participant's wife assisting him with getting onto the bike and securing his foot into the boot, he completed all the rides independently. In total the participant spent approximately 8 hours and 45 minutes using his electric trike, burning an average of 90.77 ± 85.71 calories per ride and achieving an average heart rate of 86 ± 26 Beats.min^{-1}.

The participant had high blood pressure both pre and post-intervention (pre 145/97 mmHg, post 140/95 mmHg), though a small reduction in blood pressure was observed at post-intervention. His resting heart rate was also higher at pre-intervention (75 Beats.min^{-1}) compared to post (70 Beats.min^{-1}).

The participant was unable to complete the pre-intervention data collection cycle exercise test as a result of his physical mobility limitations and right sided hypertonicity, which resulted in his paretic foot repeatedly hitting the stationary Wattbike frame. He was, however, able to complete all tasks during the post-intervention assessment (See Table 5.4).

Table 5.2: Participant two's post intervention Cycling performance data

Outcome measure	Post-intervention
Mean heart rate (Beats.min^{-1}).	60 (35% max HR)
Maximum heart rate (Beats.min^{-1}).	95
Mean power (W_{mean})	32
Maximum power (W_{max})	45
Mean cadence (revs.min^{-1})	49
Maximum cadence (revs.min^{-1})	54
Percentage left balance	100
Percentage right balance	0
Left power phase (°)	1 – 207°
Right power phase (°)	-
Left peak power phase (°)	58 – 117°
Right peak power phase (°)	-

Figure 5.6: Participant two's between limb power phases comparison, including peak power phases recorded at Post intervention

The participant applied all force during the cycle through his left pedal displayed as 100% left balance, this manifested in the right pedal not collecting power phase data (See Figure 5.6). Pre and Post-intervention cycling sEMG signals were normalised (Appendix Figure 6) and presented as %MVIC. The graphs below represent the sEMG muscle electrical activity throughout the crank cycle (Figure 5.7)

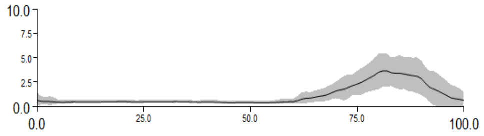
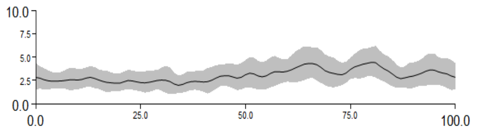
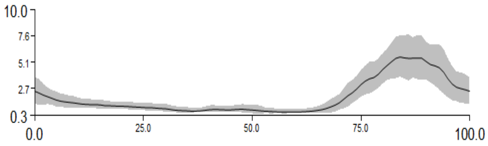
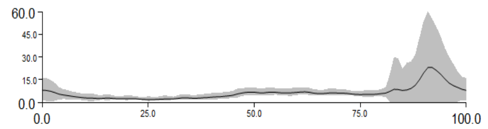
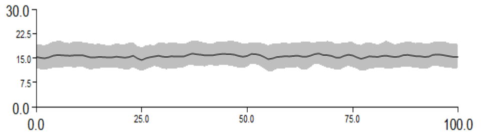
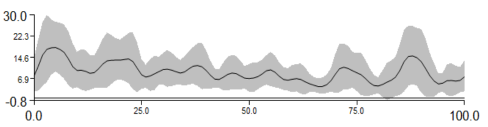
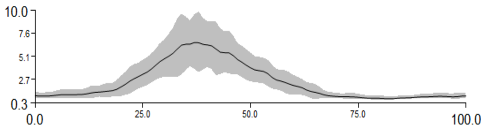
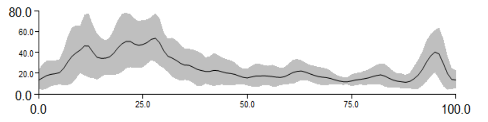
	Left limb muscle sEMG	Right limb muscle sEMG
Tibialis anterior (TA)		
Rectus femoris (RF)		
Gastrocnemius (GC)		
Bicep femoris (BF)		

Figure 5.7: Participant two's, Post intervention limb comparison of mean and standard deviation sEMG. Normalised to % MVIC over the duration of the pedal cycle. Where 0 is top dead centre and 50 is bottom dead centre on the X axis (Appendix figure 14).

The participant's ambulatory function was assessed over a 10 metre walk test (See Table 5.6) and he completed the pre-intervention assessment without the use of walking aid. However, as a result of a recent fall at home, unrelated to the study, the participant felt more confident using an aid for the post-intervention assessment. The individual's mobility function therefore did not improve and no clinically important changes (1SEM) were observed.

Table 5.3: Participant two's 10 metre walk test (10MWT) (mean ± standard deviation)

	Pre-intervention	Post-intervention
Time taken (s)	16.793 ± 0.326 (*0.188)	17.010 ± 0.511
Speed (ms^{-1})	0.595 ± 0.011 (*0.006)	0.588 ± 0.017

*1SEM

Results from the additional paired samples T-test conducted to compare differences in muscle blood oxygenation identified significant difference in SmO_2 a between the paretic limb (35.306 ± 2.222) and non-paretic limbs (50.096 ± 1.237); $t(61) = 62.137$, $p<0.05$ (See Appendix 7). These results suggest that SmO_2 levels are higher in the non-paretic limb than the paretic.

5.2.1 CASE DISCUSSION

Participant two completed both pre and post-intervention assessments and completed the entire intervention period. This participant suffered with mobility issues which initially rated him low on the ambulatory function scale and resulted in an inability to complete the pre-intervention cycle ergometry task. On returning for the post-intervention assessment he was able to complete all aspects of the intervention assessment, including the cycling task. There is a lack of quantitative data available from the cycle exercise task available to compare and identify levels of improvement. However, the fact he was able to complete the entire assessment, after taking part in the intervention, identifies a substantial improvement in ability and can confidently suggest that the intervention was of benefitted to this participant. Both the participant and his wife were amazed by his progress and expressed excitement about the future impact of regaining physical activity through eBiking.

Participant two had high blood pressure during both pre and post-intervention assessments remaining in the high-risk category identified by the American Heart Assocation (2017). Reductions in systolic and diastolic blood pressures were observed and values matched baseline figures stated by Moore et al. (2015). The intervention produced short-term improvements in the blood pressure which have been proven to reduce the relative risk of stroke (Moore et al., 2015). In this case the study also identified a reduction in resting heart rate after the intervention, and like blood pressure, resting heart rate (RHR) inversely affects cardiovascular risk and mortality. This identified decrease is supported by the work of Ofori et al. (2019) and Bateman et al. (2001) who acknowledged that cycle ergometer training significantly decreased heart rate and blood pressure. Producing encouraging results which support the application of eBikes into rehabilitation and endorsing its application to improve cardiovascular fitness.

At post-intervention the participant was able to partake in the cycle ergometer task and a reliance on his left limb (non-paretic) was identified. Hunnicutt et al. (2016) identified that reduced power output in the paretic limb can affect an individual's functional ability and in this case the participant showed clear power deficits. This information combined with evidence that the participants' walking was severely affected by his stroke contributes to the conclusion that his low ambulatory function was as a result of diminished power in the paretic limb. The participants walking time at pre-intervention (16.79 ± 0.32s) was similar to measurements obtained by Lee et al. (2012) for subacute stroke patients and assessment of specific muscles identified activation impairments between the lower limbs muscles. Although results from this thesis cannot identify if this was due to fibre atrophy (Horstman et al., 2008) they did show a lack of co-ordinated and appropriately timed muscle activity suggested to be the root cause of muscle weakness by Prado-Medeiros et al. (2012). Unfortunately, the participant had a fall a week prior to coming in for post-intervention testing and although this was unrelated to the study, he felt less confident walking and used a walking stick to complete his post-intervention 10MWT. This resulted in slower ambulatory speed and walking time presented in table 5.6 contradictory of our hypothesis.

Alves-Pinto et al. (2016) identified expected co-ordinated activation between specific muscles in healthy participants and evaluation of this participant showed co-ordinated activation of the rectus femoris and bicep femoris in the left (non-paretic) limb that was not detectable in the right. Large error distribution indicates that sEMG activation between crank cycle was not similar and demonstrates a deficit in muscle activation regulation (Roy et al., 2018) which could have resulted in a lack of co-ordination. Co-ordinated activation of muscles is required for activities like walking and this discovery reiterates that co-ordination and activation deficits are the likely cause of the participant's poor ambulatory function and motor control (Chen et al., 2005)

As stated, this suffered severe right deficiencies which maybe an effect of inappropriate muscle activation in their paretic limb. The left tibialis anterior activated phasically as reported by Chapman et al. (2008) but no clear activation pattern was visible in the paretic muscle as a result of muscle spasticity (Ma et al., 2017). The tibialis anterior muscle is primarily responsible for ankle dorsiflexion and an absence of noteworthy change in magnitude of %MVIC demonstrates a lack of ability to generate controlled muscle force, this could additionally explain why the participant struggles to ambulate independently and maybe the root cause for the mobility deficit. Assessment of the rectus femoris identified a vague activation pattern typical of a healthy individual (da Silva et al., 2016), but high margins of error in activation of this muscle evidence variability in the rectus femoris and the heightened %MVIC signposts higher magnitude of activation due to more electrical activity. Abnormal sharp maxima values also observed in the paretic rectus femoris muscle can be indicative of abnormal activation and hypertonicity which is commonly presented with continual muscle tension (Roy et al., 2018)

Unfortunately, results cannot by reliably assessed for differences in sEMG activity of the gastrocnemius as no signal was detected for the left (non-paretic) gastrocnemius. sEMG signals are affected by skin impedance and muscle interference if placed incorrectly, which manifests in an interference pattern. In this instance there is no visible interference pattern or a sudden increase in amplitude, suggesting a fault with data collection from the sensor. Fortunately this was not the case for the paretic limb, which was constantly active throughout the cycle displaying constant activation indicative of muscle spasticity (Ma et al., 2017). Finally, assessment of the left bicep femoris acknowledged activation during the downwards phase of the pedal cycle. Whilst sustained activation during the up and downward phases were identified in right bicep femoris. Again, this activation pattern was abnormal when compared to the work of Roy et al. (2018) but doesn't appear unusual when compared to the other muscles impaired activity and when taking into consideration stroke impairs muscle timing. Signals obtained from this participant also show higher normalised %MVIC in the paretic limb compared to the non-paretic in all muscles. Winzeler-Mercay & Mudie (2002) suggested that this marked increase in paretic activity is a result of increased motor unit recruitment following stroke-induced depression in motor unit firing rate. This study is unable to conclude these suggestions, but this could substantiate why stroke survivors paretic limbs fatigue faster.

This biomechanical effects of an eBike intervention could not be assessed thoroughly for this participant as he was unable to complete the pre-intervention assessment. However, changes in cardiovascular function partially support the hypothesis that eBike cycling could induce changes. The mere fact that the participant was unable to complete the pre-intervention assessment but did post-intervention also provides evidence to suggest that the intervention assisted with his mobility concerns and reduced the impact of his stroke, although specifics cannot be provided. The participant used the eBike confidently and did not report any falls, he became more physically active and reported enjoyment using the eBike. No empirical information was collected regarding his emotional state, but this could be explored in future research.

This participant would not have had access to an eBike if he had not taken part in the study and used it solely for leisure. It gave him a new lease of life and his wife was supportive of him cycling independently. The intervention was successful in providing the participant with a new physical activity regime which he thoroughly enjoyed.

5.3 PARTICIPANT THREE CASE REVIEW

5.3.1 CLINICAL DESCRIPTION

Participant three was a 69 year old male with a mass of 87.8kg and stature of 1.77m. He had suffered a left side ischaemic stroke which resulted in slight right sided weakness. The participant did not rely on the use of a walking aid or assistance from others, rating 5 in the functional ambulation categories (See Table 4.2). Prior to his stroke the participant regularly cycled long distances with his wife and was a very active individual. His slight right sided weakness did not affect daily life, but he detailed that he sometimes felt unstable placing all his weight on his right side. The participant also suffered from mild aphasia as a result of his stroke which affected his speech and ability to process and respond to verbal information.

5.3.2 INTERVENTION AND ADHERANCE

The participant was provided with a two wheeled eBike with no modifications. He was very comfortable on the bike and competent cycling around the car park during his trial. The participant only completed the pre-intervention testing and withdrew from the intervention within 2 days of starting, as a result of a fall from the eBike. He was offered an alternative eTrike to support his continued involvement but felt this was not conducive to his physical abilities. The participant did not adhere to the intervention as he withdrew from the study.

