Bio-psychosocial influences on the onset, longevity and treatment of Post Stroke Shoulder Pain

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Signed Declaration

I, Ben Beare confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.'

Signature…….

Acknowledgements

I would like to thank:

The generosity of the stroke survivors and their carers who participated in the studies in this thesis.

The Stroke Association and the Private Physiotherapy Education Foundation for funding this research..

Professor Nick Ward, Fran Brander and Dr Rachel Farrell for their supervision support and guidance.

Everyone at ARM lab for their support and advice.

My parents, siblings, family and friends. Especially my wife Alice and my children Arthur and Elowenn for all their support.

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Thesis Abstract

Background

Post Stroke Shoulder Pain (PSSP) is common in hemiparetic arm. This thesis addressed the following six questions:

i) Does early passive shoulder restriction in hemiparetic arms show a relationship with developing moderate to severe pain by 8 weeks?

ii) Is botulinum toxin injection effective in treating PSSP in the first 3 months post stroke?

iii) Which muscle groups contribute to restriction patterns when proximal spasticity is present?

iv) Are hydrodilatation injections effective in treating frozen shoulder in hemiparetic arms?

v) Are there common scapula movement adaptations in hemiparetic arms with frozen shoulder? Does active glenohumeral external rotation range show a relationship with dynamic scapula axial rotation range?

vi) What proportions of stroke survivors with PSSP show maladaptive levels of fear of arm movement and what aspects of their lived experience influenced this fear?

Thesis Abstract (Methods and Results)

Study 1: **Methods:** Baseline demographics and clinical measures of 32 ‘at risk’ stroke survivors were collected and pain was monitored up to 8 weeks. **Results:** Shoulder external rotation and abduction restriction and reduced shoulder proprioception at baseline showed a significant relationship with developing pain by 8 weeks

Study 2: **Methods:** A systematic review examined botulinum toxin injection studies for PSSP. Needle Electromyography (EMG) was used to examine individual muscle spasticity in 11 painful and stiff hemiparetic shoulders. **Results:** No studies were found examining use of botulinum toxin injection for PSSP within 3 months. No consistent muscle patterns were observed in proximal spasticity.

Study 3**: Methods**: Outcomes for 41 stroke survivors with frozen shoulder pre and post hydrodilatation injection were examined **Results:** Hydrodilatation was effective in improving passive range and pain. Age influenced range change as an outcome.

Study 4: **Methods:** Scapula movement strategies were observed in 11 hemiparetic arms with frozen shoulder **Results:** Scapula retraction was a common initiation pattern in hemiparetic arms. Dynamic scapula axial rotation range is influenced by active glenohumeral external rotation range.

Study 5: **Methods**: 41 stroke survivors with PSSP completed the Tampa Scale for Kinesiophobia **Results**: 25/41 (61%) of stroke survivors showed maladaptive levels of fear of movement. T

Thesis Abstract: Conclusions These findings will help guide future interventional research and help clinicians better identify who is most at risk of developing PSSP

Impact statement

The key findings of this thesis are:

1) Early passive shoulder restriction and loss of proprioception show an association with developing moderate to severe pain by 8 weeks. These are important clinical indicators in 'at risk' stroke survivors to help clinicians plan interventions and guide future early intervention studies.

2) Being over 65, having an hemiparetic upper arm girth < 30 cm and being female appear to make a stroke survivor more at risk of developing pain quicker (within 3 weeks of stroke). These clinical characteristics which may impact on the speed restriction and pain develop, could allude to underlying mechanisms of shoulder pathology.

3) Minimal recovery of active external rotation of the shoulder (flickers or more) by 3 weeks post stroke is associated with being pain free at 8 weeks post-stroke. This is a useful prognostic indicator and highlights the need for clinicians to promote shoulder muscle strengthening where possible. Scapula movement analysis indicated that improved glenohumeral external rotation range correlated well with dynamic scapula axial rotation range. It is possible that improved ability to produce proximal rotational torques may help scapula adjustments during arm elevation. This may improve length tension relationships; providing protection against injury.

4) Early Pain and restriction in the first 8 weeks after stroke appear to be predominantly due to spasticity; with around a quarter of cases showing signs of frozen shoulder. This indicates the need for early trials of spasticity within 3 months of stroke. However, no trials were found in a systematic review for this time period. The Needle EMG pilot study showed there was considerable heterogeneity of muscle involvement in clinical presentations of shoulder internal rotator/adductor spasticity. This indicates the need for expert assessment when applying focussed botulinum toxin treatments. This work has disproved previous assumptions that certain muscles such as subscapularis always contribute to internal rotator/adductor spasticity presentations.

5) Hydrodilatation injection (steroid and between 10 - 55ml of saline) is effective in treating frozen shoulder in hemiparetic arms. It was shown to be effective in improving passive range and pain on movement. Age was found to significantly influence passive external rotation range change. The model indicates a 50 year old receiving this injection would expect 26 degrees more external rotation range change post injections compared to an 80 year old.

6) Fear of movement (Kinesiophobia) was found to be very common in stroke survivors with painful and stiff hemiparetic arms. This may have a role in extending the longevity of conditions like frozen shoulder. Interview analysis showed that fear of movement was potentially influenced by the following two themes:

i) Negative interpretation of symptoms and

ii) Perceived poor pain management. This points to the need for clear pain management strategies for stroke survivors which should include education about symptoms.

Interviews also indicated that reduced movement unrelated to fear was influenced by the following 3 themes:

i) Stroke survivors viewing their arm as redundant

ii) Negative influences on self-management

iii) The demotivating transition from acute to community care.

This highlights that stroke survivors should have regular follow up following discharge to ensure they understand how to self-manage their arm recovery

Literature Search strategy for Chapters 1,2 and 3

The sources for topics discussed in chapters 1 -3 represents articles sourced from the following databases of MEDLINE, CINAHL (Cumulative Index to Nursing and Allied Health Literature), AMED (Allied and Complementary Medicine Database), Embase (Excerpta Medica dataBASE) and PubMed. This formed a narrative review of risk factors with a focus on the relationship between restriction and post stroke shoulder pain

Chapter 1: Introducing Post Stoke Shoulder Pain

Stroke is the commonest neurological cause of disability in the world. Middle Cerebral Artery (MCA) territory stroke is the most common ischaemic stroke syndrome with a key feature being upper limb impairments, including hemiparesis (Katan and Luft, 2018).

Pain in the weakened hemiparetic shoulder is one of the most common pain complications after stroke with a mean incidence in international studies of 54% (range 5 – 84%), (Turner-Stokes and Jackson, 2002; Saikaley et al., 2020). Variation in reported incidence is likely a due to differences in shoulder pain risk factors within study cohorts (Holmes et al., 2020). It is also likely due differences in how pain was measured (Price et al., 1999).

Defining PSSP

There are several different terms used for shoulder pain that develops after stroke in the literature, such as Hemiplegic or Hemiparetic Shoulder Pain (HSP), Post Stroke Upper Limb Pain (PULP), Painful Hemiplegic Shoulder (PHS) and Post Stroke Shoulder Pain (PSSP) (Saikaley et al. 2020; Tavora et al., 2010). Post Stroke Shoulder Pain (PSSP) appears to be the current preferred term and so is used in this report. The following definition has been created from current literature:

‘ PSSP is an umbrella term that includes all forms of pain that is perceived in the hemiparetic (weakened) shoulder and upper arm post stroke ’

A recent review has questioned the usefulness of grouping all sources of hemiparetic shoulder pain into one term (Holmes, 2020). This is because there are many different potential mechanisms that result in a stroke survivor perceiving shoulder pain including referred pain, local musculoskeletal pain and central and peripheral neurological sources. In addition, these sources can be influenced by psychosocial and lifestyle factors. There is need for a better understanding of the natural history of different shoulder pain pathologies post stroke to allow for more targeted treatments. All pathological processes that may result in PSSP are discussed within these introductory chapters.

When does PSSP start?

PSSP has been shown to develop as early as 72 hours post stroke with the majority of cases emerging by 2 months (Nadler et al., 2020; Rajaratnam et al., 2007; Gamble et al., 2000). However, a smaller percentage of cases can develop over a year post stroke (Lingren et al., 2007).

The timing of onset of the majority of PSSP cases is important as the first 3 months after stroke is often the period when stroke survivors are receiving the most service input (Rudd and Harding, 2017). PSSP has been shown to impact on participation in upper limb tasks, reduced perceived quality of life, increased depression and increased length of stay (Lingren et al., 2007; Lingren et al., 2018; Zhu et al., 2013; Saikaley et al., 2020). A significant confounding variable is that people with more severe strokes tend to develop shoulder pain (Bender and McKenna, 2009). This means the relationship between PSSP and overall arm recovery is not currently not clear (Caglar et al.,2015; Bender and McKenna, 2009). Although the effects of PSSP reducing participation in upper limb rehabilitation are likely to have some impact on recovery (Zhu et al., 2013;Lingren et al. 2007).

The challenge of measuring Pain

An important consideration in PSSP research is the way pain is measured. A common method uses an 11 point (0 -10) self report numerical rating scale (NRS). However, people with neurological impairments are less likely to be able to use these rating scales accurately (Price et al.,1999). Only 53% of stroke survivors versus 85% of age matched controls were shown to use NRSs accurately (Price et al., 1999). A key impairment that impacted on the use of NRSs was cognitive impairment (Price et al. 1999). Whereas visuospatial factors influenced ability to use horizontal scales (Price et al. 1999). This has led to the development of the Ability Q score which assesses a patients' 'ability' to use patient rated scales, with a particular focus on cognitive comprehension (Turner-Stokes and Rusconi, 2003). Vertical scales were used to prevent people with hemianopia being excluded (Turner-Stokes and Rusconi, 2003) See Appendix A. Another consideration is whether pain is rated by stroke survivors before or after the shoulder has been moved. Moving the shoulder prior to pain rating increases how severely the pain is rated by 23% compared to rating without the shoulder being moved (Nadler et al., 2015). In particular, people with cognitive and communication impairments are less likely to have pain complications identified (De Vries et al., 2017). This has resulted in the Scale of Pain Intensity (SPIN) scale being developed. It uses pictures and the circles to ensure patients fully contextualise questions about their pain (Jackson et al., 2002).

Subjective pain assessments have been developed for stroke survivors who are unable to use self rating scales where clinicians' grade observed pain behaviours (Smaling et al., 2019). A short subjective assessment called the Richie Articular Index (RAI) has been validated for assessing PSSP in cases where self reporting is unreliable (Bohannon and LaFort, 1986). Below are the criteria for each level of the RAI:

Richie Articular Index (RAI) ratings:

0. The patient has no tenderness OR visible discomfort
1. The patient complains of pain (voluntarily or when asked)
2. The patient complains of pain, winces
3. The patient complain of pain, winces and withdraws arm

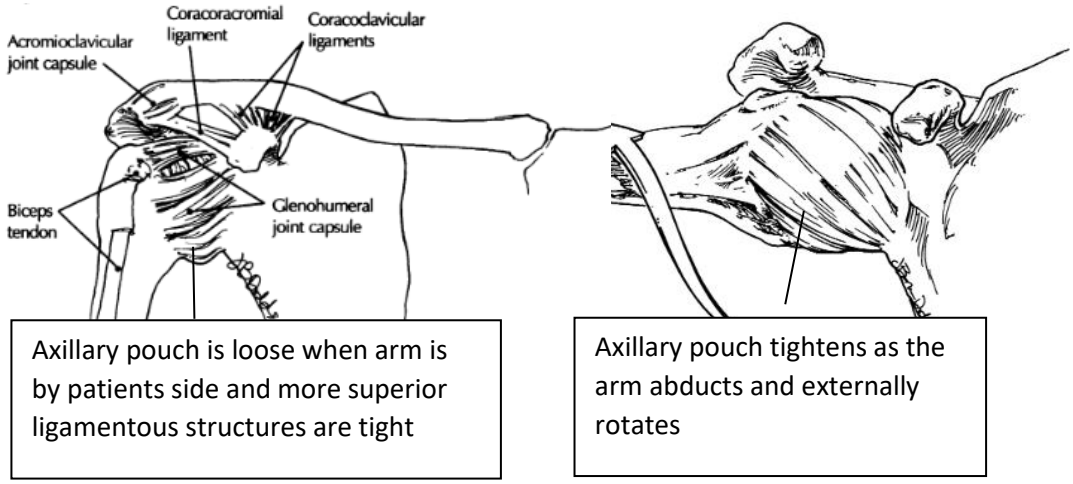
Why is shoulder pain so common in hemiparetic arms?