5.3.3 RESULTS

The participant suffered from high blood pressure at pre-intervention (147/78 mmHg) but exhibited a low resting heart rate (47 Beats.min^{-1}). The participant successfully completed the cycle task for pre-intervention (See Table 5.7) and knowing that he suffered from right sided deficiencies he exerted more power, for longer, on his right side resulting in a higher right side % balance (56%) (See Figure 5.8)

Table 5.4: Participant three's pre intervention cycling performance data

Outcome measure	Pre-intervention
Mean heart rate (Beats.min^{-1}).	85 (53% max HR)
Maximum heart rate (Beats.min^{-1}).	112
Mean power (W_{mean})	130
Maximum power (W_{max})	163
Mean cadence (revs.min^{-1})	74
Maximum cadence (revs.min^{-1})	79
Percentage left balance	44
Percentage right balance	56
Left power phase (°)	13-197 (184)
Right power phase (°)	6- 207 (201)
Left peak power phase (°)	70-120 (50)
Right peak power phase (°)	70 – 124 (54)

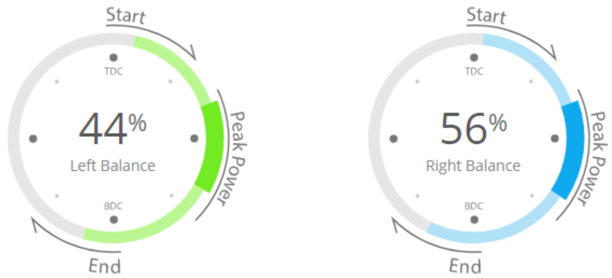


Figure 5.8: Participant three's between limb pre-intervention power phases, including peak power phases

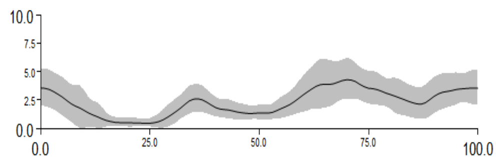
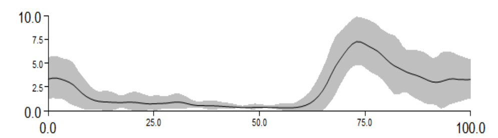
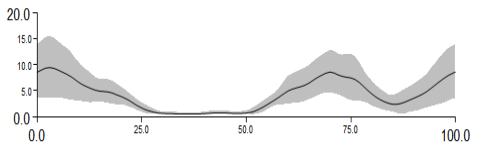
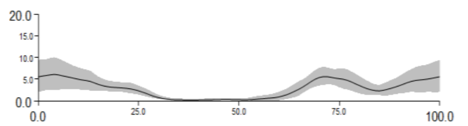
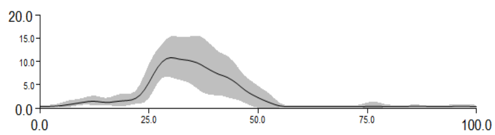
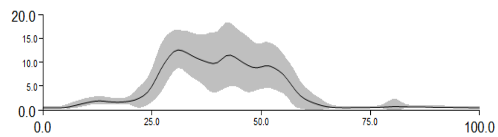
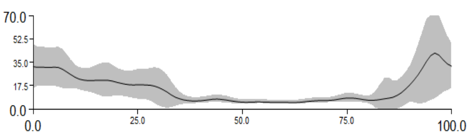
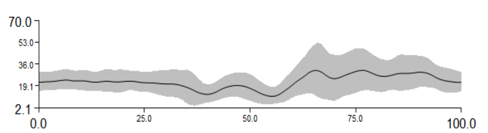
	Left limb muscle sEMG	Right limb muscle sEMG
Tibialis anterior (TA)		
Rectus femoris (RF)		
Gastrocnemius (GC)		
Bicep femoris (BF)		

Figure 5.9: Participant three, Pre-intervention mean and standard deviation sEMG normalised to % MVIC over the duration of the pedal cycle. Where 0 is top dead centre (Appendix Figure 15)

The participant's ambulatory function was assessed over a 10MWT and he could ambulate confidently without use of a walking aid and did so for the pre-intervention assessment. The participant completed the 10MWT in an average time of 8.585 ± 0.162 seconds and an average speed of 1.165 ± 0.021 ms^{-1}.

A paired samples T-test was conducted to compare differences in muscle blood oxygenation between the paretic (right) limb and non-paretic (left limb). There was no significant difference ($P>0.05$) in SmO_2 levels between the non-paretic limb (60.558 ± 10.508) and paretic limb (60.676 ± 16.429); $t(33) = -0.038$, $p= 0.970$ (Appendix Figure 7) and this result suggests that there is no difference in SmO_2 levels between the paretic and non-paretic limbs for this participant.

5.3.1 CASE DISCUSSION

Participant three attended the pre-intervention assessment but did not complete the intervention or return for post-intervention assessment. Unfortunately, the participant fell from his eBike and although he was offered other modifications did not want to continue with the study. The eBike was adapted to support the participant's involvement and careful consideration was made to provide the participant with enough support required to ease any concerns in accordance with national clinical guidelines of stroke (Royal College of Physicians, 2016a). After suffering from a stroke, individuals face more barriers to participation and have elevated concerns about falling and balance. Simpson et al. (2011) identified these safety concerns and the fact this participant did fall from this bike identifies the true risks involved in eBiking. Although the participant was a confident cyclist prior to his stroke, completing approximately 50 miles a day. He did fall from his bike early in the intervention, he reported that this knocked his confidence in eBiking and resulted in his withdrawal from the study. Identifying a concern with the application of eBiking in stroke rehabilitation.

The participant had high blood pressure at pre-intervention which placed him at heightened risk of stroke recurrence. Comparative studies like the one conducted by Ofori et al., (2019) highlighted the potential for studies like this to reduce blood pressure. The participant had a low resting heart rate, much lower than values stated by Ofori et al., (2019) for stroke survivors and this slow resting heart rate (bradycardia) is unusual in stroke. Low resting heart rate often indicates low blood pressure which was not observed for this participant. Grundvold et al. (2013) identified that this combination of elevated high blood pressure and low heart rate increases the risk of atrial fibrillation, a risk factor for stroke that leads to recurrence. So, the impact of this eBike intervention may have been beneficial in reducing this risk.

Participant three was confident walking and his average ambulatory speed was higher than maximum pace reported by Salbach et al. (2001) (1.05±0.47 ms^{-1}) and Yang et al. (2014) (0.68 ± 0.36 ms^{-1}). This higher walking speed was expected as participants recruited by Salbach et al. (2001) and Yang et al. (2014) had recently suffered their stroke, whereas individuals recruited for the present study were much further along their post stroke recovery. His walking speed was more aligned with comfortable values presented by Betschart et al., (2018) who selected participants with a similar recruitment criterion but specified that individuals should be able to walk independently without aid or orthoses. The application of this specific requirement shows a higher level of ambulatory function than those selected by Yang et al. (2014).

Assessment of the sEMG normalised to the %MVIC revealed that the paretic limb had higher muscle activity compared to the non-paretic limb at pre-intervention and sEMG activity between limbs was asymmetrical in activation. Winzeler-Mercay & Mudie (2002) suggested this marked increase in paretic activity maybe as a result of increased motor unit recruitment in response to a stroke-induced depression in motor unit firing rate, but we are unable to conclude this within the current study. Further research could be conducted to identify differences in muscle unit recruitment between the paretic and non-paretic limbs. Assessment of the pre-intervention sEMG muscle activity similarly identified a lack of synchronised muscle activation in paired muscles identified by Alves-Pinto et al. (2016) and this could be a consequence of poor locomotor control, signifying deficits in muscle activation and regulation supported by Prado-Medeiros et al. (2012).

Participant three suffered a left sided stroke which left him with slight right sided weakness. sEMG signal analysis from the cycle shows clear activation during the upcycle phase in the right (paretic) tibialis anterior suggestive of a more developed cyclist (da Silva et al., 2016). The left limb was constantly active through the crank cycle showing activation patterns identified for novice cyclist (Chapman et al., 2008). This activation suggests that the paretic limb contributes more to the cycle than the non-paretic and may identify why the right limb generated the most power.

A combination of increased %MVIC, larger right-side balance and normal activation in some of the muscles goes to suggest deficits in the left side. This could either be an underlying effect of the stroke or other health conditions that were not disclosed. The participant did not complete the intervention, therefore there is a lack of evidence within this case to assess the physiological and biomechanical impact of the eBike intervention.

5.4 PARTICIPANT FOUR CASE REVIEW

5.4.1 CLINICAL DESCRIPTION

Participant four was a 59 year old male with a mass of 118.5kg and stature of 1.85m who had suffered a right sided stroke leaving him with left sided weakness in his arm and leg. The stroke had additionally affected his speech and mental health, as he reported that he suffered with depression. The participant suffered his stroke 7 months prior to taking part in the study and although he had regained some strength since his stroke he still suffered from numbness on his right side and was unable to get a whole night's sleep. The participant did not require assistance with daily living and did not use a walking aid, rating 5 in functional ambulation '*person can walk independently anywhere*' (Kollen et al., 2006b). He could drive and was very independent, he was undergoing phased entry back into work and wanted to take part in the study because he struggled to motivate himself to go to the gym. The participant attended a local stroke charity and received social support from his wife, who had been very involved in his rehabilitation.

5.4.2 INTERVENTION AND ADHERANCE

The participant was provided with a two-wheeled eBike with no modifications. He could maintain his foot on the pedal and able to place both hands on the handlebars. He successfully completed the intervention, regularly using the eBike and attend all laboratory assessments within the study.

5.4.1 RESULTS

The participant was able to cycle for at least once a day, for 40 days over the 8 week intervention, completing a total distance of 290.65 miles (See Figure 5.11). He felt confident on the eBike, ranking 39 of his cycles 10/10 on the confidence scale, cycling with a perceived exertion of 10 ± 2 (BORG RPE scale) (See Figure 5.10). He used the eBike for pleasure (82.5%), social trips (15%) and for fun (2.5%), completing 24 of his trips independently and the remaining 16 with his wife. The participant spent approximately 32 hours and 40 minutes on the bike burning an average of 260.24 ± 119.13 calories and achieving an average heart rate of 95 ± 14 Beats.min^{-1} (Appendix Figure 9).

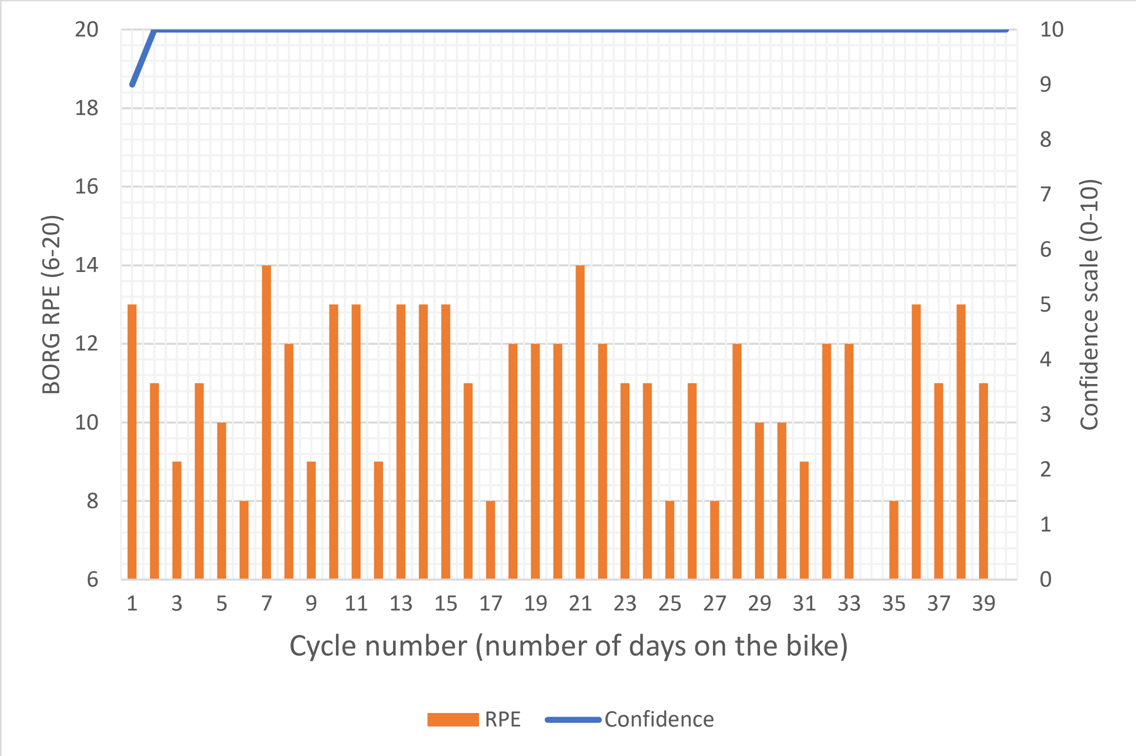


Figure 5.10: Participant four's self-reported Confidence and Rate of perceived exertion (RPE) over the duration of the intervention. Reported as days cycled.

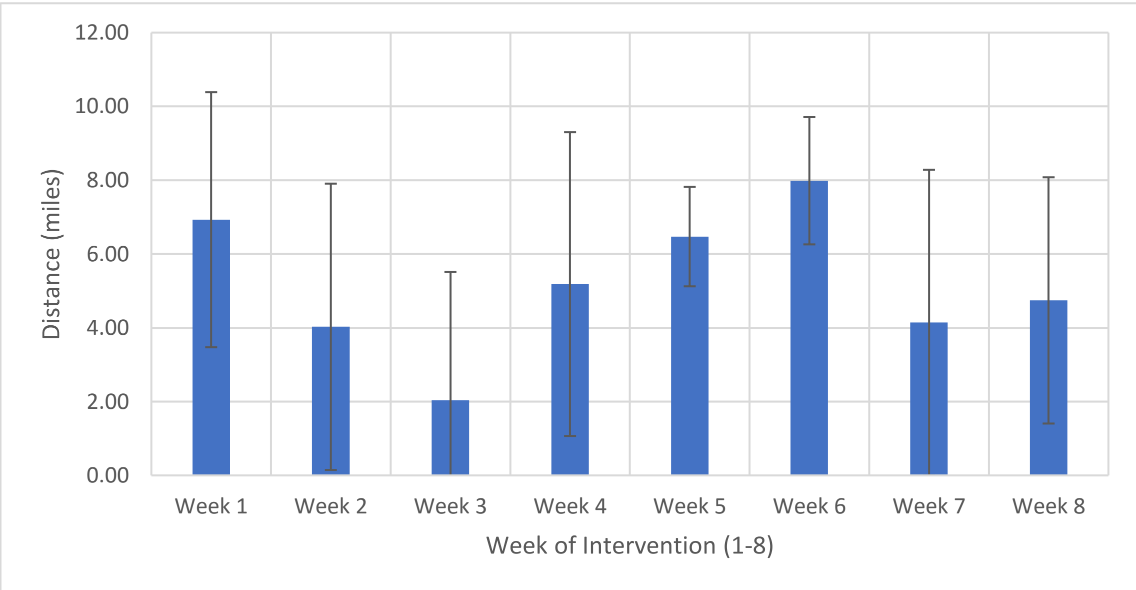


Figure 5.11 Participant four's weekly recorded cycling distance (mean with standard deviation), taken from the cycle diary recorded throughout the intervention.

The participant suffered from high blood pressure at pre-intervention (130/91 mmHg) and a decrease in blood pressure was observed at post-intervention (123/88 mmHg). The participant resting heart rate remained consistent at pre and post-intervention (81, 82 Beats.min^{-1} respectively).

The participant completed the post-intervention cycle at a higher mean (77 revs.min^{-1}) and peak cadence (83 revs.min^{-1}) than pre-intervention (average: 63 revs.min^{-1}/ peak: 72 revs.min^{-1}). The participant's mean heart rate was much higher at post-intervention as a result of maintaining this higher cadence and exertion (Table 5.9).

Table 5.5: Participant four pre and post intervention cycling performance data

Outcome measure	Pre-intervention	Post-intervention
Mean heart rate (Beats.min^{-1}).	70 (41% max HR)	133 (80% max HR)
Maximum heart rate (Beats.min^{-1}).	118	164
Mean power (W_{mean})	159	127
Maximum power (W_{max})	221	188
Mean cadence (revs.min^{-1})	63	77
Maximum cadence (revs.min^{-1})	72	83
Percentage left balance	45	47
Percentage right balance	55	53
Left power phase (°)	7 – 201 (194)	13-203 (190)
Right power phase (°)	357 – 217 (218)	14 – 200 (186)
Left peak power phase (°)	62 – 117 (55)	68 – 118 (51)
Right peak power phase (°)	53-108 (55)	68 – 118 (51)

The participant displayed expected left limb deficiencies during the cycle ergometry tasks, identified through differences between the left and right side % power balance (See Figure 5.12). The difference between the two limbs was greater at pre-intervention (11%) than post-intervention (6%). A shift is also identified in the length of the power phase (See Table 5.9) as both sides post-intervention exert power over a similar angular range.

A)

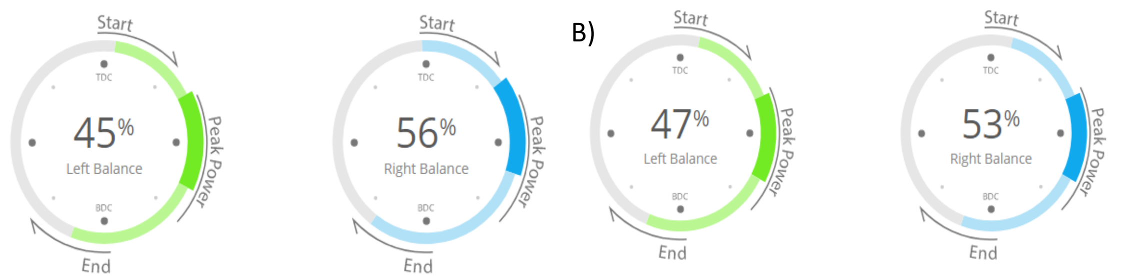


Figure 5.12: Participant four's between limb power phases comparison, including peak power phases taken at: A) Pre intervention, B) Post intervention

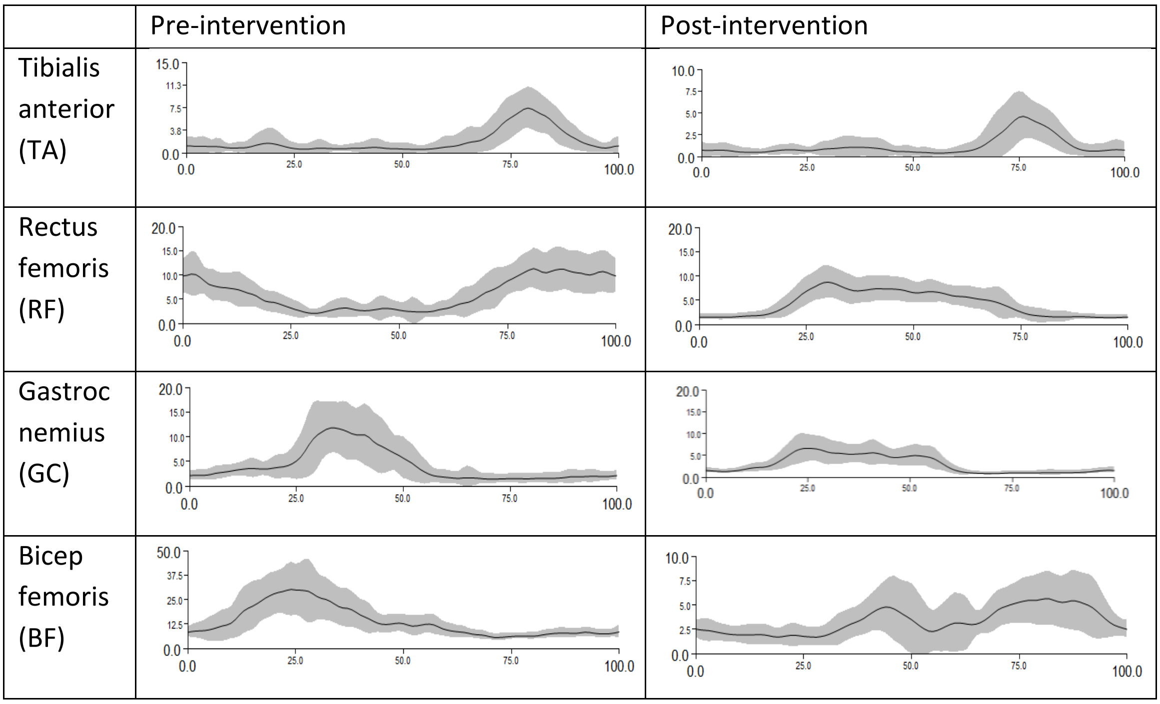


Figure 5.13: Participant four's, Pre and Post intervention left limb comparisons of mean and standard deviation sEMG. Normalised to % MVIC over the duration of the pedal cycle. Where 0 is top dead centre and 50 is bottom dead centre on the X axis (Appendix figure 16).

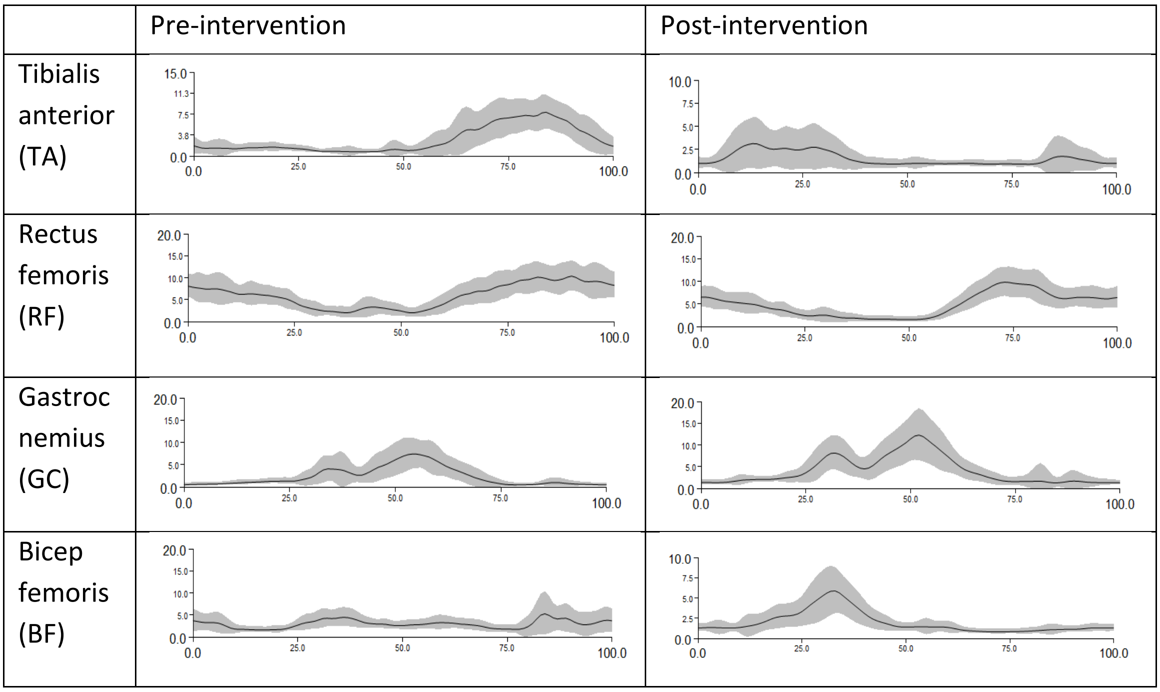


Figure 5.14: Participant four's, Pre and Post intervention right limb comparisons of mean and standard deviation sEMG. Normalised to % MVIC over the duration of the pedal cycle. Where 0 is top dead centre and 50 is bottom dead centre on the X axis (Appendix Figure 17).

The participant's ambulatory function was assessed over a 10MWT. He didn't require assistance with his walking and his ambulatory function improved by 1.396 seconds over the 8 week intervention; recording walking times of 8.643± 0.313s at pre-intervention and 7.246± 0.222s at post-intervention. The improvement exceeded the clinically important differences (CID) calculated for time and speed (0.180 and 0.024 respectively) and also exceeded clinical difference identified by Tilson et al. (2010) of 0.160 ms-1

The paired samples T-test identified a significant ($P<0.05$) difference in SmO2 between the paretic (31.262 ± 2.786) and non-paretic (21.032 ± 1.015) limbs; t (60) = 24.680, $p<0.05$ (Appendix Figure 7). This significant difference indicated a larger volume of SmO2 in the paretic limb.

5.4.1 CASE DISCUSSION

Participant four completed every aspect of the study and reported positive emotional and physical changes in response to the intervention. At the point of recruitment this participant was about to begin a phased entry back to work and explained how he felt it was too early and was anxious about returning. He stated that he suffered from depression and hoped that involvement in the study would create a distraction. During the intervention the participant regularly used the provided eBike cycling both independently and with his wife. He totalled a distance of 290.65 miles over the 8-week intervention and recorded high levels of confidence. When the participant attended the laboratory for his post-intervention assessment, an informal chat was had about his experience, where he stated that he was in the process of purchasing an eBike of his own. The participant had also successfully returned to work and attributes this to the eBike intervention, reporting that he felt better in himself and was now able to sleep through the night. The participant also explained that the constant feeling of cramp had resided from his right leg and stated this in a follow up email; *'The Lasting effect was numbness in right leg and feelings of cramp, which the bike stopped!'*. Although some of these improvements were albeit subjective, findings of this intervention appear to improve this participant's quality of life. In additional the study was not designed to assess psychological improvements, but the participant expressed appreciation for the benefits of using the eBike.

The participant suffered from high blood pressure recorded at both pre and post-intervention and these were similar to baseline measurements recorded by Moore et al. (2015). A 7mmHg reduction in diastolic blood pressure moved the participant out of a 'high risk' classification identified by American Heart Assocation (2017) for blood pressure and into 'high normal'. The diastolic reduction was larger than the 5 mmHg identified by Law et al., (2003) to reduce risk of stroke by approximately 34% indicating that these positive reductions minimise the risk of further stroke, echoing positive changes in cardiovascular fitness presented by Cornelissen & Smart (2013). It can be proposed that the short term eBike intervention contributed to identified reductions in blood pressure and this supports the hypothesis that eBiking may improve cardiovascular fitness. (Furie et al., 2011).

Despite reductions in blood pressure, resting heart rate did not change. Several factors could have influenced this, such as; medication, activity prior to measurement, time of the day and stress. At the time of assessment, the participant was not on any form of medication but had walked to laboratory so his physical activity prior to the assessments could have contributed to his elevated reading

Assessment of this participant's ambulatory function saw improvements in average speed and walking time. The participant was able to ambulate comfortably without the use of a walking aid and achieved higher average walking speeds than those stated by Salbach et al. (2001) and Yang et al. (2014), likely a result of diminished stroke severity. He also completed the test faster than participants studied by Paul et al. (2016). The comparative study assessed participants who were younger than the earlier stated studies but were home dwelling and spent most of their time sedentary. Participant four was within the age bracket analysed but was not sedentary and this correlates with the higher self-selected walking speed. FIVE Calculated improvements in ambulatory function were clinically important (1SEM) and larger than the minimum value of improvement (0.16m/s) identified by Tilson et al. (2010). The participant was beyond the 11 week walking function recovery window suggested by Jorgensen et al. (1995) by still recorded important changes implying improvements are still achievable a result of the eBike intervention. This discovery is supported by the work of Yang et al. (2014) who utilised cycling for stroke rehabilitation, demonstrating that eBikes can generate similar improvements in ambulation as cycling. Further investigation is required to identify the root cause of these improvements; as walking function requires both modulation and activation of muscles to produce power but the improvements do demonstrate possible physiological benefits supporting the hypothesis that eBiking can improve locomotion.

Examination of muscle activity during the cycling tasks identify changes in limb activity which contribute to the improved ambulatory capacity and change in power balance. The participant detailed that the stroke created a left sided muscle weakness but also identified cramping and numbness in his right (non-paretic) leg. This weakness was recognised as an imbalance in power generation, concluding that the participant generated more power through his right limb which could attenuate injury (Kell & Greer, 2017). Comparison of this increased right-side power to the left identifies that power was generated over a longer phase and applied earlier in the crank cycle, supporting a right sided reliance. At post-intervention this power balance difference was smaller, but the participant still generated most of his power through his right side. Increased power generation in the left limb was emulated by changes in the power phases which revealed that the left power phase lasted longer. Aaron et al. (2017) identified that muscle training could improve power generation and these results reflect a positive increase in power suggesting that the eBike intervention was successful in balancing power output generating similar effects to muscle training.

Throughout the pre-intervention assessment the participant exhibited normal activation of the rectus femoris in both the paretic and non-paretic limbs producing two distinctive bursts during the first and last 25% (0-90^{o} and 270 - 0^{o}) of the crank cycle (da Silva et al., 2016). At post-intervention a change activation was detected as the left (paretic) limb is least active at the expected periods of the cycle. This shift in activation contradicts improvements identified in activation pattern of the tibialis anterior and ambulation, suggestive of incorrect sensor placement and crosstalk between other muscles. Comparison of muscle activity between pre and post-intervention of the tibialis anterior indicates improvements in muscle control as it is recruited biphasically after the intervention (da Silva et al., 2016). Higher variability in sEMG activity does indicate a level of variability between crank cycles but Seki et al. (2009) identified this is common in stroke due to a lack of efficient activation

Changes are also observed between the pre and post gastrocnemius on the paretic side indicating enhanced muscle control. Gregor et al. (1991) posed that the gastrocnemius is most active during the down stroke of the cycle and pre-intervention assessment of the left muscle shows this. However, Chapman et al. (2006) identified issues with Gregor et al. (1991) assessments and further suggested that the gastrocnemius is active throughout, with moments of inactivity around bottom dead centre. At post-intervention this was seen. Further suggesting that the eBike intervention did alter muscle activation. Evaluation of the right gastrocnemius during pre and post-intervention clearly displays patterns suggested by Chapman et al. (2006) confirming that the right limb was unaffected by the stroke, exhibiting correctly timed activation. Larger changes in magnitude were observed in this muscle magnitude typical of trained cyclist promoting application of the eBike intervention.