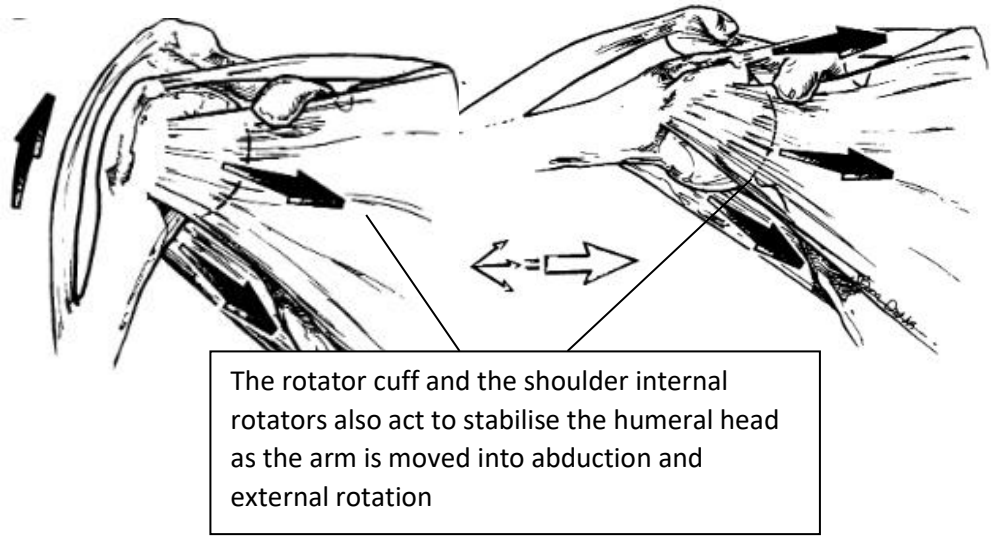
The shoulder complex consists of four joints: the glenohumeral, acromioclavicular, sternoclavicular and scapulothoracic joints**.** The reason for the shoulder being such an 'at risk' joint post stroke, lies in its mobility. Efficient function and range at the shoulder relies on minimal bony articulation with torque controlled by static and dynamic muscular and ligamentous structures (Dean et al., 2013). The scapula is only attached by suction forces supplied by serratus anterior and subscapularis muscles and ligament attachments at the acromioclavicular joint. In addition, the humerus only articulates with the glenoid fossa of the scapula, with the remaining stability being via a ligamentous capsule and the rotator cuff muscles; supraspinatus, subscapularis, teres minor and infraspinatus (Dean et al. 2013).

Cadaveric studies have shown there is asymmetric tightening of the shoulder ligamentous capsule according to the amount of rotation (McQuade et al.,1999). The shoulder capsule ligaments tighten during abduction and external rotation to maintain joint congruity and the rotator cuff also act as additional stability and suction force on the humeral head See Fig 1 (Kadi et al., 2017; Terry et al., 2000). Essentially, the inferior glenohumeral ligament is like a sling which wraps around the humerus as rotation occurs to stabilise the joint (McQuade et al., 1999). It acts to limit excessive external rotation and abduction of the humeral head (See Fig 1 overpage).

The rotator cuff and additional shoulder internal rotator muscles also act to control excessive external rotation and abduction of the humeral head in elevation (see Fig 1).

Fig. 1: Diagram showing how the ligamentous capsule and the rotator cuff provide dynamic stability to the humeral head. (Anterior views)

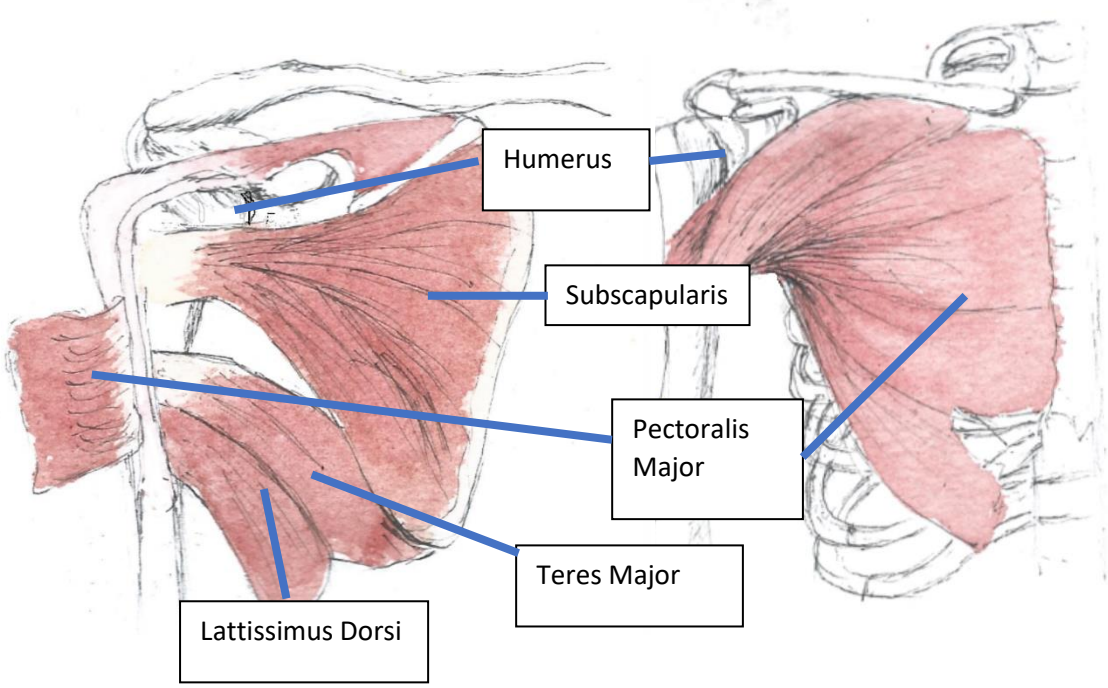




(Images from Fig 4, p251 and Fig 7, p252 Terry et al. 2000)

The main shoulder internal rotators/adductors muscle are: Subscapularis, Teres Major, Latissimus Dorsi and Pectoralis Major (see Fig 2).

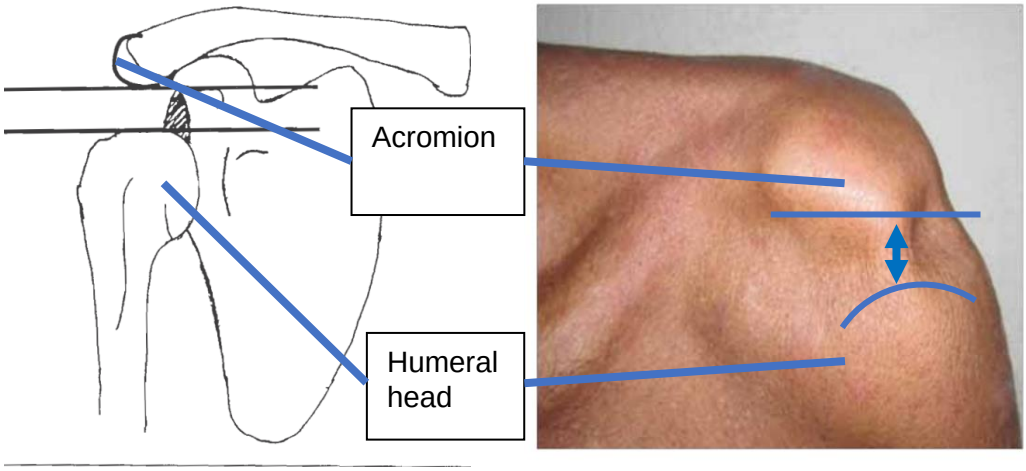
Fig. 2: The Shoulder Internal Rotators/Adductors (Anterior view)



Stability at the humerus is reliant on the discussed ligamentous and muscular systems more than bone articulation (Dean et al. 2013). After a stroke which causes significant arm weakness, the usual pattern of initial flaccidity results in inactivity of the rotator cuff and scapula stabilisers (Saikaley et al. 2020). Joint integrity is then only maintained by ligamentous structures especially in arms when complete hemiplegia is present (Saikaley e al., 2020).

Proximal shoulder weakness can result in a palpable gap between the Humerus head and the scapula acromion; known as subluxation, as shown if Fig 3 below.

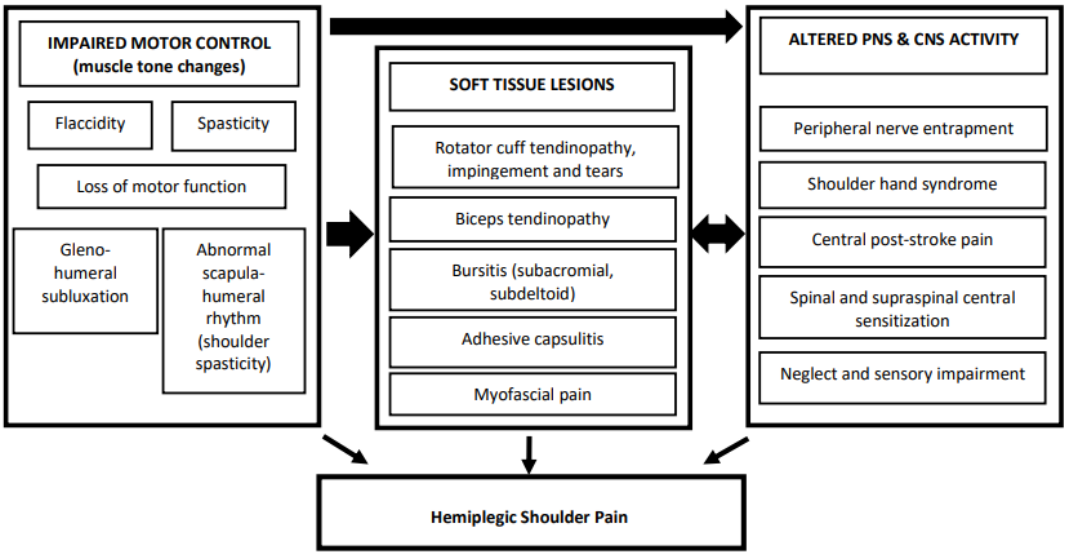
Fig. 3: Subluxation: Acromial to Humeral head distance (Anterior view)



(Images taken from Fig 1 on page 529 Hall et al.,1995: and Fig 1 Razaq et al., 2016)

These motor control and alignment impairments may result in soft tissue structures being more susceptible to injury (Idowu et al., 2017). Figure 4 over page, illustrates that PSSP can result from a single source or from interactions of impaired motor control, soft tissue lesions or lesions in the peripheral or central nervous system.

Fig. 4: Different potential biological drivers for PSSP



Taken from Fig 4, p23 Saikaley et al., 2020, Adapted from Kalichman and Ratmansky, 2011).

This model in Figure 4 can be simplified further into;

(i) neurological factors; of which there are upper and motor neuron components.

(ii) mechanical factors relating to soft tissue injury, joint alignment and capsule pathology such as frozen shoulder

(Vasudevan and Browne, 2014).