The eBike intervention also improved synchronisation of muscle activation in some paired muscles (Alves-Pinto et al., 2016) as positive changes in muscle co-activation characteristic of healthy participants was observed. Enhanced co-ordination ultimately improves locomotor control and confirms a level of muscle regulation which attributes to higher ambulatory functional observed at post-intervention.

The combination of improved ambulatory function, balanced power output and changes in muscle co-ordination with reductions in blood pressure; supports the hypothesis that eBiking was successful for this participant. Suggesting that its application was reasonable in promoting rehabilitation and evidences its use for future research.

5.5 PARTICIPANT FIVE CASE REVIEW

5.5.1 CLINICAL DESCRIPTION

Participant five was a 47 year old male with a mass of 87.6kg and stature of 1.86m. He had suffered a left side haemorrhagic stroke 122 months before commencing that study which had resulted in severe right sided weakness and speech deficits. The participant was unable to use his right arm as a result of hypertonicity and struggled with limited mobility. The participant did not rely on the use of a walking aid but had some support at home from his son, identifying him as 3, 'person requires verbal supervision or stand-by held from 1 person without physical contact' in the functional ambulation categories. Prior to his stroke the participant had a steady job and was helping to raise his young family.

5.5.2 INTERVENTION AND ADHERANCE

The participant was provided with a three wheeled eTrike which was fitted with a right boot attachment to secure his right foot onto the pedal. The participant was unable to place his arm on the right handlebar but was comfortable controlling the bike with his left arm so all controls; brakes, gears and power assistance were moved onto the left handlebar. The participant only completed pre-intervention testing and withdrew from the intervention within 5 days, as a result of a fall from the eTrike, he therefore did not adhere with the intervention.

5.5.3 RESULTS

The participant had high blood pressure at pre-intervention (135/87 mmHg) and resting heart rate of 63 Beats.min^{-1}). The participant successfully completed the cycle task for pre-intervention despite having severe right-side mobility issues (See Table 5.12). The participant exerted 88% of his power through his left (non-paretic) limb and 12% through the right whilst power phase and peak power phases in the right limb reportedly lasted longer.

Table 5.6: Participant five's pre intervention cycling performance data

Outcome measure	Pre-intervention
Mean heart rate (Beats.min^{-1}).	89 (50% max HR)
Maximum heart rate (Beats.min^{-1}).	116
Mean power (W_{mean})	119
Maximum power (W_{max})	181
Mean cadence (revs.min^{-1})	58
Maximum cadence (revs.min^{-1})	64
Percentage left balance	88
Percentage right balance	12
Left power phase (°)	1-185 (184)
Right power phase (°)	348 – 198 (210)
Left peak power phase (°)	59 – 110 (51)
Right peak power phase (°)	50 – 107 (57)

Figure 5.15: Participant fives's between limb power phases comparison, including peak power phases taken at Pre intervention

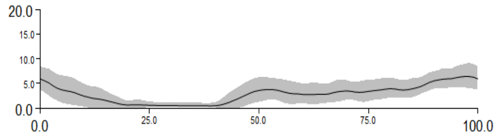
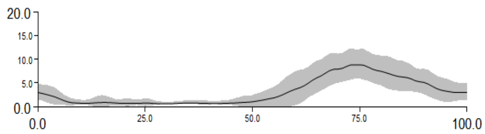
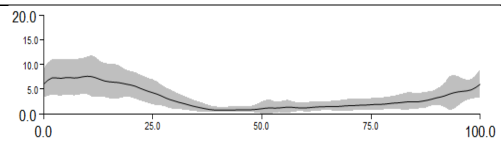
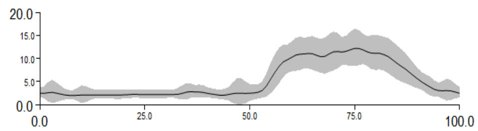
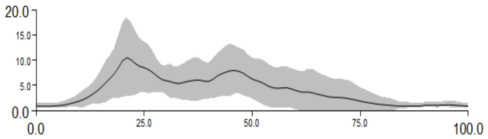
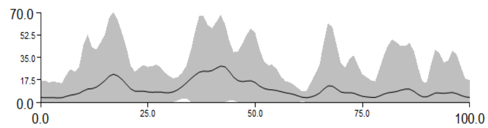
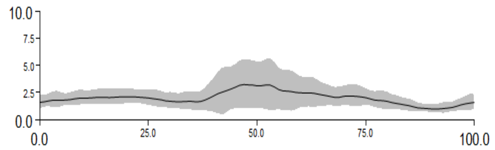
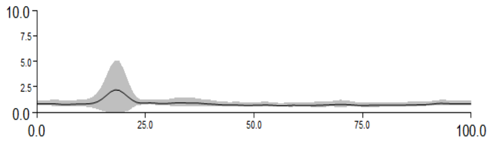
	Left limb muscle sEMG	Right limb muscle sEMG
Tibialis anterior (TA)		
Rectus femoris (RF)		
Gastroc nemius (GC)		
Bicep femoris (BF)		

Figure 5.16: Participant fives's, Pre-intervention limb comparisons of mean and standard deviation sEMG. Normalised to % MVIC over the duration of the pedal cycle. Where 0 is top dead centre and 50 is bottom dead centre on the X axis (Appendix figure 18).

Ambulatory function was assessed over a 10MWT. The participant did the assessment without use of a walking aid completing the task with an average time of 9.05 ± 0.38 seconds and speed of 1.10 ± 0.04 ms^{-1}. A paired samples T-test was additionally conducted to compare differences in muscle oxygenation between the paretic (right) limb and non-paretic (left) limb. There was a significant difference ($P<0.05$) in SmO_2 levels between limbs $t(60) = -62.024$, $p<0.05$ (Appendix Figure 7). Identifying a higher concertation of SmO_2 in the paretic limb.

5.5.1 CASE DISCUSSION

Participant five attended the physiology lab for all pre-intervention assessments but was unable to complete the intervention and subsequently did not attend for the post-intervention assessments. The participant was provided with a suitably modified eBike but withdrew very early on in the intervention following a couple of falls from the eBike. The participant independently volunteered for the research and attended all the assessments alone. Research into barriers and enabler of stroke highlights the importance of social support into rehabilitative care and its positive impact on completing exercise interventions. This participant appeared socially isolated with 'three or fewer' people that he could rely upon. This social isolation worsens risk factors by decreasing participation in physical activity (Boden-Albala et al., 2005) and could have contributed to this participant's withdrawal.

The participant had high blood pressure which matched baseline measurements recorded by Moore et al. (2015). As the leading modifiable risk for stroke, the identified high blood pressure placed the participant at high risk of secondary stroke and reduced the chance of good recovery (Ishitsuka et al., 2014). A combination of this and low RHR also placed him at risk of atrial fibrillation (Grundvold et al., 2013).

Analysis of sEMG activation was unsuccessful in identify muscle co-ordination between paired muscles typical of healthy participants (Alves-Pinto et al., 2016). Simultaneous activation of paired muscles, a common effect of stroke, is suggestive of poor ambulatory function (Dyer et al., 2011). This participant was however confident ambulating independently completing the 10MWT in less time than subacute stroke survivors recruited by Lee et al. (2012). It could be suggested that he adapted to his limitations as a result of additional post-stroke care but further investigation would be required to identify how he has achieved this.

A difference in power balance supports claims made by Hunnicutt et al. (2016) that stroke hemiparesis affects power generation. A confirmed decrease in power in the right side is substantiated by differences in muscle activation. da Silva et al. (2016) suggested that the tibialis anterior activate biphasically but assessment of the right tibialis anterior shows that the muscle remained active from 50% (180 - 0^o) of the pedal cycle. This sustained contraction is typical of novice untrained cyclists who are unable to recruit muscles efficiently. Near constant activation of the left tibialis anterior could be a response to this uncoordinated activation, providing support throughout the crank cycle. A similar support is provided by the left rectus femoris.

During the intervention the participant was provided with a boot to keep his foot on the pedal during the cycle because he struggled with hip and knee flexion. Assessment of activity in the right gastrocnemius identifies why he struggles so much with this, as the muscle was constantly active showing spasticity in the muscle (Ma et al., 2017) and lack of muscle control.

Findings also revealed that the non-paretic limb displayed lower normalised %MVIC activity compared to the paretic limb. This could be result of higher EMG activation of the non-paretic limb during the MVIC, which the cycles were normalised against. On assessment of the peak EMG values obtained during the MVIC the GC and BF recorded higher levels of activation in the non-paretic limb compared to the paretic and therefore the participant may have recruited a higher proportion of motor units in the paretic limb during the cycle in comparison, but we are unable to confirm this with further research.

This participant did not complete the intervention so the effects of the eBike are unknown. Results confirm that the participant had elevated blood pressure and reduced muscle co-activation associated with stroke. They also confirm his right-side deficit presented through power imbalance.

CHAPTER 6 EPILOGUE

6.1 GENERAL SUMMARY

This investigation is unique as it is the first to report physiological and biomechanical findings on the use of eBikes for stroke rehabilitation. The purpose of this thesis was to establish if an 8-week eBike intervention could promote stroke recovery. Substantial evidence has suggested that similar aerobic exercise can reduce the occurrence of a secondary stroke and improve physical wellbeing. It was anticipated that this eBike intervention would show similar effects. The study's findings may have important clinical implications and could provide evidence that eBiking should be considered for increasing levels of physical activity in stroke survivors.

The prescribed intervention was sufficient in challenging and promoting physiological improvements in some participants. Individuals who took part in the intervention embraced the opportunity to take control of their rehabilitation and progressed from no cycling to cycling between 45.7 and 290.7 miles over the 8-week period. Participants who completed the intervention reported they were confident in using the eBike with specific modifications and rated their perceived exertion between fairly light and somewhat hard. The participants averaged between 60 and 80% of their maximum heart rate during eBike rides supporting the work of Gojanovic et al. (2011), who suggested that eBikes were suitable in achieving moderate intensity exercise. It can therefore be suggested that eBikes can support some post-stroke conditions and facilitate aerobic exercise.

All participants recruited for the study had high blood pressure. High blood pressure is present in 75% of acute stroke survivors (Appleton et al., 2016) and places individuals at heightened risk of stroke reoccurrence and a lower probability of good recovery (Ishitsuka et al., 2014). The eBike intervention lowered systolic and diastolic blood pressure in some participants minimising the risk of further cardiopulmonary conditions and reflecting positive changes in cardiovascular fitness supported by the findings of Cornelissen & Smart (2013). Despite resting heart rate being conducted after period of sitting still and concurrently to blood pressure, only one participant presented with lower resting heart rate after the intervention. Careful consideration needs to be taken when assessing changes in RHR as some stroke survivors, as documented, were prescribed medication to control modifiable risk factors. This could be addressed in future research through alteration of the recruitment criteria.

Gait speed was utilised as a quick and easy method to measure walking disability and assess the effectiveness of the eBike stroke intervention (Kwakkel et al., 2017). At pre-intervention all participants completed the 10 metre walk test (10MWT) task at a comfortable pace without the use of a walking aid. Post-intervention assessment of the one of the participants that completed the intervention showed clinically important improvements (1SEM) in ambulatory function. The Individual was well beyond the 11 weeks walking function recovery window (Jorgensen et al., 1995), but improvements were still recorded. Identification of this improvement in ambulation is a result of the eBike intervention and is supported by the work of Yang et al. (2014). We are unable to categorically conclude that eBike intervention improves ambulatory function as improvements were identified in one participant that had and one that hadn't completed the intervention. However, the identified improvement does suggest that in one instance application of the eBike intervention was successful in improving ambulatory function and demonstrates the physiological benefits of an eBike intervention.

All four of the muscles assessed on each limb were active during the ergometry task and suitably selected for the study. Participants displayed irregular sEMG activation patterns that were not all typical of healthy participants (Roy et al., 2018). These were identified as irregular and sustained typical of unskilled cyclists (Ma et al., 2017). Thorough pre-intervention assessment recognised a lack of defined synchronised muscle co-ordination (Alves-Pinto et al., 2016), indicating deficits in muscle activation and regulation which could result in poor locomotor control. At post-intervention favourable changes in activation were observed in a couple of participants signifying improvements in muscle co-activation that would be expected from healthy participants (Alves-Pinto et al., 2016). Knowledge of this signifies that an eBike intervention promotes muscle activation synchronisation in some paired muscles. Some improvements were also identified in activation patterns of individual muscles. These were individual to each participant, as stroke rehabilitation is unique, and detailed within the case reviews. These Improvements in muscle co-activation and co-ordination promotes the application of eBikes into rehabilitation partially supporting the studies hypothesis.

Power metres identified power differences between paretic and non-paretic limbs. They were used to differentiate limb contribution expanding on research by Janssen et al. (2008). All participants displayed differences in percentage power balance, and this was more apparent in individuals who rated lower in the functional ambulation categories. The observed effects of the eBike suggest that the intervention can be successful in improving power in paretic limbs, reducing the power exerted from the non-paretic limbs and balancing power generation. This study was able to differentiate the contribution of each leg and can confidently conclude that the shift in power balance was an effect of paretic limb training and more efficient muscle recruitment. Further supported by improvements in ambulatory function.

In addition to the main outcome measures, muscle oxygenation was assessed during the pre-intervention cycle task. It was identified that three of the five participants had a significantly larger concentration of SmO_2 in the paretic limb; demonstrating that the paretic muscle relied on glycolytic metabolism to work anaerobically and did not utilise the readily available oxygen as suggested by MasoudiMotlagh et al. (2015). This could explained why survivors tire faster and equate to a reduction in power output on the paretic side. MasoudiMotlagh et al. (2015) did identify that these results could not be generalised for all survivors and it can be confirmed that which wasn't the case for the remaining two participants.

6.2 STRENGTHS TO THESIS

As one of the first studies to provide biomechanical and physiological evidence for the implementation of eBikes into rehabilitation research identified some benefits of its application.