Neurological Factors (Upper and Lower Motor Neuron Lesion)

Central Post Stroke Pain occurs when stroke lesions can affect pain modulation centres such as the ventroposterior thalamus and the lateral medulla (Klit et al., 2009). This is often a diagnosis of exclusion where pain does not follow a mechanical pattern and there are sensory changes as a result of the stroke lesion with incidence reported between 8 and 12% (Klit et al., 2009; Dydyk and Munakomi, 2022). 18% of thalamic strokes and 25% of medullary strokes show signs of Central Post Stroke Pain (Klit et al., 2009).

Peripheral nerves may also be a potential pain source if direct trauma or traction occurs at the Brachial plexus (Kalichman & Ratmansky, 2011). **Chapter 2**.

Mechanical Factors

After a stroke that results in significant upper limb weakness, there is usually an initial flaccid phase resulting in traction forces followed by compression forces when tone develops (Li, 2017). These forces could cause injury or irritation to many shoulder soft tissue structures. Also, ongoing inactivity results in atrophy and potential changes in muscle and nerve tissue that could make them more susceptible to injury (Gray et al., 2012; Pollock et al. 1984)). Soft tissue injury or irritation then can result in a pro-inflammatory environment that may result in joint fibrosis. These soft tissue changes are discussed further in **Chapter 2**.

Further to the discussed neurological and mechanical factors, it is important to acknowledge that pain is a biopsychosocial phenomenon. Pain perception is a complex interaction between past experience, perceived threat and environment as well as tissue damage (Thacker 2015; Gifford 1998). Psychosocial factors that may influence PSSP are therefore discussed in introductory **Chapter 3**.

Current clinical practice in managing PSSP

A 2015 UK survey of Specialist Neurological Physiotherapists found 24% (n=170) agreed or strongly agreed that they were not confident in identifying different PSSP pain sources (Beare Unpublished). This lack of confidence is possibly driven by a perceived lack of training when dealing with the complexity of PSSP cases (Kumar et al. 2021). A survey of Specialist Neurological Physiotherapists and Occupational Therapists found 91% (n= 60) of clinicians reported they had not received training in how to manage PSSP (Kumar et al., 2021).

Lack of confidence and perceived training appear to have driven a large variation in interventions for PSSP with a survey of 576 Physiotherapists, Occupational Therapists and Nurses indicating a total of 175 different interventions were being used (Pomeroy et al.,2001). It seems that clinicians have been applying interventions for PSSP without a good understanding of the underlying pathology. This is also likely to be because there is limited research into pathology mechanisms to guide clinical reasoning (Holmes et al., 2020). This is problematic, because some treatments may be employed inappropriately and lead to worsening of symptoms, as is the case with some shoulder supports (Van Bladel et al., 2017)

The discussed survey evidence indicates that more research is required into the biological, psychological and social processes that cause PSSP to inform future clinician training (Holmes et al., 2020).

In light of the complexity of potential pain drivers presented in the model above, it is useful to consider what is most common. Understanding common risk factors and clinical presentations of PSSP will help to indicate which are the most common pathological processes.

Common Presentations of PSSP

PSSP is most commonly associated with restriction of passive external rotation and abduction (Ada et al., 2020; Lingren et al., 2013). This presentation is likely to be driven by two pathological processes:

(i) frozen shoulder (mechanical) a

(ii) spasticity of the shoulder internal rotators (neurological).

These pathologies and other factors that may result in these restriction patterns are discussed in introductory **Chapter 2; The stiff shoulder after stroke and its relationship with pain.**

Risk Factors for developing PSSP

Below are common risk factors identified in research studies to date:

Risk Factors: Weakness

Weakness of the shoulder muscles early after stroke is a key predictor of developing PSSP (Holmes et al. 2020). This is confirmed in outcomes of a large observation study:

i) 83% of those with absent upper limb movement developed PSSP

ii) 50% with reduced upper limb movement

iii) 5% of those with normal motor function after stroke developed PSSP

(Lingren et al., 2007).

Furthermore, an admission score of ≥3 on item 5 of the National Institutes of Health Stroke Scale (NIHSS) (no effort against gravity in their affected arm) increased the chances of PSSP developing (OR) 3.0 (95% confidence interval (CI) = 1.1– 7.7) (Kim et al., 2014). In my subsequent work, an admission score of ≥3 on item 5 of the NIHSS was used to identify those at high risk of developing early PSSP.

Risk Factors: Stroke severity

Arm weakness is more common with more severe stroke and so it is unsurprising that strokes with NIHSS total scores were more predictive of developing PSSP (Jönsson et al., 2006). Stroke survivors followed up at 4 months who had no pain or mild pain in their shoulders had a mean baseline NIHSS total score of 4.2, whereas those with moderate to severe pain had mean baseline scores of 6.6 (Jönsson et al., 2006).

As more severe strokes are associated with PSSP, it is therefore unsurprising that reduced light touch, reduced proprioception, higher levels of disability, neglect, communication impairments and periods of unconsciousness have also found to be predictor of the early appearance of PSSP (Hadianfard & Hadian-Fard, 2008; Niesson et al. 2009; Lingren et al., 2013).

However, reduced sensation and neglect of the upper limb may also make the shoulder more susceptible to injury independently of their association with stroke severity. Patients with sensory loss and neglect are particularly vulnerable during transfers (Lingren et al., 2013)**.** This may explain a previous study result where 18/30 (58%) of stroke survivors who were dependent for transfers developed PSSP compared to 21/70 (30%) of patients who were able to independently transfer (p =<0.01) (Wanklyn et al., 1996).

Risk Factors: Comorbidities

A recent meta-analysis indicated that stroke survivors with diabetes are significantly more likely to develop PSSP with a pooled odds ratio of 2.1 (CI 1.2 -3.8) (Holmes et al., 2020). Another risk factor was found to be a history of shoulder pain with a pooled odds ratio of 2.8 (CI 1.3 – 6.0) (Holmes et al., 2020). It is possible that diabetes and pre stroke joint changes may make a shoulder joint more susceptible to pro inflammatory processes when hemiparesis develops after stroke. Joint changes that are more common with age and may contribute to a pro-inflammatory joint environment are osteoarthritis and muscle tendinosis (Bass et al. 2012).

Risk Factors: Early Pain

Recent findings have found that pain within 3 days of stroke is 90% (n=121) predictive of pain being present at 8 weeks (Nadler et al. 2020). This is important as another study examining outcomes showed that the rate at which pain reduced after presentation significantly affected outcomes (Zhu et al., 2013). It appears that there is growing evidence that early PSSP needs to be identified and managed quickly to prevent further complications.

Risk Factors: Influences of mood and anxiety

Self-reported low mood has been shown to be a risk factor in the development of moderate to severe PSSP (Wanklyn et al., 1996). In addition, in the non-neurologically impaired population, guarding behaviours where the subject self limits their movements due to fear of harm are more predicted by anxiety ratings rather than perceived severity of pain (Olugbadeet al., 2019). In a case series of 5 non neurologically impaired subjects with frozen shoulder, external rotation was shown to increase by 15– 40 degrees, when participants were given a general anaesthetic indicating guarding likely due to fear of pain and injury can be a factor in reduced external rotation (Hollman et al.,2018). The psychosocial influences on shoulder pain are further discussed in Chapter 3.

Other potential Risk factors including the presence of subluxation

Some studies suggest that the side of stroke, gender, stroke type (haemorrhagic versus ischaemic), age and the presence of subluxation can be predictors of PSSP, however meta-analyses currently do not show consistent results (Saikaley et al. 2020; Lingren et al. 2013).

Subluxation tends to more prevalent as stroke severity increases; which is why loss of proprioception and haemorrhagic stroke are often associated with subluxation (Suethanapornkul et al., 2008). it believed that traction forces when subluxation is present impact on soft tissue and poor joint alignment which may make a stroke survivor more susceptible to pain (Paci et al., 2007). However, a systematic review found 7 studies showed a relationship between subluxation and PSSP and 7 studies did not (Kumar et al., 2013). This variation could be a consequence of study sample sizes (Paci et al., 2007). In a larger sample study (n=107) subluxation explained 46% of variance in shoulder pain as an outcome at 30 days (Paci et al., 2007). This figure indicates that the presence of subluxation does not guarantee pain.

One significant challenge with studying subluxation has been accurate and consistent measurement (Price et al., 2003). As the shoulder joint has multiple degrees of freedom, the space between the Acromion and humeral head is significantly affected by body position especially in cases of low tone and hemiplegia (Price et al., 2003; Kumar et al., 2014). Recently Ultrasound techniques have been developed that have shown acceptable levels of sensitivity and specificity (Kumar et al, 2014). However, palpation and calliper techniques are reliable, repeatable and more readily available clinically (Bohannon and Andrews, 1990; Hall et al., 1995).

Chapter 2: The stiff shoulder after stroke and its relationship with pain

The relationship of pain with stiffness

Passive restriction can develop in hemiplegic arms within 2 week of stroke, especially in arms with minimal signs of motor recovery in the acute period (first 7 days) to subacute period (7days to 3months) (Ada et al. 2020; Allison et al 2018; Bernhardt et al. 2017). Passive shoulder restriction is closely related to developing moderate to severe pain on movement in the hemiplegic shoulder (Rajaratnam et al., 2007). The most common patterns of restriction are reduced passive external rotation and abduction (Ada et al., 2020; Lingren, 2013; Rajaratnam et al., 2007). The presence of 10 degrees of passive shoulder external rotation restriction was found to have 93% sensitivity and 83% specificity for identifying cases of PSSP (n=135) (Rajaratnam et al., 2007). 5 degrees of abduction restriction was found to have 93% sensitivity and 80% specificity in identifying cases of PSSP. The following chapter discusses biological processes that may influence the development of passive external rotation and abduction restriction and the association of these processes with Post Stroke Shoulder Pain (PSSP). Potential treatments will also be discussed as will the impact of pain and restriction on movement in the recovering upper limb.

Defining different causes of restriction

Passive external rotation and abduction restriction can be the result of three different processes:

1) Non-neural frozen shoulder (capsule fibrosis)

2) Neural spasticity

3) Non-neural shortening of muscles

Non neural Frozen shoulder

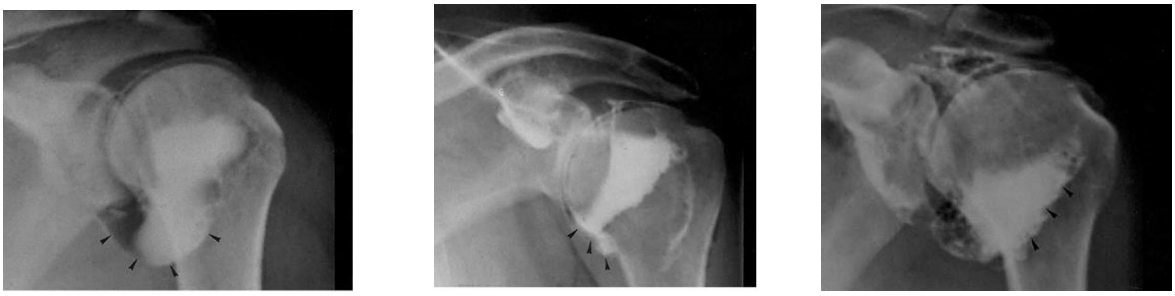
Frozen shoulder (FS) is associated with continuous fibrosis and contraction of the shoulder capsule, which is why it is sometimes known as Frozen Shoulder Contracture Syndrome (Lewis et al. 2015). Although in this thesis, I will refer simply to the term 'Frozen Shoulder'. 41 - 88% of cases of PSSP were shown to have evidence of active frozen shoulder processes in contrast MRI and arthrogram studies (Tavora et al., 2010; Pompa et al., 2011; Lo et al., 2003; Kalichman and Ratmansky, 2011). This includes evidence of fibrosis of the shoulder capsule at the Rotator Interval, Coracohumeral ligament, Subscapular recess and the anterior and interior axillary fold (Lewis et al., 2015). This results in passive shoulder external rotation and abduction restriction.

Fibrosis of the joint capsule causes a reduction in available volume around the humeral head (Lewis et al., 2015). In hemiparetic shoulders clinical measures of passive external rotation and abduction, but not flexion have been shown to correlate well with joint volume measurements (Lo et al., 2003). Generally, shoulder joint capsule volume is around 20ml, which can drop to 5ml in cases of Frozen shoulder (Kraal et al., 2020).

Arthrogram images (with 2ml of contrast) clearly show soft tissue changes associated with frozen shoulder in Fig 5 overpage (Lo et al., 2003). Image A (Fig 5) shows a healthy joint capsule with the presence of an axillary pouch to allow shoulder abduction and external rotation. In Image B (Fig 5) active frozen shoulder fibrosis appears to have obliterated the axillary pouch (Lo et al., 2003). Image C (Fig 5) shows another case of suspected frozen shoulder with irregular capsular margins (Lo et al.,2003). These changes were associated primarily with loss of external rotation and abduction restriction. Irregular joint margins result in greater passive external rotation and abduction restriction, likely because fibrosis is more extensive and joint volume is less (Lo et al., 2003).

Fig. 5: Arthrogram images of Shoulder Ligament capsule with 2ml of contrast medium

A B C



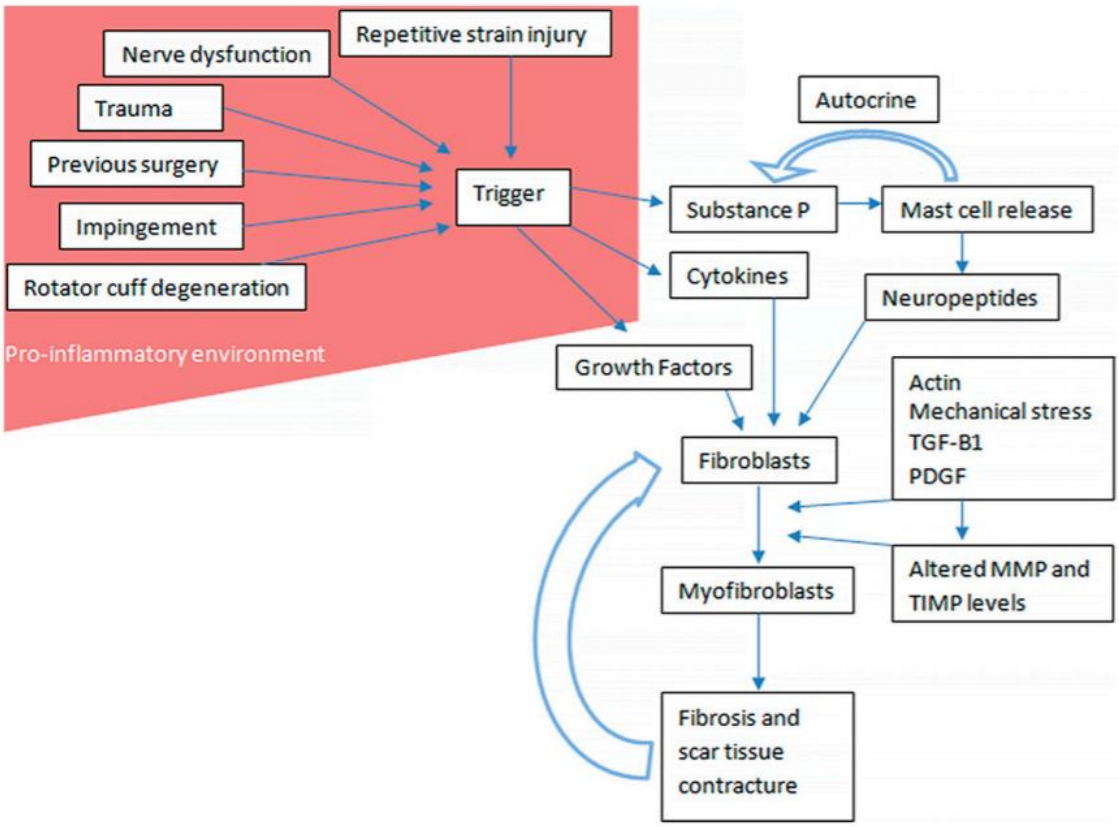
Taken from Fig 1, page 1787 (Lo et al., 2003)

What triggers this frozen shoulder process?

There is building evidence that frozen shoulder results from a pro-inflammatory trigger environment disrupting joint remodelling homeostasis (Jump et al., 2021). Matrix metalloproteinases (MMP) are responsible for regulating collagen remodelling activity as part of normal healing by degrading the extracellular matrix and influencing fibroblast activity (Jump et al., 2021). Tissue inhibitor of matrix metalloproteinase (TIMP) regulates production and activity of MMPs. MMP and TIMP are usually presented a ratio when considering joint homeostasis (see Fig 6 overpage). In frozen shoulder cases MMP:TIMP ratio levels are significantly lowered compared to controls (Lubis and Lubis, 2013). This study examined serum levels of MMP:TIMP in 50 subjects (25 with frozen shoulder and 25 controls), however this study has not yet been replicated in the general or stroke population.

The relationship of frozen shoulder processes and reduced MMP activity have been further proved when MMP inhibitor medication, such as Rebimastat used in cancer treatment has also been shown to increase the risk of people developing frozen shoulder (Jump et al., 2021).

Fig. 6: Model for the development of Frozen Shoulder



(Taken from Fig 2, page 13 Jump et al., 2021)

What could be triggering a pro inflammatory environment in hemiparetic shoulders?

Inflammation can occur when soft tissue structures are injured or irritated. As discussed in Chapter 1 the shoulder can undergo traction forces during early flaccidity after stroke, which can then be followed by compression forces if tone develops. In stroke survivors moderate to severe soft tissue changes have been shown to occur in the hemiparetic shoulder compared to the non-hemiparetic side and age matched controls, see Table 1 overpage (Idowu et al., 2017). Soft tissue changes include rotator cuff degeneration such as rotator cuff tendinopathy, rotator cuff tears, bursitis and biceps tendinopathy. These soft tissues structures generally sit beneath the Scapula Acromial space. When they are associated with pain are often grouped under the term Subacromial Pain Syndrome (SAPS) which replaced the previously used 'impingement syndrome' (Dierks et al., 2014). Rotator Cuff tendinopathy can include an acute tendonitis inflammation (Bass et al., 2012).

These inflammatory responses can be more common in tendons that have already undergone age related collagen changes and calcification, otherwise known as 'tendonosis' (Bass et al., 2012). If the rotator cuff is torn either partially or completely, this has been shown to allow the humeral head to sit more anteriorly in cadavers (Shah et al. 2008). This could further exacerbate joint alignment and stability problems which could also cause inflammation (Shah et al., 2008).

Table 1: Comparison of ultrasound soft tissue finding (Idowu et al. 2017)

Ultrasound grading (Number of soft tissue changes)	Hemiplegic side (n =45)	Non Hemiplegic side (n = 45)	Control (n =90)
Normal (0)	0 (0.0)	20 (44.4%)	51 (56.7%)
Mild Damage (1-2)	16 (35.6)	24 (53.3)	35 (38.9)
Moderate Damage (3-4)	24 (53.3)	1 (2.2)	29 (16.1)
Severe Damage (5-6)	5 (11.1)	0 (0)	5 (2.8)

(Modified from Table 2 p145 Idowu et al., 2017)

Upper Limb Spasticity of Shoulder Internal Rotators and Abductors

The European work group 'SPASM Consortium' defined spasticity as: '*disordered sensorimotor control resulting from an upper motor neurone lesion, presenting as intermittent or sustained involuntary activation of muscles'* (Dressler et al., 2018; Squire, 2009). There is a loss of central descending inhibition of suprasegmental spinal inputs causing hyperexcitable spinal reflex arcs (Bhimani and Anderson, 2014). This results in a velocity dependent increase in muscle resistance (Chalard et al., 2020). When a muscle is stretched and action potentials are sent to spinal cord via sensory neurons, the feedback system to the muscle via alpha motor neurons is disrupted, resulting in abnormal muscle activation (Bhimani and Anderson, 2014).

Spasticity, like pain, has a number of levels of influence from tissue to higher centres affected by environment and emotion (Thibaut et al., 2013). This explains why there are many potential internal and external aggravating factors that could influence levels of tone and spasticity (Ashford et al., 2018). Important internal factors that can aggravate spasticity are urinary tract infections, bowel impaction, skin or nail lesion, ill-fitting clothing, anxiety and mood (Edwards, 2002). External factors can be noise, lighting and base of support (Edwards, 2002). It therefore important when assessing spasticity that efforts are made to limit these internal and external factors to get a true representation of hyperexcitability driven by the upper motor lesion.

Upper limb spasticity can develop within days of stroke when upper limb paresis is present (Opheim et al. 2014). 25% have been shown to have upper limb spasticity by day 3 and 46% have spasticity by 12 months (Opheim et al., 2014). Common tonal patterns that develop due to sensorimotor deficits result in shoulder internal rotators and adductor spasticity (Zorowitz et al., 1996). This tonal pattern then results in a resting position of the arm in an internally rotated and adducted position particularly in very weak arms (Zorowitz et al., 1996). This explains why the presence of upper limb spasticity correlates with passive restrictions in the following shoulder movements:

i) Shoulder External Rotation ($r = 0.65$ ($p=<0.05$)
ii) Shoulder Abduction ($r = 0.65$ ($p=<0.05$).
iii) Shoulder Flexion ($r= 0.64$ ($p=<0.05$),

(r = correlation coefficient with the presence of upper limb spasticity)

(Lo et al., 2003)

Stroke survivors in Brunnstrom recovery stages 1-3 are more likely to develop PSSP (Ping Pong et al., 2009). Therefore, it is possible that developing spasticity itself drives pain or there could be a relationship between internal rotator and adductor spasticity and the development of soft tissue changes such as Frozen Shoulder.

Influence of tone and disuse on non-neural changes

Stroke paresis results in reduced firing rate of the motor units in the upper limb (Thibaut et al., 2013), which results in reorganisation of motor units as early as 9 days post stroke (Gray et al., 2012). Motor units with large alpha neurons innervating fast twitch fibres appear to be lost first resulting in the remaining muscle being mainly composed of slower motor units (Gray et al., 2012). In addition, increased levels of intramuscular fat develop and muscle mass reduces which is likely a result of disuse vascular atrophy (Ryan et al., 2002; Huang et al., 2014). Muscle fibres lose sarcomeres and surrounding connective tissue loses its elasticity (Farmer and James,2001; Alison et al., 2018). ‘Thixotropy’ in healthy muscle is its pseudoplastic property where its stiffness reduces with movement (Lakie and Campbell, 2019). However, when muscle stiffness does not change with movement it is likely true ‘contracture’ has developed.

Motor unit changes and muscle atrophy appear to occur at faster rates when stroke paresis is more severe (Gray et al., 2012). Muscles have different numbers of motor units and fibre types according to their function and so it is possible that some muscle groups atrophy and shorten quicker (Gray et al., 2012; Ward et al., 2006). MRI evidence of 89 stroke survivors (mean age 58) found evidence of muscle atrophy of rotator cuff, biceps and deltoids in 40% of subjects with less than 50% of maximum power compared to 14% with over 50% power (Shah et al., 2008). The subjects were on average 8 months post stroke and had experienced PSSP for an average of 7.5 months (Shah et al., 2008). Atrophy was similar among most muscles studied, ranging between 20 and 23% (Shah et al., 2008). The exceptions were Teres Minor and Biceps Brachii which only showed 14% atrophy and Subscapularis which did not display any atrophy (Shah et al.,2008). Atrophy was found to be more common in women and women were more likely to have Subscapularis tendinopathy (Shah et al., 2008). These findings show that even though there is some variation in muscle atrophy rates there is currently no evidence that would explain preferential atrophy and shortening of shoulder internal rotators and adductors. Currently evidence tends to indicate habitual shoulder positions as a result of weakness and increased tone, rather than a susceptibility of adductors and internal rotators to shorten are the more likely cause of non-neural external rotation and abduction restriction (Ada et al., 2020; Allison et al., 2018).