Firstly, as a home-based rehabilitation study, participants were able to use the eBike in a natural setting that they were familiar with; with full flexibility to use the eBike around their schedule. This enabled the participants to take control of their rehabilitation and document their use which has been proven to be effective in previous rehabilitation projects (Jones et al., 2016). Secondly, Individuals were offered the opportunity to improve their physical fitness and provided with an opportunity to access exercise without assistance. This was achieved through assessment of needs and modification of the eBikes to promote involvement as recommended by the NICE guidelines (Dworzynski et al., 2013). In turn this permitted assessment of the eBike intervention on an inclusive range of physical limitations and post-stroke conditions.

The study was also successful in identifying a novel way of comfortably attaining surface sEMG during a maximal voluntary isometric contraction within stroke survivors and produced opportunity for its future application. Maximum Voluntary Isometric Contractions (MVIC) was assessed through combination of manual muscle testing (MMT) and the use of a Theraband. MMT had been shown to provide highly reliable and valuable results as an alternative to the application of an isokinetic dynamometer for the collection MVIC results (Lin et al., 2008) and it was decided not to use the Cybex isokinetic dynamometer for this study as stroke present with mobility limitations that could have been strained. Initial investigatory research conducted by Jakobsen et al. (2012) identified that elastic tubing (similar to a Theraband) induced similar sEMG muscular activity during knee extension when compared to isotonic training. Therefore, the suggestion of utilising a Theraband to apply resistance therefore appeared appropriate and supported. The application of a Theraband within MMT and MVIC assessments was successful in this instance and easy to utilise within this stroke survivor assessment. Its effective use within this research offers an example of application that could be further developed.

Finally, this research adds to the limited research that is currently available on eBikes in healthcare and furthermore the specific application of eBikes into stroke rehabilitation. The research provides the initial biomechanical and physiological evidence for further research into eBikes and identifies individual case studies that can facilitate other methods of rehabilitation. Detailing suitable improvements that could be implemented in future research.

6.3 LIMITATIONS TO THESIS

This study was ultimately restricted by time and recruitment size. As a Master of Science (by research) this study was determined by a one-year deadline and although a similar stroke rehabilitation research topic had been completed at the university, ethical approval was challenging to obtain and altered the intended project timeline. Time of year and forecasted weather also had to be considered for planning the intervention period, as participants were being provided with an outdoor activity. This resulted in delays in the commencement of the intervention until late May and a reduced the intervention period to 8 weeks.

The small sample size limits the studies generalisation and interpretation. The study was initially restricted by funding and resultant access to only 8 eBikes. This did not immediately impact the recruitment process, but it could have been a limiting factor to recruitment. The recruitment process was successful in raising awareness of the research but the number of individuals who were finally recruited was far smaller than those who initially showed interest, and, in most instances, this because potential participants were refused GP permission. GPs were provided with a full information sheet and consent forms, with details to request further information. Despite this some GPS did not seem willing to provide consent; through lack of understanding of fear of being held liable for adverse effects. This resulted in many individuals not having the opportunity to trial the intervention and ultimately responsible for the reduced sample size.

Furthermore, results collected from this study had to be presented as case studies due to limited numbers and eventual withdrawal of some participants. Of the five participants that started the research only three attended the university for post-intervention assessment and of those only two were successful in completing the intervention. Presenting results as in a case review format provided us with the opportunity to present novel findings but restricted representation of population samples and prevented the generation of incidence data (Nissen & Wynn, 2014)

All these limitations impacted the study in some form; but as the aim of the investigation was to conduct initial research into the application of eBikes into rehabilitation, these limitations can be addressed in future research.

6.4 DIRECTIONS FOR FUTURE RESEARCH

Considering that this was a pilot study into eBike application, identified changes in health and reported improvements are encouraging. Application of physical activity into stroke rehabilitation is already encouraged and this novel method of rehabilitation provides an alternative way of taking part in physical activity. The findings of this research could have a positive impact on stroke survivors, healthcare professionals and researchers and the reported findings could be utilised to further develop stroke rehabilitative care. This study paths the way for future research into the physiological impact of eBiking and further large-scale quantitative reports. Furthermore, this research clearly identifies methodological alternatives for assessment of MVIC within stroke survivors and applied recommended assessments for functional walking ability.

6.5 CONCLUSION

It is reasonable to attribute some of the success of individual improvements to the application of eBike as Individuals prior to the intervention were not physically active and were no longer receiving rehabilitation. Application of this research suggests that eBiking can promote physical activity within a stroke population and supports stroke induced limitations. Marked improvements were recorded in ambulatory function and power balance whilst individual changes in muscle co-ordination and activation were recognised in some participants who completed the intervention. The eBike intervention provided individuals with a suitable exercise modality which they would have otherwise not had access to and promoted aerobic exercise whilst reducing risk of a secondary stroke. More in-depth research would be required to ensure that improvements were not as an effect of 'just becoming active' or spontaneity but the importance of identified improvements cannot be dismissed. This pilot study acts as a foundation to further develop methods and investigative variables. Its application can be used as a comparative for future research, whilst encouraging further research into eBike application within stroke

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CHAPTER 8 APPENDICES

Appendix Figure 1:Participant information sheet

All communications should be made to-

Lead tester - Adrienne Day at **acday@uclan.ac.uk**

Principle Investigator – Howard Hurst

School of Sport and wellbeing

Darwin building, DB223

PR1 2HE

Hthurst@uclan.ac.uk

Telephone: +44 (0) 1772 89 3911

The Physiological and Biomechanical effects of a short term e-bikes cycling intervention in Stroke survivors

You are being invited to partake in a study to assess the physical effects of an 8 week eBike intervention in stroke survivors. It is important for you to understand the purpose of the study and what it will involve. Please ensure that you read this entire document in detail and contact us if you have any questions or concerns.

What is the purpose of the study?

This is a funded master's research project being conducted by Adrienne Day, a postgraduate student at the University of Central Lancashire (UCLan), under the supervision of Dr Howard Hurst, Prof. Jim Richards and Dr Louise Connell. The study is being conducted to assess any changes that occur as a result of using an Electric bike over 8 weeks and is being supported by I-cycle electric, an electric bike supplier.

Who is organising the study and has it been reviewed?

The study is being overseen by research staff at UCLan. The research has gained ethical approval from the Research ethics committee, an impartial group of people assigned to protecting your safety, wellbeing and rights.

Am I eligible and do I have to take part?

To take part in this study you must be:

- Over the age of 18
- Suffered a stroke more than 3 months ago
- No longer be receiving physiotherapy
- Have a one sided weakness, (or a most effected side)
- Able to understand and read basic English
- Storage facilities for a bike (inside a house/garage)
- Some past experience of cycling

We will require confirmation from your doctor that they are happy for you to participate in the study.

What will happen if I choose to take part in the study?

If you choose to take part in the study there are few stages that you would need to be involved in.

Stage 1 – A member of the testing team supported by a I-cycles representative will arrange to meet with you, at home or in a mutual location, to discuss the details of the study and help identify what modifications we could make to an eBike to support your involvement.

Stage 2 – You will attend the University of Central Lancashire for Pre-testing lasting approximately 90 minutes. Here you will be asked to perform a series of strength and endurance tests shown below (See Table 1: Scientific tests and an explanation).

Table 1: Scientific tests and an explanation

Scientific Test	Explanation
Spirometry (breathing) Test	In a seated position you will be asked to breath normally into a hand-held device, you will also be asked to inhale and exhale deeply.
10 meter walking test	You will start in the standing position and be asked to walk a distance of 14 meters at your own pace. You will be timed for the middle 10 meters.
Surface Electromyography (sEMG)	This technique involves surface electrodes being placed on your legs. The electrodes do not hurt and are easy to remove, they transmit muscle activity wirelessly and do not have cables attached
Cycle Ergometry	Whilst positioned on the stationary you will be asked to cycle for a maximum of 5 minutes at a self-selected. Surface Electromyography will be used to track your muscle activation and pedals will be used to assess your left and right power output. You will be asked to cycle at a 'somewhat hard' rating, this is unique to you.
Maximum Voluntary Contraction	You will be asked to sit in an upright position and told to push/pull against a fixed resistance. During this time sEMG data will be collected.

Stage 3 – You will be loaned an eBike from I-cycles and asked to use the eBike for a period of 8 week. During this time you will be provided with a cycling diary to record some information (See Figure 1: Example cycling diary)

Week commencing: ____________________	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Total distance cycled (miles):							
Time spent cycling (minutes):							
Reason for your ride:							
Did you cycle independent-ly?							
Average calories burnt (taken from fit watch):							
Average heart rate (taken from fit watch):							
Did you have any falls? If so, how many?							
Using the confidence scale, how confident were you cy-cling?							
Using the BORG RPE scale, how would you rate your cycle?							

Figure 1: Example cycling diary

Stage 4- You will reattend the University of Central Lancashire for Post-testing. These tests will be exactly the same as those taken in Pre-testing.

Will my information remain confidential?

Yes. All information collected about you and data collected from the study will be kept confidential. You will not be identifiable through any data. Your name will be removed from collection and any data collected will be assigned a code so that it cannot it associated to you.

How will the results of the study be used?

Findings of this study will be used in a variety of ways including; conference presentations, thesis papers, case studies and peer-reviewed publications. Participants may also request written feedback.

What are the benefits and risks to the study?

The study will give you the opportunity to try an electric bike that has been modified to your needs. Through use of the electric bike you may see improvement in daily fitness, balance and strength. Your participation may also support the development of eBike use in rehabilitation interventions for stroke survivors.

We require GP permission to ensure that you are fit enough to partake in this study and safely ride a modified eBike. There are risks associated with riding an eBike and to minimise these you will be provided with a safety helmet. You will also receive instruction by a member of I-cycles limited on how to safely ride.

What happens if I change my mind and I don't want to continue?

You are free to withdraw from the study at any time, without question. At the point of withdrawal please notify a member of the research team. Data collected up until withdrawal will still be analysed and cannot be removed from the investigation.

What if there is a problem?

If you have any problems at any stage of the study, we ask you speak to a member of the research team who will try to resolve any issues (Adrienne Day – Acday@uclan.ac.uk or Howard Hurst - 01772 89 3911).

Any specific queries in regard to the study, please contact the Principle investigator

Appendix Figure 2: Participant consent form

CONSENT FORM

The Physiological and Biomechanical effects of a short term eBike cycling intervention in Stroke Survivors

Adrienne Day, Howard Hurst, Jim Richards, Louise Connell

This is a research project design to assess any changes that occur as a result of using an Electric bike over 8 weeks and is being supported by I-cycle electric, an electric bike supplier.

Please initial box

I confirm that I have read and understand the information sheet for the study titled 'The Physiological and Biomechanical effects of a short term eBike cycling intervention in stroke survivors' and have had the opportunity to ask questions.	☐
I understand my involvement is voluntary, and I can withdraw at any point, without reason. I understand that data collected up to the point of withdrawal may still be included in the final report.	☐
I confirm that I will gain GP approval prior to participating in this study and have provided them with the 'Participant letter of approval'.	☐
I agree to the loan of an electric bike or trike for a maximum duration of 3 months during which I must adhere to safety information provided by I-cycles. I agree that whilst using the cycle I must wear the provided safety helmet and the bike is stored in a secure location with the provided lock.	☐
I understand that my involvement in the study will involve visiting UCLan Darwin sports lab on 2 separate occasions and taking part in an 8 week intervention where I must document my eBike usage using the eBike diary	☐
I confirm that I am happy to meet with the UCLan Masters Student and an I-cycles representative before testing commencing to discuss bike modifications and ensure suitability for the study.	☐
I agree to take part in the above study.	☐

_________________________ _________________ _____________________

Name of Participant Date Signature

__________________________ _________________ _____________________

Researcher Date Signature

Appendix Figure 3: GP permission form

Letter of Information And

Consent to Participate in Research

The physiological and biomechanical effects of a short term e-bikes cycling intervention in Stroke survivors

Investigators:

Adrienne Day	Dr Howard Hurst
Student researcher (MSc)	Principle investigator
MSc Student, BSc	PhD, PGCert, MPhil, BSc
Acday@uclan.ac.uk	HTHurst@uclan.ac.uk

Dear Sir or Madam

___________________ has shown interest in participating in the study name above; funded by Collaborations for Leadership in Applied Health Research and Care (CLAHRCs). The study is directed explicitly at stroke patients who have suffered a stroke more than 3 months ago, to assess changes that may occur after an 8 week self-directed eBike intervention (Please see the attached Participant Information Sheet).

The study will involve pre and post intervention testing under the supervision of Adrienne Day at the University of Central Lancashire Darwin Sports Labs. Participants will be required to use an Electric Bike for 8 weeks, which will be suitably adapted to facilitate any disability and provided by I-cycle ltd.

Due to this study specifically recruiting stroke survivors, we are legally required to obtain doctors approval prior to participation. We require confirmation that the participant is safe to partake in this research and they have no other condition that may be worsened through participation.

To confirm the participant is safe to partake in this study, please complete the section on the follow page:

I <insert name>……………………………… of <doctors surgery/practice>…………………………….. can confirm that in my opinion <participants name>………………………………………………… is safe to participant in this research. I have read and understood the participant information sheet and can confirm that the participant has no other health condition(s) that may be exacerbated through use of an eBike. I can also confirm that they have no condition which will endanger theirs or others safety.

___________________	________________	___________________
Print name	Date	Signature

If you have any questions or concerns regarding this study, please contact:

Dr Howard Hurst

School of Sport and Wellbeing

University of Central Lancashire

Preston,

PR1 2HE

Email address: HTHurst@uclan.ac.uk

Telephone: +44 (0) 1772 89 3911

Appendix Figure 4: Cycle diary template

Week commencing: ______________________	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Total distance cycled (miles):							
Time spent cycling (minutes):							
Reason for your ride:							
Did you cycle independently?							
Average calories burnt (taken from fit watch):							
Average heart rate (taken from fit watch):							
Did you have any falls? If so, how many?							
Using the confidence scale, how confident were you cycling?							
Using the BORG RPE scale, how would you rate your cycle?							

Appendix Figure 5: Clinical meaningful difference (1SEM) SPSS output

Descriptive Statistics

Pre-intervention Walking time (s)	N	Mean		Std. Deviation
	Statistic	Statistic	Std. Error (1SEM)	Statistic
ebsr01	3	8.6167	.49330	.85442
ebsr02	3	16.7933	.18853	.32655
ebsr03	3	8.5833	.09404	.16289
ebsr04	3	8.6433	.18095	.31342
ebsr05	3	9.0533	.22430	.38850

Descriptive Statistics

Pre-intervention Walking speed (ms^{-1})	N	Mean		Std. Deviation
	Statistic	Statistic	Std. Error (1SEM)	Statistic
ebsr01	3	1.1679	.06441	.11156
ebsr02	3	.5956	.00661	.01145
ebsr03	3	1.1653	.01264	.02189
ebsr04	3	1.1580	.02404	.04164
ebsr05	3	1.1059	.02702	.04680

Descriptive Statistics

Post-intervention Walking time (s)	N	Mean		Std. Deviation
	Statistic	Statistic	Std. Error	Statistic
ebsr01	3	7.6567	.39767	.68879
ebsr02	3	17.0133	.29554	.51189
ebsr03	0			
ebsr04	3	7.2467	.12837	.22234
ebsr05	0			

Descriptive Statistics

Post-intervention Walking speed (ms^{-1})	N	Mean		Std. Deviation
	Statistic	Statistic	Std. Error	Statistic
ebsr01	3	1.3133	.06958	.12051
ebsr02	3	.5881	.01030	.01785
ebsr03	0			
ebsr04	3	1.3808	.02490	.04313
ebsr05	0			

Appendix Figure 6: Maximum sEMG amplitude during MVIC values for each participant

Pre-intervention sEMG MVIC	Left BF	Right BF	Left GC	Right GC	Left TA	Right TA	Left RF	Right RF
Participant one	0.0001160	0.0000920	0.0002190	0.0000670	0.0001160	0.0004220	0.0000940	0.0000900
Participant two	0.0004420	0.0001480	0.0001770	0.0002280	0.0009010	0.0002760	0.0003720	0.0001510
Participant three	0.0000860	0.0002120	0.0009430	0.0008590	0.0008700	0.0010460	0.0005400	0.0007110
Participant four	0.0000590	0.0003320	0.0003300	0.0006990	0.0007310	0.0004880	0.0001800	0.0002420
Participant five	0.0003050	0.0005460	0.0004540	0.0005620	0.0015000	0.0007120	0.0004540	0.0001720

Post-intervention sEMG MVIC	Left BF	Right BF	Left GC	Right GC	Left TA	Right TA	Left RF	Right RF
Participant one	0.0003710000	0.0002530000	0.0007140000	0.0003400000	0.0005600000	0.0010650000	0.0002970000	0.0002570000
Participant two	0.0003330000	0.0000390000	0.0003870000	0.0000920000	0.0008840000	0.0002890000	0.0004330000	0.0001720000
Participant four	0.0002800000	0.0002920000	0.0003320000	0.0002880000	0.0009460000	0.0006620000	0.0001970000	0.0002310000

Appendix Figure 7 SPSS output (MOXY)

Participant one

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	left_limb	31.2979	47	11.20348	1.63420
	right_limb	19.0851	47	11.39952	1.66279

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	left_limb - right_limb	12.21277	2.70214	.39415	11.41939	13.00614	30.985	46	.000

Participant two

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	left_limb	50.0968	62	1.23752	.15717
	right_limb	35.3065	62	2.22201	.28220

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	left_limb - right_limb	14.79032	1.87422	.23803	14.31436	15.26628	62.137	61	.000

Participant three

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	left_limb	60.5588	34	10.50885	1.80225
	right_limb	60.6765	34	16.42932	2.81760

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	left_limb - right_limb	-.11765	18.12710	3.10877	-6.44249	6.20720	-.038	33	.970

Participant four

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	left_limb	31.2623	61	2.78629	.35675
	right_limb	21.0328	61	1.01599	.13008

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	left_limb - right_limb	10.22951	3.23725	.41449	9.40041	11.05861	24.680	60	.000

Participant Five

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	left_limb	36.2623	61	.65579	.08396
	right_limb	56.6066	61	2.31861	.29687

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	left_limb - right_limb	-20.34426	2.56180	.32801	-21.00037	-19.68815	-62.024	60	.000

Appendix Figure 8 Participant two cycle diary output

	Cycle diary									Garmin watch			
	Distance (Miles)	Time spent cycling (mins)	Reason for ride	Independent (y/n)	Average calories burnt	Average heart rate	Any falls?	confidence scale rating	BORG RPE rating	Calories	Time	Avg. HR	Max HR
13/05/2019	3.8	50.33	Exercise	Y	278	120	N	8	15	278	00:50:34	120	142
15/05/2019	2.2	25.39	Exercise	Y	155	122	n	8	15	155	00:25:40	122	132
16/05/2019	4.2	46.17	Exercise	y	139	87	n	10	11	139	00:46:17	87	153
18/05/2019	5	53.36	Exercise	y	296	119	n	9	15	296	00:53:36	119	121
20/05/2019	2.2	25	Exercise	y	102	108	n	8	15	102	00:25:01	108	135
23/05/2019	2.5	26.36	Exercise	y	85	101	n	8	15	85	00:26:37	101	107
27/05/2019	1.3	13	Exercise	y	38	103	n	10	14	38	00:13:07	103	107
28/05/2019	2.4	40	Visiting a friend	y	166	86	n	10	15	166	01:11:59	86	141
03/06/2019	2.4	14.25	Exercise	y	56	108	n	10	15	56	00:14:25	108	117
06/06/2019	1.5	21.57	Exercise	y	68	101	n	10	15	68	00:21:57	101	109
09/06/2019	2.4	22.39	Exercise	y	69	103	n	9	13	69	00:22:40	103	105
12/06/2019	3	30.13	Exercise	y	37	61	n	10	13	37	00:30:14	61	120
14/06/2019	1.5	18.56	Exercise	y	17	56	n	10	11	17	00:18:57	56	88
24/06/2019	0.5	15.24	Exercise	y	14	55	n	8	15	14	00:15:24	55	59
26/06/2019	2.5	25.32	Exercise	y	22	56	n	8	15	22	00:25:33	56	59
28/06/2019	0.5	15.49	Exercise	y	13	51	n	8	15	13	00:15:49	51	59
02/07/2019	3.5	33.11	Exercise	y	29	55	n	9	13	29	00:33:11	55	59
04/07/2019	4.3	51.18	Exercise	y	50	57	n	9	15	50	00:51:18	57	59

Appendix Figure 9 Participant four cycle diary output

	cycle diary										**Garmin watch**		
	Distance (Miles)	Time spent cycling (mins)	Reason for ride	Independent (y/n)	Average calories burnt	Average heart rate	Any falls?	confidence scale rating	BORG RPE rating	Calories	Time	Avg HR	Max HR
13/05/2019	10.5	75.00	social	y		88	1	9	13	-	-	-	-
14/05/2019	8	55.00	social	y	288	92	n	10	11	-	-	-	-
15/05/2019	6.5	80.00	social	n	435	98	n	10	9	-	-	-	-
16/05/2019	10	60.00	social	y	70	88	n	10	11	-	-	-	-
17/05/2019	6.5	45.00	social	y	295	91	n	10	10	-	-	-	-
18/05/2019	7	60.00	pleasure	n	283	88	n	10	8	-	-	-	-
20/05/2019	8.7	60.00	pleasure	y	184	87	n	10	14	-	-	-	-
21/05/2019	5.5	40.00	pleasure	y	235	89	n	10	12	-	-	-	-
22/05/2019	7	60.00	pleasure	n	302	89	n	10	9	-	-	-	-
24/05/2019	7	50.00	pleasure	n	121	89	n	10	13	-	-	-	-
28/05/2019	6.75	42.00	pleasure	y	155	83	n	10	13	-	-	-	-
02/06/2019	7.5	70.00	pleasure	n	261	82	n	10	9	-	-	-	-
03/06/2019	7	40.00	pleasure	y	340	119	n	10	13	-	-	-	-
05/06/2019	10	60.00	pleasure	y	498	121	n	10	13	-	-	-	-
06/06/2019	3.3	32.00	social	n	87	74	n	10	13	-	-	-	-
07/06/2019	7	43.00	pleasure	y	289	107	n	10	11	-	-	-	-
09/06/2019	9	76.00	fun	n	551	111	n	10	8	-	-	-	-
10/06/2019	5	26.00	pleasure	y	208	110	n	10	12	-	-	-	-
11/06/2019	5	28.00	pleasure	y	164	101	n	10	12	-	-	-	-
12/06/2019	7	40.00	pleasure	y	151	83	n	10	12	-	-	-	-
13/06/2019	8.6	53.00	pleasure	y	331	103	n	10	14	-	-	-	-

14/06/2019	7.2	32.00	pleasure	y	309	123	n	10	12	-	-	-	-
15/06/2019	5.5	39.00	pleasure	n	298	114	n	10	11	-	-	-	-
16/06/2019	7	40.00	pleasure	y	137	80	n	10	11	-	-	-	-
17/06/2019	7	58.00	pleasure	n	311	97	n	10	8	-	-	-	-
18/06/2019	11.1	65.00	pleasure	y	137	69	n	10	11	-	-	-	-
19/06/2019	9.8	67.00	pleasure	n	310	91	n	10	8	310	01:07:01	91	132
20/06/2019	7	39.00	pleasure	y	163	86	n	10	12	163	00:39:40	86	137
21/06/2019	7	41.00	pleasure	y	138	80	n	10	10	138	00:41:08	80	125
22/06/2019	7	59.00	pleasure	n	531	125	n	10	10	531	00:59:34	125	164
23/06/2019	7	59.00	pleasure	n	240	87	n	10	9	240	00:58:05	87	119
24/06/2019	5	27.00	pleasure	y	213	117	n	10	12	213	00:26:51	117	142
26/06/2019	7	45.00	pleasure	n	301	106	n	10	12	301	00:45:40	106	136
28/06/2019	10	90.00	pleasure	n	457	93	n	10	6	457	01:32:46	93	138
30/06/2019	7	62.00	pleasure	n	264	87	n	10	8	264	01:02:46	87	129
01/07/2019	8.2	48.00	pleasure	y	203	86	n	10	13	203	00:48:58	86	124
02/07/2019	6	26.00	pleasure	y	161	102	n	10	11	161	00:26:32	102	138
03/07/2019	6	35.00	pleasure	y	208	101	n	10	13	208	00:35:39	101	132
05/07/2019	6	33.00	pleasure	y			n	10	11	174	00:33:24	95	133
07/07/2019	7		pleasure	n			n	10	6	-	-	-	-

Appendix Figure 10 Pre-intervention raw data

Anthropometric measures

Participant	Stature(m)	Mass (kg)	Age (years)	Resting HR (bpm)	Diastolic BP	Systolic BP	affected side	Months post stroke	maximum HR
EBSR01	1.82	96.3	78	68	91	123	L	108	153.4
EBSR02	1.83	94.6	51	75	97	145	R	102	172.3
EBSR03	1.77	87.8	69	47	78	147	R	36	159.7
EBSR04	1.85	118.5	59	81	91	130	L	7	166.7
EBSR05	1.86	87.6	47	63	87	135	R	122	175.1
mean	**1.83**	**96.96**	**60.8**	**66.8**	**88.8**	**136**		**75**	**165.44**
standard dev	**3.580921669**	**12.66384618**	**12.77497554**	**13.00769003**	**7.014271167**	**10.09950494**		**50.42816673**	**8.942482877**

10 MWT

Participant	aided (Y/N)	walk 1 (s)	speed (ms^{-1})	walk 2 (s)	speed (ms^{-1})	walk 3 (s)	speed (ms^{-1})
EBSR01	N	9.57	1.044932079	8.36	1.196172249	7.92	1.262626263
EBSR02	N	17.17	0.582411182	16.62	0.601684717	16.59	0.602772755
EBSR03	N	8.51	1.175088132	8.77	1.140250855	8.47	1.180637544
EBSR04	N	8.98	1.113585746	8.59	1.164144354	8.36	1.196172249
EBSR05	N	9.48	1.054852321	8.96	1.116071429	8.72	1.146788991

Garmin vector pedals - ergometry

Participant	avg power	peak power	avg cadence	peak cadence	left power	right power	power diff.
EBSR01	65	159	63	84	42	58	-16
EBSR02	1	22	18	33	64	36	28
EBSR03	130	163	74	79	44	56	-12
EBSR04	159	221	63	72	45	55	-10
EBSR05	119	81	58	64	88	12	76

Wattbike pro Data

Participant	Elapsed time	Distance	avg power	peak power	power/mass	avg cadence	peak cadence	avg speed	L force	right force
EBSR01	5.31	2.15	88	211	0.91	61	90	25.2	49	51

EBSR02	unsuccessful cycle									
EBSR03	6.23	3.03	107	165	1.24	69	79	28.5	53	47
EBSR04	5.23	2.77	125	241	1.03	76	78	30.5	51	49
EBSR05	6.03	3.11	123	184	1.39	58	64	30.7	64	36

Appendix Figure 11 Post-intervention raw data

Anthropometric measures

Participant	Stature(m)	Mass (kg)	Age (yrs)	Resting HR (bpm)	Diastolic BP	Systolic BP	affected side	Months post stroke	maximum HR
EBSR01	1.82	96.3	78	77	93	128	L	108	153.4
EBSR02	1.83	94.6	51	70	95	140	R	102	172.3
EBSR03									
EBSR04	1.85	118.5	59	82	88	123	L	7	166.7
EBSR05									

10 MWT

Participant	aided (Y/N)	walk 1 (s)	speed (ms^{-1})	walk 2 (s)	speed (ms^{-1})	walk 3 (s)	speed (ms^{-1})
EBSR01	n	8.3	1.204819277	7.74	1.291989664	6.93	1.443001443
EBSR02	y	17.11	0.584453536	17.47	0.572409845	16.46	0.607533414
EBSR03							
EBSR04	n	7.38	1.35501355	6.99	1.430615165	7.37	1.356852103
EBSR05							
EBSR06							