What else could be affecting how quickly external rotation and abduction restriction develops?

The rate of muscle shortening and capsule restriction may be related to genetic, vascular and peripheral nerve factors (Walsh et al.,2005; Lewis et al. 2015; Giang et al. 2016).

One genetic factor might be an inherited fibromatosis called Dupuytren's contracture that causes thickening and shortening of connectivity tissue around the hands (Lewis, 2015). Dupuytrens contracture, is where 'collagen knots' forms in palmar fascia that impede finger flexor tendons (Hart and Hooper, 2005) (see Fig 7 below). 5% (n =65) of people operated on for Dupuytrens had associated Frozen Shoulder (Degreef et al., 2008).This indicates that rates of fibrosis in frozen shoulder cases are possibly influenced by genetic factors (Lewis et al., 2015).

Fig. 7: Dupuytrens contracture: usually affects fourth and fifth fingers initially

(web image: mayo clinic,2021)

The ability of shoulder peripheral nerves to accommodate tension when new hemiparesis develops is a product of an intra-neural and extra-neural anatomy (Walsh et al., 2005). Alterations in blood supply that appear to occur in the paretic limb may impact on the tension response of the nerve, which may result in increased irritability (Walsh et al. 2005). Also,extraneural restriction due to tissue changes around peripheral nerves may also contribute to stiffness. Restriction or irritation of the Median and Ulnar nerves could influence external rotation and abduction restriction (Coppieters & Alshami et al., 2007).

Impaired microcirculation around soft tissue structures may be enhanced in stroke survivors with diabetes (Strain et al., 2018). This may accelerate muscles changes and impair healing which explain higher rates of PSSP in people with diabetes (Holmes et al., 2020).

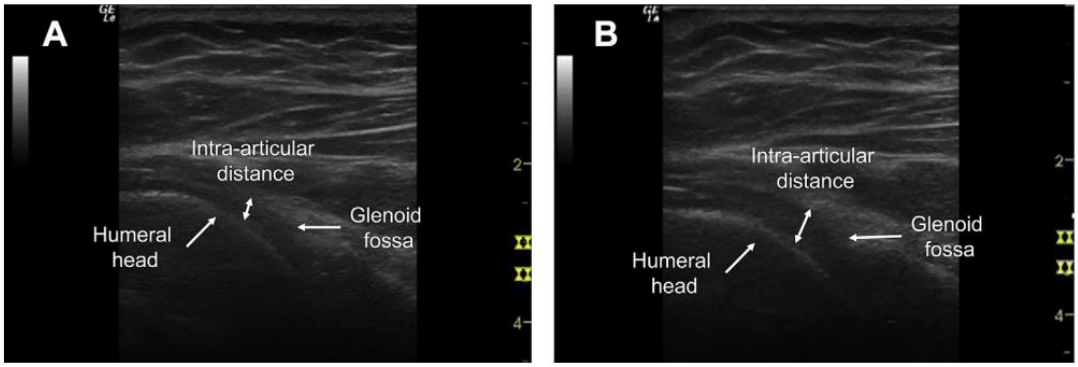
Arm paresis and disuse have been shown not to affect the flow of lymph (Werner et al., 1997). Oedema tends to pool in distal areas, therefore shoulder stiffness is less likely to be due to lymph accumulation. Although, there is some evidence hand oedema can be linked with PSSP (Isaakson et al.,2013). This may be due to dysfunction of absorption and filtration of lymph due to vascular changes already discussed (Giang et al.,2016). In addition, altered autonomic nervous system activity in more chronic cases can result in Complex Region Pain Syndrome (CRPS) with associated oedema and skin changes (Saikaley et al., 2020). Developing CRPS in the hemiplegic arm is relatively rare although some rates as high as 16.4% have been reported (Saikaley et al., 2020). Discussion of CRPS as phenomenon is beyond the scope of this thesis.

Treatments for Frozen Shoulder in the hemiplegic arm

Treatment of Frozen Shoulder (FS) common involves ultrasound guided steroid injection or hydrodilatation injection in combination with physiotherapy (Wu et al., 2017).

Hydrodilatation involves injecting steroid with the addition of 20-40ml of saline to distend the shoulder capsule (see Fig 8 below) (Lewis, 2015; Wu et al., 2017).

Fig. 8: Pre (A) and Post (B) Hydrodilatation: 30mls of saline increases intra-articular space



Techniques vary between capsule preserving to capsule rupturing techniques, with upto 90mls being recorded as being injected (Rymaruk et al., 2017). There has not been any reported benefits of capsule rupturing techniques and so this is a less common technique (Rymaruk et al., 2017). The standard drug is Triamcinolone, a corticosteroid otherwise known as a glucocorticoid, with the usual dose being 40mg per injection (Saikaley et al., 2020).

An important question in regard to findings for the general public is, do stroke survivors respond the same when treated with hydrodilatation injection in combination with post-injection therapy? In non-stroke subjects with frozen shoulder with lowered MMP/TIMP ratios, moving into external rotation, forward elevation, horizontal adduction and internal rotation for 10 seconds, four times a day allowing tolerable pain can restore normal joint homeostasis levels by 12 weeks (Lubis and Lubis, 2013). This means normal MMP/TIMP ratios are restored by this treatment (Lubis and Lubis, 2013). However, stroke survivors who develop PSSP tend to have significant motor weakness and so it's harder for them to move into end of range stretch positions (Lingren et al.,2007). As additional saline aims to increase articular space and distend the joint capsule, it is possible that this is important for stroke survivors to help with restoring joint homeostasis.

Joint compliance which will be affected by variations in joint fibrosis may influence how much distension is possible (Torrence et al., 2018). This explains why non-stroke subjects with frozen shoulder who were unable to receive 30mls or more saline as part of a hydrodilatation injection due to capsule compliance were 1.86 times more likely to require arthroscopic capsular release due to poor response to injection (Torrence et al.,2018).

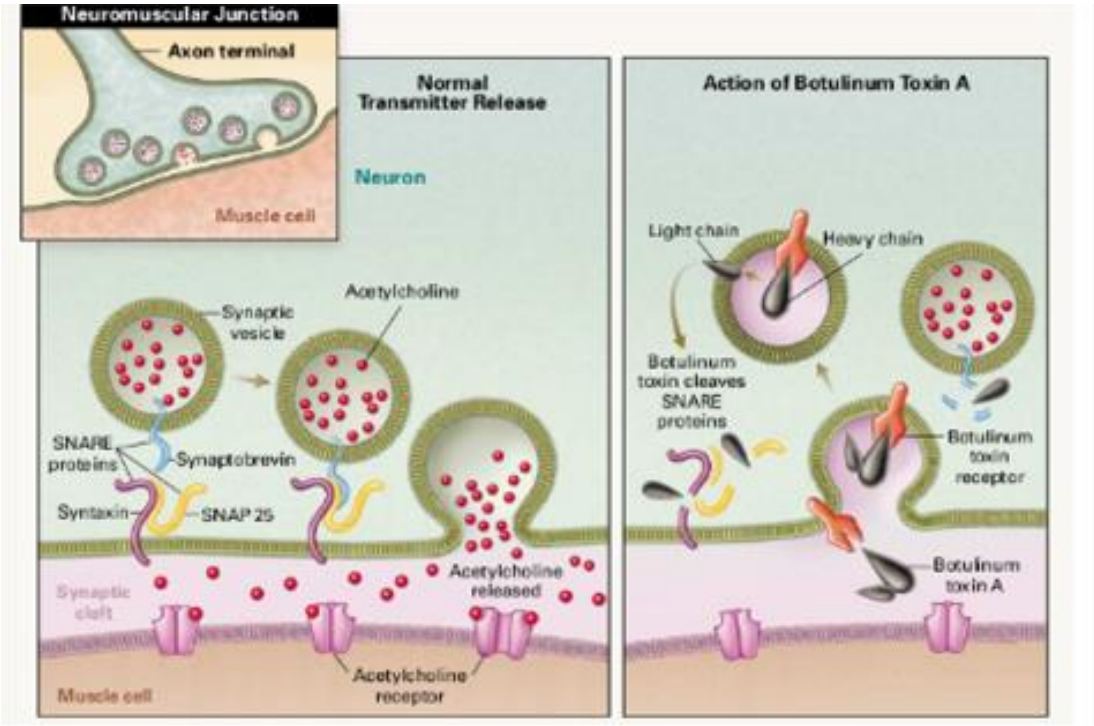
Treatment of Spasticity of Internal Rotator

Oral spasticity medication especially in high doses can have unwanted effects on the Central Nervous System such as sedation (Chang et al., 2015). This means in cases of focal spasticity, botulinum toxin injections into affected muscle groups are a preferred treatment approach (Ashford et al., 2018). These have been shown to be safe as well effective in treating upper limb spasticity (Gracies et al., 2015; Ashford et al.,2018),

Botulinum toxin is neurotoxin produced by the bacterium Clostridium botulinum (Ghasemi et al., 2013). There are seven serotypes; A, B, C1, D, E, F, and G which all act at the neuromuscular junction by inhibiting acetylcholine release (Ghasemi et al.,2013). All act to cleave snare proteins responsible for allowing the docking of Acetylcholine neurotransmitter vesicles, which results in muscle fibre paralysis (Ghasemi et al. 2013) See Fig 9 overpage.

Each different serotypes have a different length of duration, with serotype A being most commonly used clinically (Pirazzini et al., 2017). Botox, Dysport and Xeomin are the main manufacturers of Botulinum Toxin type A (BoNT-A) (Ashford et al. 2018).

Fig, 9: Diagram showing effect of Botulinum toxin on Neuromuscular junction



(Diagram taken from Fig 1, page 2 Al-Ghamdi et al.,2015)

The onset of muscle paralysis occurs over the first week post-injection with treatment effects lasting for upto 4 months after BoNT- A activity stops (Ashford et al., 2018). Effects are also dependant on the dosage regimes applied (Ashford et al., 2018). Treatments aim to temporarily paralyse overactive muscle groups and then provide input to stimulate antagonist muscle groups as well as passive stretches to improve range. One adjunct that has proved useful on the distal arm is neuromuscular electrical stimulation (NMES), with better outcomes in terms of passive range improvement compared to botulinum injection alone (Lindsay et al., 2021). It has been shown that rehabilitation in addition to botulinum injection is critical to its success as a treatment (Denier et al., 2017).

As well as acting on Neuromuscular junction there is also some evidence that Botulinum toxin may influence neurotransmitter release of sensory neurons, with rat models indicating it may influence the release of Substance P (Lucioni et al., 2008). However, although it has been shown to influence nociceptor transmitter release in humans, it antinociceptive effect is still not definitively proven (Matak et al., 2017).

There is growing evidence that focal botulinum toxin injection within the first 3 months post stroke used in combination with upper limb rehabilitation could be useful in treating PSSP associated with proximal shoulder spasticity. This could also help to prevent detrimental secondary changes such as contracture. Chapter 5 of this thesis involves a systematic review to establish the current evidence base for the use of botulinum toxin within the first 3 months post stroke to treat PSSP associated with proximal shoulder spasticity. In addition, a small pilot study was completed to examine if the shoulder internal rotator Subscapularis is a key target for botulinum toxin in cases of PSSP and shoulder spasticity within 2 months of stroke.