Garmin vector pedals - ergometry

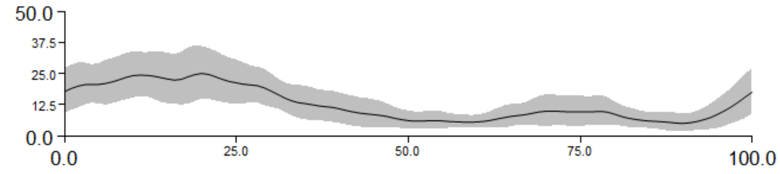
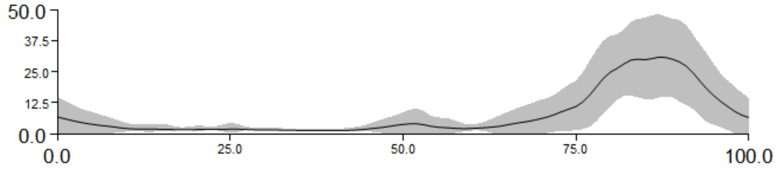
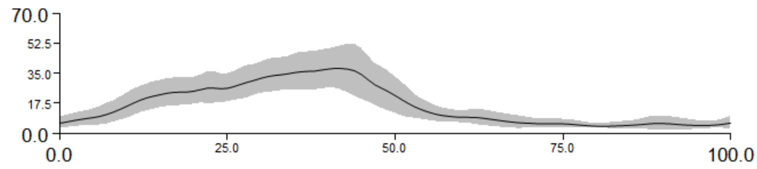
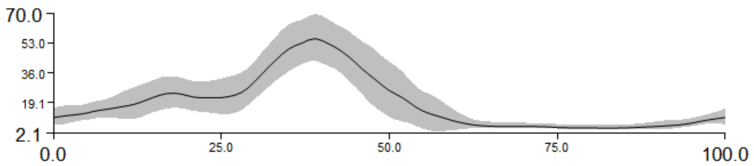
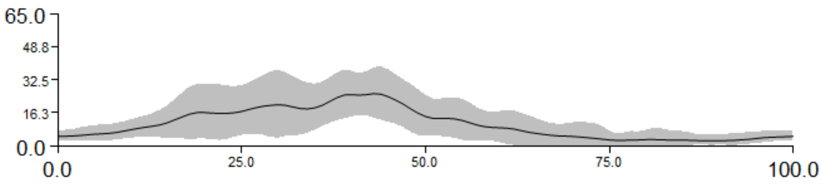
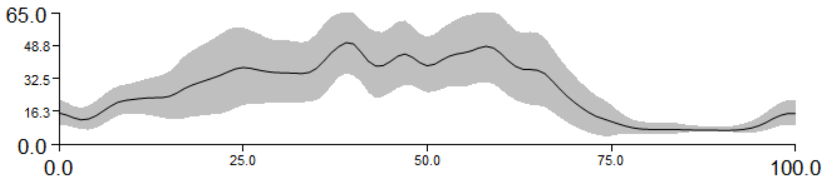
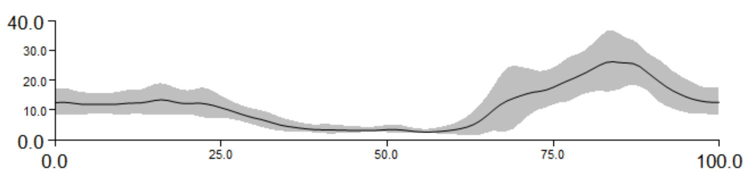
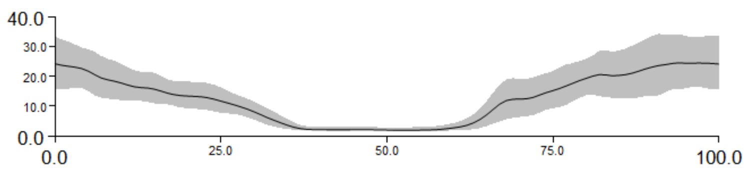
Participant	avg power	peak power	avg cadence	peak cadence	left power	right power	power balance difference
EBSR01	88	152	70	82	50	50	0
EBSR02	32	45	49	54	100	0	100
EBSR03							
EBSR04	127	188	77	83	47	53	6
EBSR05							

Wattbike pro Data

Participant	Elapsed time	Distance	avg power	peak power	power/mass	avg cadence	peak cadence	avg speed	L force	right force
EBSR01	2.03	0.84	94	155	1.021276596	71	81	24.82	49	51
EBSR02	5.08	1.81	44	63	0.47	48	55	21.1	69	31

EBSR03										
EBSR04	5.48	3.07	137	209	1.14	75	83	31.5	49	51
EBSR05										

Appendix Figure 12 Participant one, Pre-intervention sEMG signals normalised to %MVIC

Left TA	
Right TA	
Left BF	
Right BF	
Left GC	
Right GC	
Left RF	
Right RF	

Appendix Figure 13 Participant one, post-intervention sEMG signals normalised to %MVIC

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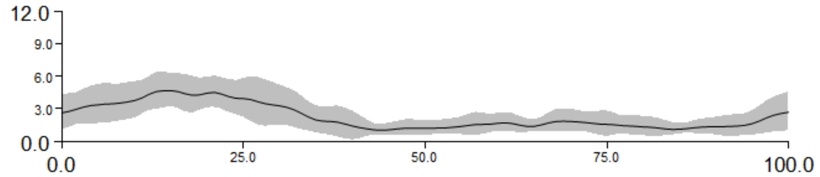

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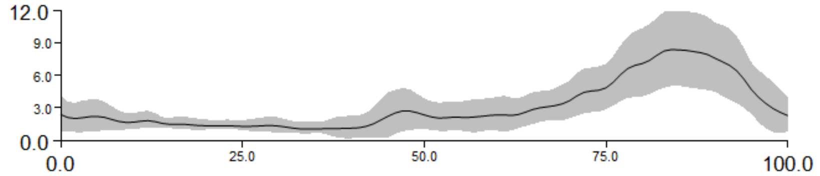

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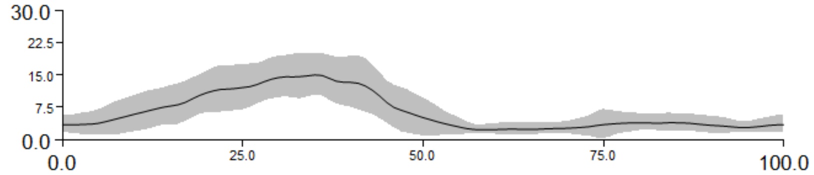
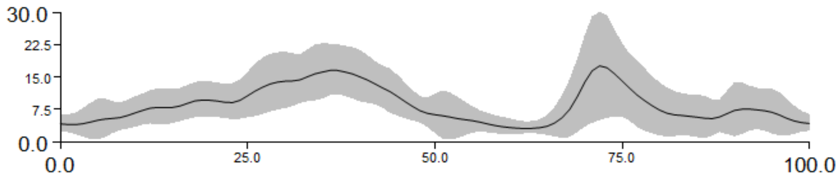


Right BF



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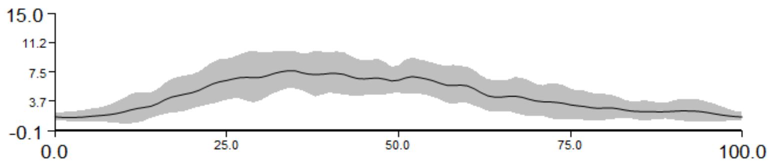

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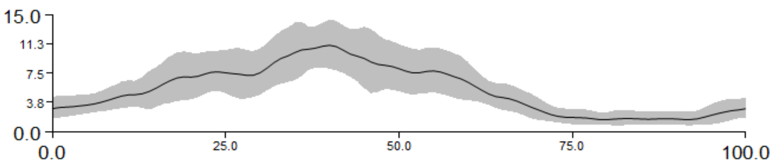

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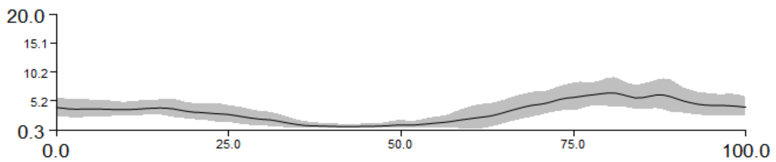

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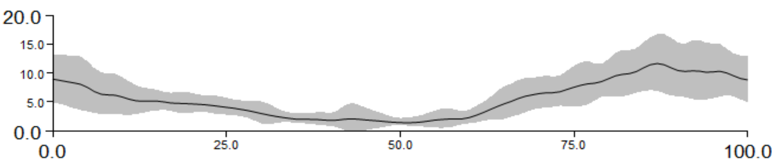

Appendix Figure 14 Participant Two, post-intervention sEMG signals normalised to %MVIC

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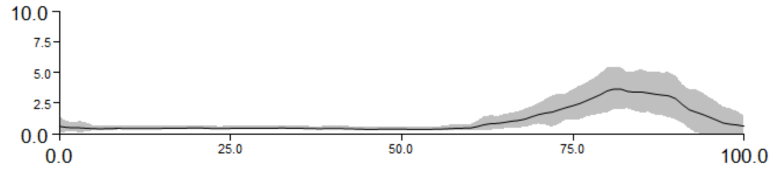

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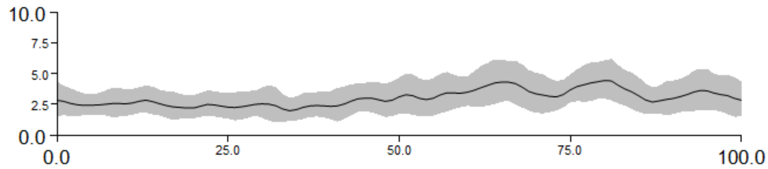

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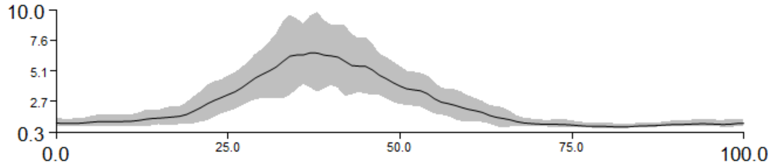

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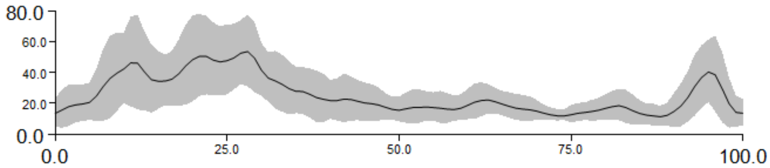

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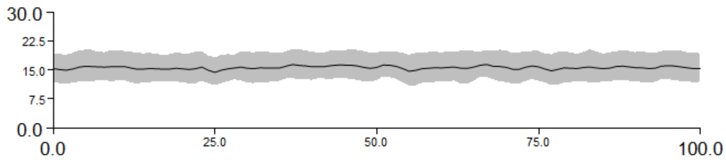

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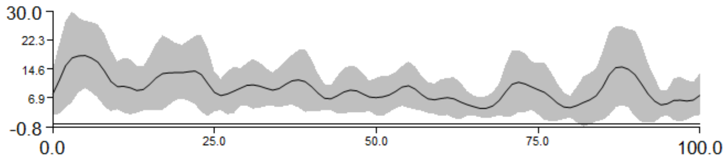

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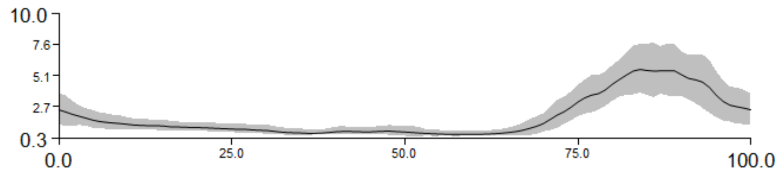

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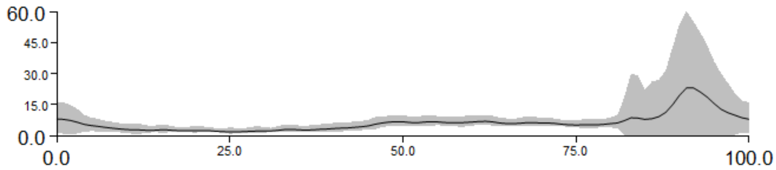
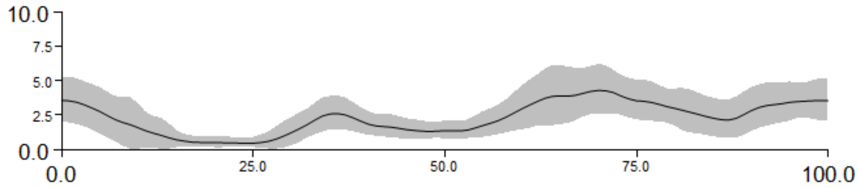
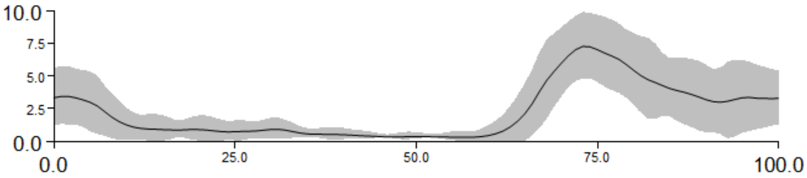
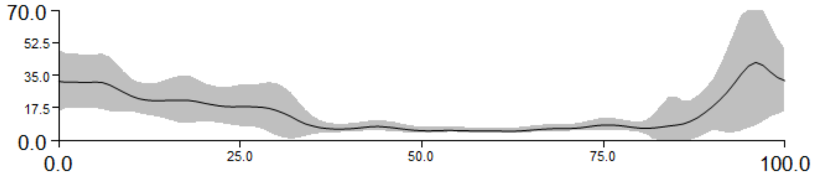
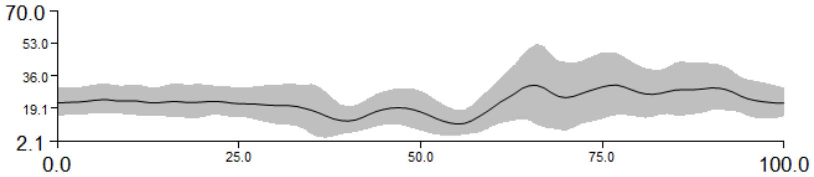
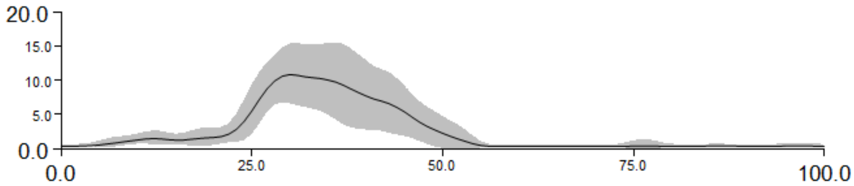
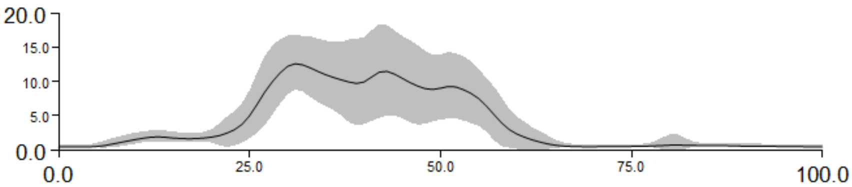
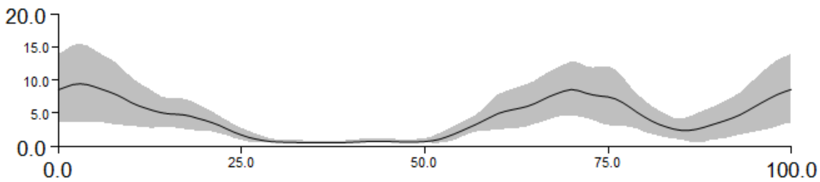
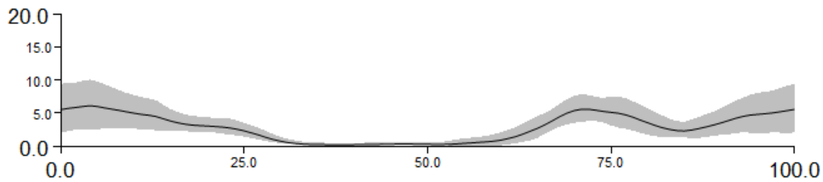
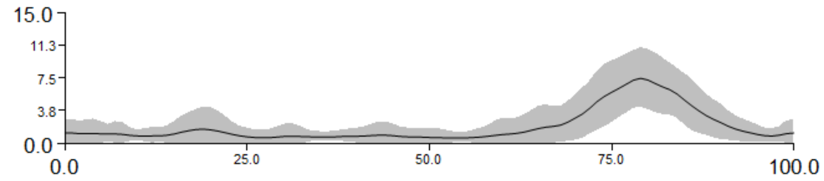


Appendix Figure 15 Participant Three, pre-intervention sEMG signals normalised to %MVIC

Left TA	
Right TA	
Left BF	
Right BF	
Left GC	
Right GC	
Left RF	
Right RF	

Appendix Figure 16 Participant Four, pre-intervention sEMG signals normalised to %MVIC

Left TA



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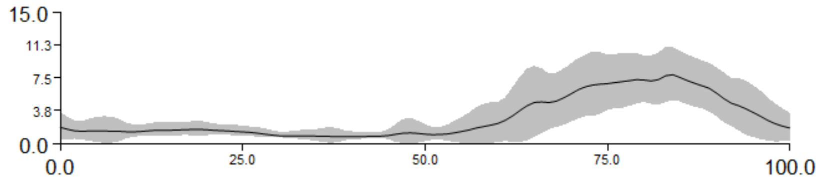

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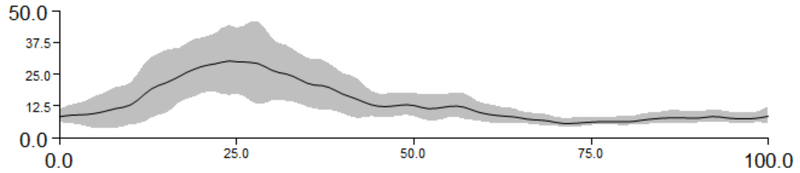

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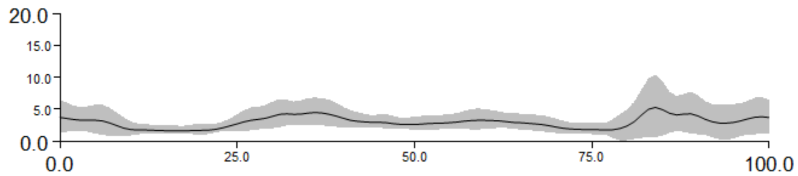

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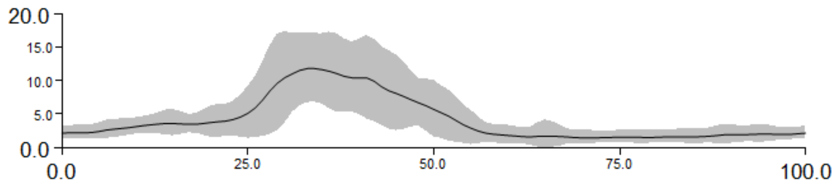

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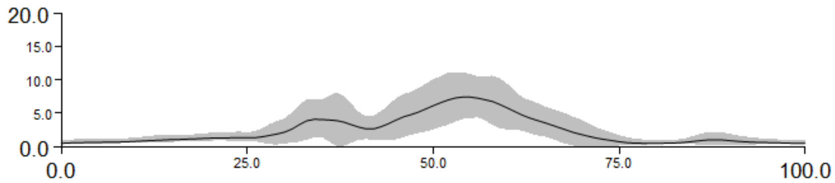

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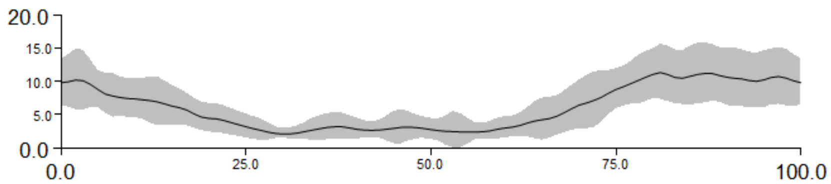
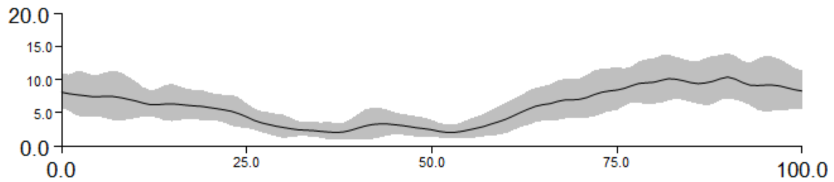


Right RF



Appendix Figure 17 Participant Four, post-intervention sEMG signals normalised to %MVIC

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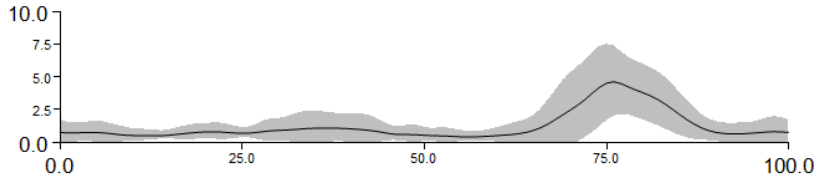
<tr><td>Left TA</td><td>
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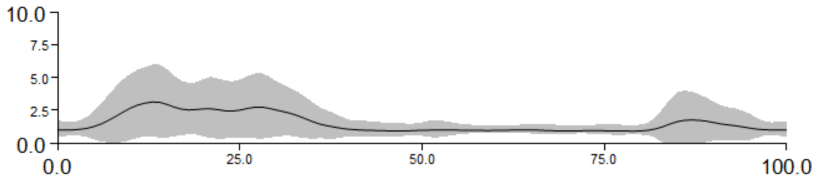
<tr><td>Right TA</td><td>
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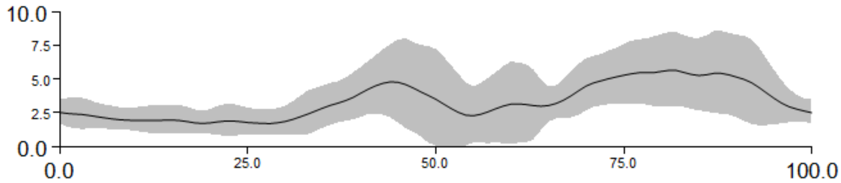
<tr><td>Left BF</td><td>
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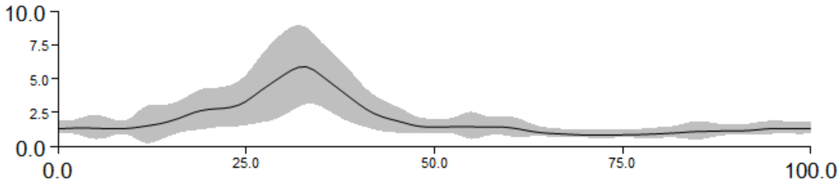
<tr><td>Right BF</td><td>
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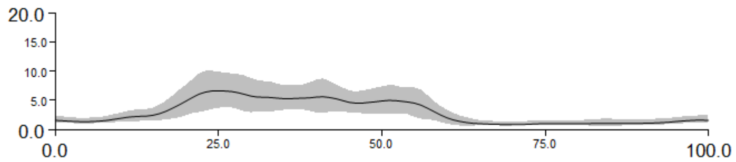
<tr><td>Left GC</td><td>
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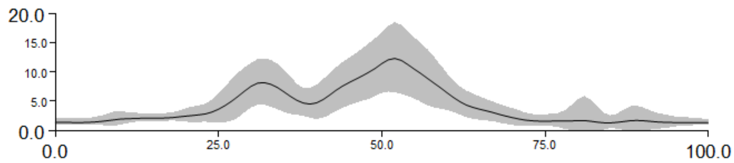
<tr><td>Right GC</td><td>
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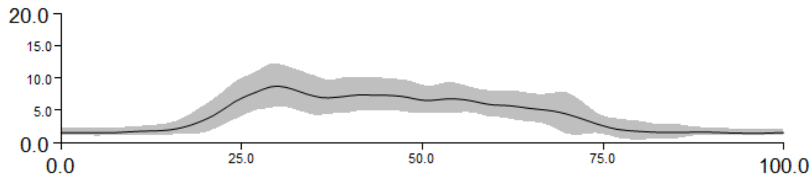
<tr><td>Left RF</td><td>
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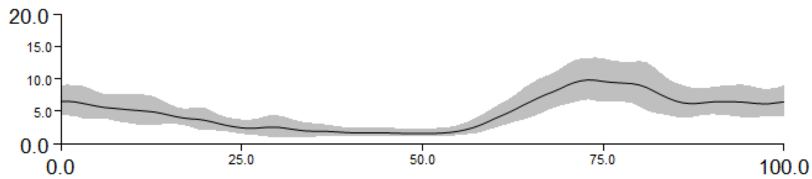
<tr><td>Right RF</td><td>
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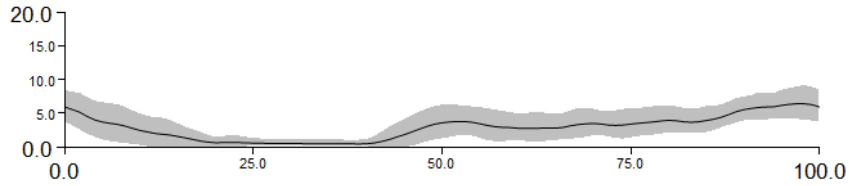
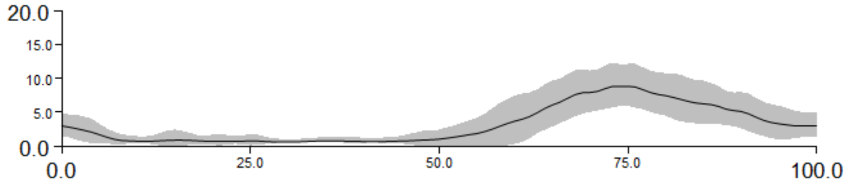
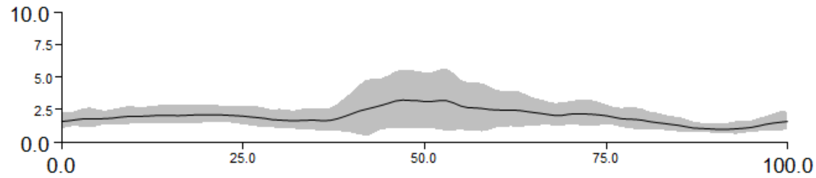
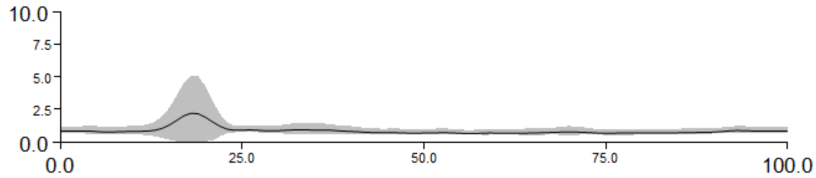
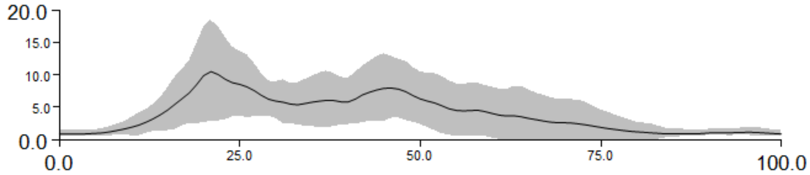
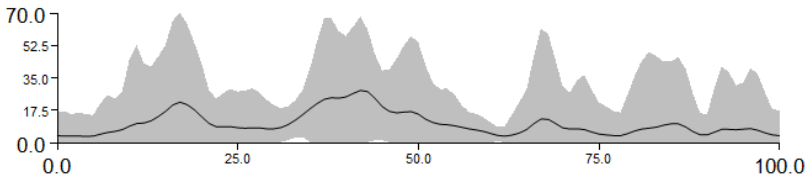
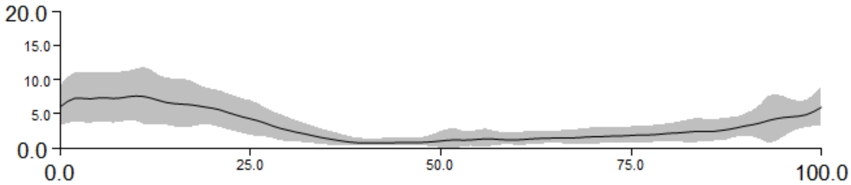
Appendix Figure 18 Participant Five, pre-intervention sEMG signals normalised to %MVIC

Left TA	
Right TA	
Left BF	
Right BF	
Left GC	
Right GC	
Left RF	
Right RF