Considering active movement changes

Passive shoulder joint restriction and pain often result in compensatory scapula movement changes in order to achieve elevation (Niesson et al., 2008). This is important as altered positions of the scapula relative to the humerus during active elevation influences length tension relationships which reduces efficiency of movement (Kibler et al.,2014; Smith et al., 2002). This may result in further injury or irritation of shoulder soft tissue structures (Kibler et al., 2014; Da Baets et al., 2014). Inflammation of soft tissue structures may exacerbate tone and/or fibrosis processes discussed. It is useful to understand how scapula movements change when pain and restriction develops so comparison can be made when treatments are applied. Prior to discussing scapula movements changes as a result of stroke it is useful to consider the different movements available at the scapula:

1) Upward rotation (also sometimes referred to as lateral rotation) refers to upward movement of the inferior angle of the Scapula in the coronal plane (see Fig 10 a). Upward rotation is coupled with relative posterior tilting of the scapula during forward humeral flexion, whereas downward rotation during lowering is coupled with relative anterior tilting (Ludwig et al. 1996). (see Fig 10 b)

2) Axial rotation where the Scapula if viewed from above rotates in the transverse plane into internal rotation or external rotation. (see Fig 10 c)

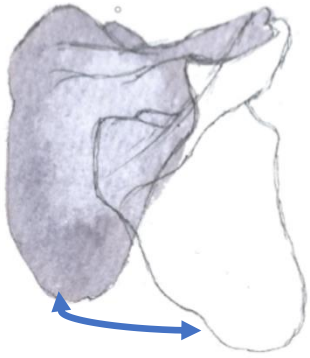
3) Elevation and depression within the coronal plane (see Fig 10 d)

4) Abduction and Adduction within the coronal plain (see Fig 10 e)

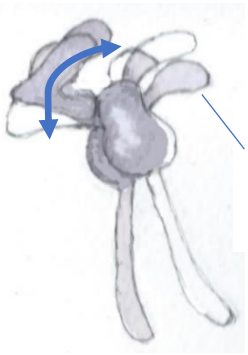
Scapula ‘protraction’ is the coupled movements of internal rotation and abduction whereas ‘retraction’ is the coupled movements of external rotation and abduction.

Fig. 10: Scapula Movements

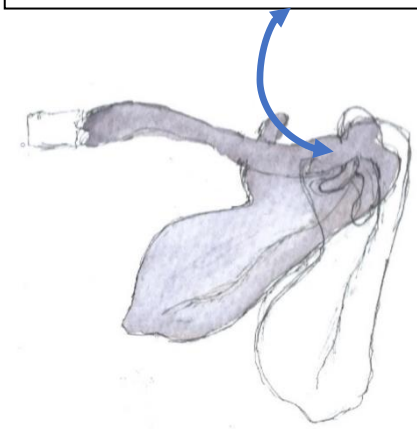
a: Upward/ Downward Rotation (posterior view)



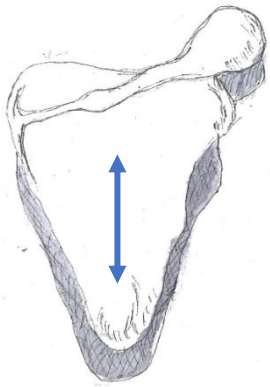
b: Anterior /Posterior tilt (side view looking at Glenoid)



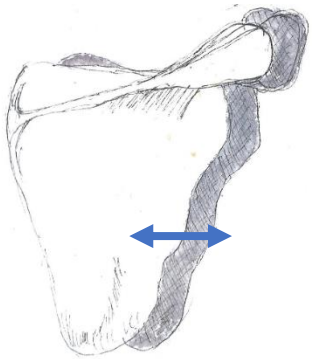
c: Axial Rotation: Internal/External Rotation (view from above)



d: Elevation/ Depression (posterior view)



e: Abduction/ Adduction



Scapula Upward Rotation changes after stroke

During shoulder complex elevation the dominant scapula movement is upward rotation (Ludewig et al., 2009). The amount of Scapula upward rotation relative to humeral elevation is known as the 'Scapulohumeral rhythm' (SHR). Early work reported a 2:1 ratio; where for every 2 degrees of humeral elevation, a 1 degree of Scapula upward rotation was observed (McQuade et al., 2016). This ratio was adopted by rehabilitation therapists as an established rule, however, ratios in shoulders have been proven to be very variable. SHRs between 1:1 to 6:1 have been reported in the general population (McQuade et al., 2016).

In stroke survivors SHR has been shown to relate to a subject's total shoulder elevation ability (Rundquist et al., 2012). Total shoulder elevation ability was divided into 3 categories and corresponded to the following SHR ratios:

ii) Between 45 to 50 degrees SHR was 4.1:1;

ii) Between and 95, SHR was 1.5:1;

iii) Between 105 to 130 degrees SHR was 2.1: 1

(Rundquist et al., 2012).

These data do not show a complete linear relationship between total elevation ability and SHR. However, <45 degrees elevation ability appears to result in at least double the amount of Scapula involvement in movement compared to when a subject can raise their arm >80 degrees (Rundquist et al.2012).

There is limited evidence for the effects of pain on scapula movement. Comparison of a small group of stroke survivors with different amounts of arm weakness, subluxation and levels of pain have shown different scapula strategies (Price et al. 1999). Pain in the hemiparetic arm results in a scapula lead strategy where Scapula upward rotation occurs earlier during shoulder elevation compared to the non hemiparetic side (Price et al., 1999). This pattern has also been observed in subjects without neurology who have frozen shoulder (Babyar et al.,1996). Subluxation was shown to result in scapula lag where Scapula upward rotation is delayed during elevation compared to the non-hemiparetic shoulder (Price et al. 1999). Scapula symmetry was observed when subjects had higher arm motoricity scores and where the majority could shoulder shrug (Price et al. 1999)

.

Humeral Rotation During Active Shoulder Elevation

Approximately 35 degrees of external rotation at humerus relative to the scapula is required to clear the glenoid tuberosity of the humerus of Scapula Acromion, and so allows greater joint elevation (Browne et al., 1990). In addition, proximal shoulder external rotation may impact on distal selectivity such as elbow extension (Beer et al., 2007). This means that potentially Glenohumeral external rotation restriction could limit total elevation achievable. When pathology such as frozen shoulder results in Glenohumeral external rotation restriction, it will be useful to examine if this results in adaptive axial rotation changes at the Scapula during shoulder elevation (Saikaley et al., 2020).

Scapula Axial Rotation changes after stroke

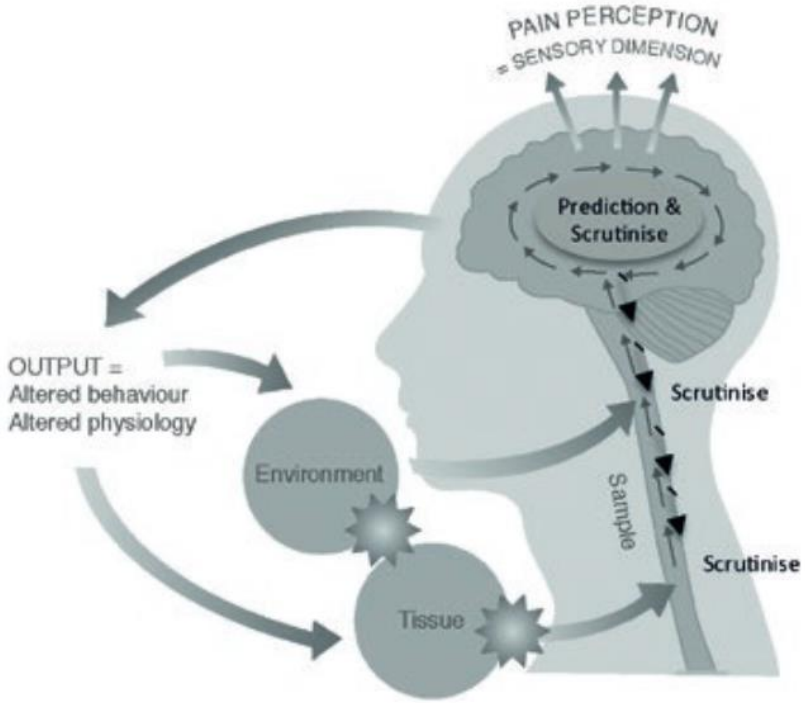
The main focus of studies to date have been upward scapula rotation and so axial rotation strategies are poorly understood. Only two studies have examined scapula axial rotation strategies during active elevation of hemiparetic arms (Linxandra et al., 2017; Meskers et al., 2005). In regard to axial Scapula movements during elevation there is currently no clear evidence for a common strategy in PSSP cases. When subjects were allowed to self select their elevation plane, a predominant scapula internal rotation axial strategy was demonstrated during forward flexion (Meskers et al., 2005). In contrast another study found predominant Scapula external rotation during elevation (Linxandra et al., 2017). However, underlying pathology and available passive joint ranges were poorly defined in these studies.

In light of the current evidence base, further research is required where pain presentations are well defined clinically, using standardised elevation protocols. This will help to improve understanding around Scapula movement changes when pain and restriction is present in the hemiparetic shoulder.

Chapter 3:Psychosocial factors that influence PSSP perception

Perception of pain is a complex interaction between biological ‘tissue damage’ and psychosocial factors such as perceived threat, past experience, social persuasion and the current environment (Thacker, 2015). This complex interaction is represented in the Mature Organism Model (MOM) where pain perception and modified behaviour (Output) are the result of higher level processes scrutinising inputs, see Fig 11 below.

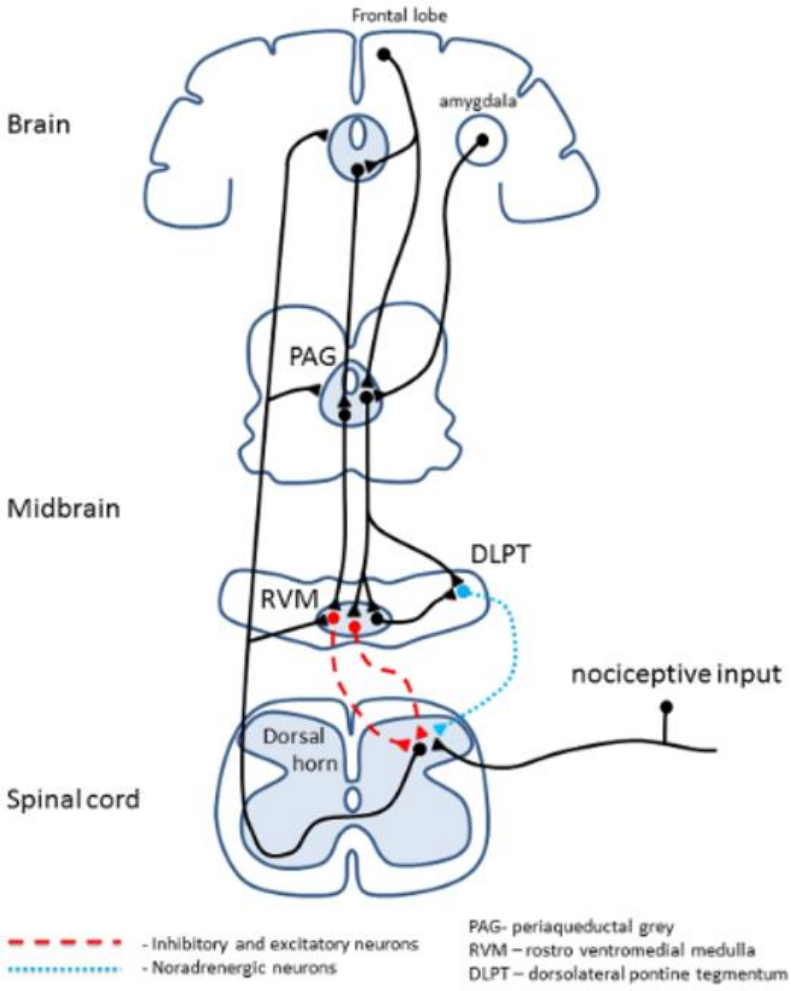
Fig. 11: The Mature Organism Model



(Taken from Fig 4, page 160, Thacker 2015, modified from Gifford 1998)

To consider how psychosocial factors influence pain perception in the Central Nervous System it worth considering the neuroanatomy of pain processing (Dean et al., 2013). The Rostral medial Medulla (RVM) and Periaqueductal grey (PAG) are important pain modulating areas which receive direct and indirect inputs from higher centres (Dean et al., 2013), These higher centres include the Amygdala, Anterior cingulate cortex and Anterior Insula, which are involved in processing emotion and perceived threat (Dean et al., 2013), see Fig 12. Therefore, pain perceived is a conscious experience that is the result of complex central nervous system responses to peripheral inputs across time (Dean et al., 2013; Gifford et al., 1998).

Fig. 12: Pain modulating and perception systems



As discussed in Chapter 1, stroke lesions can affect these pain modulating areas and this is believed to be the main cause of Central Stroke Pain (CSP) (Klit et al.,2009). Also, altered cognition and perception may also influence pain experience in stroke survivors adding to the challenges of understanding pain problems in this cohort (Payton and Soundy, 2020). Stroke survivors who were suspected of having CSP were excluded from research studies in this thesis.

As discussed in Chapter 2, the paretic arm may be more susceptible to soft tissue injury. After an initial injury is suffered, there is a local hyperalgesia mediated at the spinal level and by local chemical markers (Dean et al., 2013). This results in an adaptive avoidance of activity, to help protect the area which supports healing activity. However, in some people this initial adaptive behaviour can turn into maladaptive chronic fear avoidance and disuse after primary healing is complete (Vlaeyen et al.,2000). Ongoing pain can then impact in levels of social interaction and perceived quality of life' which in turn impact on motivation to engage in rehabilitation (Kemp et al., 2011)

Fear avoidance behaviour in people with lasting or chronic pain has been known about for many years with models developed in the 1990s (Vlaeyen and Linton, 2000). In the model below (Fig 13) fear avoidance beliefs appear to feed into hypervigilance and decreased movement of the affected body part which then influences perceived disability (Vlaeyen and Linton, 2000). Pain perception has sometimes been described as a balance between 'Danger in me' DIM beliefs versus 'Safety in me' SIM beliefs (Moseley and Butler, 2017). In the case where fear avoidance is dominating, it appears the 'danger in me' beliefs are dominant (Vlaeyen and Linton 2000; Moseley and Butler, 2017),

Fig. 13: The fear avoidance model (Vlaeyen et al., 2000)

Fear of movement is also known as ‘Kinesiophobia’ (Vlaeyen et al.,2000). Significant predictors of upper limb disability in the general population are Kinesiophobia and catastrophising beliefs, predicting 55% of variance in regression models (Das et al., 2013; Roelofs et al., 2007). Psychological factors influence Kinesiophobia levels and appear to predict ongoing chronic pain and perceived disability (Martinez-Calderon et al., 2018).

Depression and anxiety at baseline have been found to predict shoulder pain at 10 years in 607 factory worker (Leino and Magni, 1993). Also, psychosomatic stress in high school children predicted shoulder pain 7 years later in young adulthood (Siivola et al., 2004). These are therefore important factors to consider for stroke survivors. It has been reported suicidal ideation has been shown to be linked with higher rates of pain In stroke survivors (Tang et al.,2013). 59.9% of stroke survivors who experienced suicidal ideation experienced some form of pain whereas 37.7% of stroke survivors without suicidal ideation experiencing pain (Tang et al.,2013). Poorer ratings of mood, anxiety and lower scores for rehabilitation motivation have been shown to have a relationship with PSSP (Wanklyn et al., 1996; Gamble, 2002; Hadianfard & Hadianfard, 2008). This may be because more severe strokes are associated with PSSP, however psychosocial factors may influence perceived pain severity.

There is a lack of evidence regarding levels of fear avoidance in stroke survivors who have develop PSSP .This is important because if a stroke survivor is limiting their arm movement due to fear avoidance, this may extend pain longevity, exacerbate restriction processes and reduce functional recovery (Zhu et al., 2013; Jump et al.2021; Vlaeyen et al. 2010).

Chapter 4: Study 1: Investigating early passive external rotation restriction in the hemiplegic shoulder as a predictor of moderate to severe pain by 8 weeks post stroke.

Abstract

Purpose: Does early (upto 3 weeks post-stroke) restriction in passive external rotation of the hemiparetic shoulder predict moderate to severe shoulder pain by 8 weeks after stroke? Can other demographic and clinical measures help to predict the onset of post-stroke shoulder pain (PSSP) in the early or later (3 – 8 weeks) phase.

Methods: Stroke survivors were recruited as soon as possible after their first stroke (upto 2 weeks) and were considered at 'high risk of developing post-stroke shoulder pain if they did not exhibit voluntary movement against gravity in their affected limb on admission. High-risk participants were monitored for shoulder pain for upto 8 weeks post-stroke. Pain was classified moderate to severe if (i) self-rated pain on passive movement ≥5/10 on a Numerical Rating Scale (NRS) or (ii) pain was rated as ≥2 on the Richie Articular Index (patients unable to use self rating scales). Motor recovery was monitored upto 3 weeks post stroke.

Results: 32 stroke survivors at high-risk of PSSP were recruited. Those who developed pain within 8 weeks of stroke onset were more likely to have developed 10 degrees of external rotation restriction, 15 degrees of abduction restriction and reduced shoulder proprioception within 2 weeks of stroke. Those developing early (upto 3 weeks after stroke) compared to later (3-8 weeks after stroke) were more likely to be ischaemic strokes; female; over 65 years old; upper arm girths <30cm. Participants who remained pain free at 8-weeks post-stroke were more likely to have had recovery of external rotation motor power (≥1/5 on Medical Research Council motor assessment scale) at 3 weeks compared to the late pain group.

Conclusion: This study has identified useful clinical and demographic markers for identifying who will develop PSSP and by what stage post-stroke.

(4.1) Introduction

Post-stroke shoulder pain (PSSP) is commonly associated passive shoulder external rotation restriction (PSERR) and passive shoulder abduction restriction (PSABR) (Rajaratnam et al.,2007 and Lingren 2012). It is likely this restriction pattern is caused by two main pathologies: Frozen Shoulder and Spasticity of Shoulder Internal rotators (Saikaley et al., 2020).

It appears progressive loss of passive range in hemiparetic shoulder starts within days of stroke (Bohannon & Andrews, 1989; Ada et al., 2020). A small amount of pain free restriction may indicate the beginning of a pathological process or a combination of pathological processes that later result in pain later(Jump et al.,2021). It is therefore useful to establish if minimally detectable clinical signs of early PSERR and PSABR within the first few weeks of stroke, predict pain later.

A significant proportion of post stroke shoulder pain cases will present within the first 8 weeks post stroke (Rajaratnam et al., 2007; Gamble et al., 2002). The average length of stay in a London stroke unit is 3 weeks (21.4 – 23.7 days) (Rudd and Harding, 2017). Therefore, finding clinical markers in the first 2 weeks would be most useful to clinicians to inform early interventions.

Upper Limb motor weakness is well established independent predictor of PSSP (Saikaley et al. 2020). Admission National Institute of Health Stroke Severity Score (NIHSS) item 5 (upper limb) scores of ≥ 3 score on their affected arm (indicating no effort against gravity) have been found to have an Odds Ratio of 2.96 ($p = 0.03$) in predicting the development of PSSP (Kim et al., 2014).

Therefore, people with this amount of arm weakness tend to develop pain 3 times more often than people with more power post stroke (Kim et al. 2014). This is already useful clinicians in understanding the most at risk.

However, there are likely to be other demographic and baseline clinical characteristics that influence pathological processes within this high risk population. Certain characteristics could mean pain develops earlier and could give further insights into predominant pathological processes at work. Passive shoulder restriction as discussed will form the primary variable under investigation in this study but other clinical measures and demographics which have shown potential value as predictors of pain will now be discussed.

The relationship between clinical measures and developing pain

Hemiplegic Shoulder Subluxation

The relationship between subluxation and developing PSSP is unclear, possibly due to variation in how it is measured and study sample sizes in published literature (Saikaley et al., 2020). A large sample study indicated that subluxation explains around 46% of variance in who develops shoulder pain post stroke indicating that the presence of subluxation needs to interact with other factors such as poor handling in order for pain to develop (Paci et al., 2007; Wanklyn et al.,1999). This indicates it is still a relevant factor in developing pain so measuring subluxation should be included in any observation study protocol.

Arm Girth assessment

Loss of upper arm muscle bulk occurs in all upper limbs that experience significant weakness post stroke (Gray et al., 2012). This atrophy is likely to impact on the onset of stiffness and pain (Gray et al., 2012; Alison et al. 2018). Upper arm girth of stroke survivors has been found to range from 30.5 – 31cm when measured within 48 hours of stroke (n = 40) (Linn et al.,1999). This represents a baseline value prior to atrophy. This sample was composed of 18 men and 22 women, 9 with right side hemiparesis and 31 with left hemiparesis (Linn et al. 1999). It is likely there was some variation between women and men but this analysis was not included in the published article (Linn et al. 1999). As upper arm girths were on average > 30cm in this study, the relationship of the dichotomous variable (<30cm (below average) and ≥ 30cm) of upper arm girth at baseline will be explored to establish if it has a relationship with shoulder pain outcome.

It is known that regular exercise helps to protect against age related joint and tendon changes (such as tendinosis) and reduces age related sarcopenia (Seguin et al. 2003). It is therefore possible that stroke survivors with great upper arm bulk at baseline may have better joint health and this may influence if they develop pain and the rate of onset of pain and stiffness when hemiparesis develops. It is of interest to investigate if stroke survivors who have arm girths narrower than average (<30cm) at baseline compared to average and above (≥30cm) are different in relation to their risk of developing pain at 8 weeks post stroke.

Sensation (Light Touch and Joint Position Sense)

As discussed, motor weakness is a key predictor of PSSP and the extent of upper limb weakness is associated with increased stroke severity (Saikaley et al., 2020). It is therefore unsurprising that light touch and joint proprioception impairment which is also associated with increased stroke severity have been found to have an association with PSSP (Hadianfard & Hadianfard, 2008; Niesson et al. 2009; Lingren et al. 2013). However, no studies to date have examined how variations in baseline clinical measures of sensation and proprioception within high risk stroke survivors influences the onset of pain within 8 weeks of stroke.

Participant rated Mood, Anxiety and Health

Patient rated measures of mood and anxiety have been shown to be potential predictors of developing PSSP in 3 separate studies (Wanklyn et al., 1996; Gamble, 2000; Hadianfard & Hadianfard, 2008). This is likely because pain is modulated by inputs from higher centres that perceive threat and that scrutinise sensory inputs based on past experience as highlighted in the Mature Organism Model (Gifford, 2013).

The relationship between stroke survivor demographics and developing pain

In addition, to the clinical measures discussed above the following patient demographics are of interest as potential predictors of pain by 8 weeks post stroke.

Gender (Male/Female)

In the general population women seem to be more affected by frozen shoulder, which causes external rotation and abduction restriction (Erikson et al.,2019). In a large population examining all patients treated for frozen shoulder by a consultant 946 were women and 431 were men (Erikson et al.,2019). This could be explained by the phenomenon that men are less likely to seek help for musculoskeletal problems (Galdas et al., 2005). Alternatively, this could be because gender genuinely influences the biology of shoulder stiffness and pain. This may explain why in large population studies women lose external rotation with age quicker than men (Gill et al. 2020)

Age (Over/Under 65 years old)

As muscle and joint change as result of ageing, it is of interest if this is predictor of developing pain by 8 weeks post stroke. Participants over 65 are more likely to have arthritis and shoulder active range (Loeser et al., 2010; Gill et al., 2020). Reduced range at baseline and metabolic changes related to age could result in faster rates of range loss in the paretic shoulder and faster development of pain after stroke (Cucchi et al. ,2017). It is likely that age related tendon changes and calcification called 'Tendonosis' may make soft tissue structures more susceptible to injury (Bass et al.,2012). This could result in a pro inflammatory joint environment allowing restriction and pain processes to develop quicker (Jump et al., 2021).

Type of Stroke (Haemorrhagic vs Ischaemic):

The potential inter-relationship between frozen shoulder and ischaemic stroke has previously been explored in a large population study (Kang et al. 2010). Developing frozen shoulder seemed to increase risk of having an ischaemic stroke within 2 years by 1.22 (Kang et al., 2010). However, there was concern about an imbalance in vascular risk factors between groups and a repeat study was completed (Wu et al., 2012). In 657 subjects, similar proportions of around 3% in frozen shoulder and non-frozen shoulder cohorts suffered a stroke at 2 years (Wu et al.,2012). However, there is a possibility that vascular processes that result in someone being more susceptible to ischaemic stroke may make them more at risk of frozen shoulder. Therefore, it is of interest to establish if this influences outcome at 8 weeks.

Side of hemiplegia (Left vs Right)

One study examined the relationship between side of hemiplegia in 58 stroke survivors with pain as an outcome at 16 months. It found a significant relationship between left side hemiparesis and pain. Odds Ratio of for this variable was 10.47 (CI 1.92 – 57.05) (Lindgren et al., 2012). The large confidence intervals here could be because the percentages of included participants (41% right hemiparesis and 59% left hemiparesis (n=58)).This was not discussed by the authors but there may have been some selection bias, as potentially people with right hemiparesis are more susceptible to communication difficulties and are therefore harder to recruit (Lingren et al.,2012). It has been speculated that this may be result of a higher proportion of associated neglect in left side hemiparesis and so it may enhance learned non-use of the limb (Lingren et al. ,2012). Therefore, it is of interest to establish if side of hemiplegia predicts pain earlier by 8 weeks post stroke.

Hemiplegia on the dominant hand

A study of 1000 right handed men showed they had significantly reduced range in their dominant arms compared to their non-dominant side (Gunal et al., 1996). Tendon changes that may have occurred in the dominant side may therefore influence the onset of pain and restriction in the hemiparetic arm stroke compared to hemiparesis that affects non dominant arms.

Transfer Status

In a study of 69 stroke survivors an association was found between people who required assistance with transfers and developing PSSP (Wanklyn et al.,1996). A possible mechanism for this association is that people with higher dependence in regard to transfers and activities of daily living have been found to be more susceptible to shoulder soft tissue injury (Idowu et al. 2017). This is potentially due to more severe upper limb paresis being present in people with increased transfer dependence and could also be due to poorer joint protection (Wanklyn et al. 1996) A significant confounding variable that needs to be considered in this association is stroke severity but it of interest to establish if transfer dependence does have an association with those that develop pain.

Diabetes

A recent meta-analysis of PSSP risk factors has shown that diabetes could be a useful predictor (Holmes et al. 2020). This is because advance glycation end produces (AGES) accumulate in soft tissues in people with diabetes which makes soft tissue stiffer and weaker (Holmes et al.2020).In the general population active shoulder range in flexion, abduction and external rotation was shown to be significantly reduced in people with diabetes even after adjusting for age and sex (Gill et al., 2020).

Glycation end products have also been found to accumulate with age and have been found to act as immune modulators by attracting cells that release pro-inflammatory cytokines (Miller et al. 2022). This could explain why diabetes has a close relationship with people developing frozen shoulder.

(4.2) Study 1 Hypotheses

This study will test six hypotheses. Hypothesis 1 is the primary hypothesis of this study:

Background to Hypothesis 1

When the characteristics of 105 stroke survivors without PSSP were compared to 30 subjects with PSSP; 10 degrees of passive shoulder external rotator restriction (PSERR) was found to have a 93% sensitivity and 83% specificity in predicting that a stroke survivor would have PSSP (Numerical Rating Scale ≥5/10), (Rajaratnam et al., 2007). Interrater analysis of shoulder complex external rotation measurements found that to be 90% certain that an observed change is not the result of measurement variability or error, a minimum of 8 degrees of change is required (Salamh et al. 2012). Another study found potential error of measurement for external rotation measurement to be a similar value of 8.4 degrees (Dougherty et al., 2018). Therefore, a marker of 10 degrees of external rotation restriction will ensure change is not the result of measurement error. The presence or absence of 10 degrees of external rotation restriction at baseline features was therefore a dichotomous variable that could then be compared to the outcome:

1) Pain by 8 weeks post stroke

2) No Pain by 8 weeks post stroke.

Hypothesis 1: The development of moderate to severe pain on passive hemiplegic shoulder movement occurring within 8 weeks of stroke can be predicted by the development of at least 10 degrees of passive shoulder external rotation restriction within 2 weeks of stroke

Background to Hypothesis 2

As abduction and flexion restriction can also develop in cases of Frozen Shoulder (FS) and/or Spasticity of Shoulder Internal Rotators (SpIR), these movements will also be examined as potential predictors**.** Glenohumeral flexion and abduction is measured by blocking scapula movement. 8.8 and 8.98 degrees were found to be standard measurement errors for Glenohumeral flexion and abduction respectively (Dougherty et al., 2018). Therefore, 10 degrees will be set as a marker of meaningful change in these movements.

Shoulder complex flexion and abduction is measured by allowing the scapula to move. 14.30 and 14.98 degrees were found to be standard errors of shoulder complex flexion and abduction measurement respectively (Dougherty et al., 2018). Therefore, a marker of 15 degrees was set as meaningful change in shoulder complex passive movements.

Hypothesis 2:

a): The development of moderate to severe pain on passive hemiplegic shoulder movement occurring within 8 weeks of stroke can be predicted by the development of at least 15 degrees of shoulder complex abduction and/or flexion restriction within 2-weeks of stroke is a predictor of subsequent moderate to severe pain on hemiplegic shoulder movement within 8-weeks of stroke.

b) The development of moderate to severe pain on passive hemiplegic shoulder movement occurring within 8 weeks of stroke can be predicted by the development of at least At least 10 degrees of glenohumeral flexion and/or abduction restriction will be a predictor of subsequent moderate to severe pain in the hemiplegic arm within 8 weeks post stroke

Background to Hypothesis 3

As discussed, certain demographics such as gender, age and side of stroke may be useful predictors. In addition, other clinical markers such as proprioception and subluxation require further investigation to establish if they are also predictors of pain.

Hypothesis 3:

a) Developing moderate to severe pain on passive hemiplegics shoulder movement within 8 weeks will show a statistical relationship between previously identified as risk factors, such as gender, age, mood and anxiety.

b) Developing moderate to severe pain on passive hemiplegic shoulder movement within 8 weeks will show a statistical relationship between clinical measures of shoulder joint subluxation, upper arm girth, upper limb light touch, upper limb proximal proprioception and upper limb spasticity

Background to Hypothesis 4

As the average length of stay in on a stroke unit is 3 weeks, Early Pain was defined as within 3 weeks of stroke (0 – 21 days) and Late Pain was defined as between 3 and 8 weeks (21 – 56 days)

.

Hypothesis 4: Baseline clinical measures will be different for stroke survivors who develop moderate to severe pain on shoulder movement within 3 weeks (Early Pain) compared to those who develop pain between 3-8 (Late Pain) weeks post-stroke.

Background to Hypothesis 5

As motor weakness is a key predictor of developing PSSP and restriction, it is likely that motor recovery could be protective of developing pain by 8 weeks.

Hypothesis 5: High risk stroke survivors who do not develop pain by 8 weeks post stroke will have significantly more proximal shoulder motor recovery at 3 weeks compared to those that develop pain between 3 and 8 weeks (Late pain).

Background to Hypothesis 6

When stroke survivors develop pain, the following clinical criteria will be used to establish if Frozen Shoulder (FS) and Spasticity of the Internal Rotators (SpIR) are present. This will help to compare proportions to previous research in a high-risk population.

¶ Frozen shoulder is clinically diagnosed by at least 50% external rotation restriction compared to the unaffected side (Ranagan et al., 2020). Alternatively, 30% External rotation in combination with either 30% Abduction restriction or 30% Internal rotation restriction also confirms Frozen shoulder clinically (Ranagan et al., 2020).

A cut-off value of ≥2 on the Modified Ashworth Scale (MAS) was chosen to define Spasticity of the shoulder internal rotators. This has been used by previous researchers to ensure muscle guarding is not misinterpreted as spasticity (Rajaratnam et al., 2007).

Stroke survivors with upper limb spasticity show much higher proportions of PSSP (80%) compared to those with flaccidity (18%) (Van Ouwenaller et al.,1986). Therefore, it is possible the development of SpIR and FC are co-related in PSSP.

Hypothesis 6: Participants who develop moderate to severe pain on movement will have associated clinical signs of Frozen Shoulder and Spasticity of the shoulder internal rotators.

(4.3) Methods

Subjects

In this cohort study, consecutive patients admitted to a London Hyper Acute Stroke Unit (HASU) and Acute Stroke Unit (ASC) were screened for inclusion over 14 months. Stroke survivors were considered for recruitment if they were deemed at 'high risk' of developing shoulder pain in their hemiplegic arm. High risk was defined as having a score of ≥3 on the NIHSS scale item 5 In the hemiplegic arm: i.e., no effort against gravity (Kim et al., 2014). The following inclusion/exclusion criteria were used:

Inclusion Criteria

a) Within 14 days of 1st stroke

b) An admission score of 3 or more on item 5 of NIHSS scale

c) Aged 18 years old or over

Exclusion Criteria

a) Pain in the shoulder (on the hemiplegic side) in the 6 months prior to stroke

b) Moderate to significant pain (≥5 Numerical Rating Scale) in hemiplegic shoulder on passive movement at screening (to be defined later in this methodology)

c) History of surgery or orthopaedic fixation in hemiplegic shoulder

d) Passive bone restriction and/or injury. Whilst it was not possible to have plain x-rays conducted on all participants, any participant with a hard 'end feel', suspected trauma and or significant joint crepitus were x-rayed as per usual care

Study 1 Timeline:

Baseline: a suite of clinical measurements (see below) was collected as close as possible to the participants 1st stroke (with 14 days).

Pain, Motor Activity and Passive Range was measured every 3 – 4 days upto 3 weeks post stroke. Pain at rest, on movement and at night was then monitored upto 8 weeks.

Study end point for participants

Participants' involvement in the study was complete if they:

(i) Developed moderate to severe pain in their hemiplegic shoulder by 8 weeks

(ii) They reached 8 weeks post stroke without developing pain.

Screening for ability to use a Numerical Rating Scale (NRS)

Participants were screened to ensure they were able to rate their pain use vertical numerical rating scales, via the Ability Q (Turner-Stokes and Rusconi, 2003), see Appendix A. The Ability Q checks if a potential subject can mark the middle, top and bottom of a scale (Turner-Stokes and Rusconi, 2003).It is a check that they conceptually understand the question and understand that the vertical line is scale with a top and bottom.

Participants were then categorised as below:

Category 1: participants who completed the Ability Q accurately and so could accurately rate pain on a Visual Analogue Scale.

Category 2: participants who made errors in the ability Q and so participated in a reduced protocol and their pain was rated using the Richie Articular Index (RAI).

Category 1 participants were asked to rate their shoulder pain on vertical 11 point (0 -10) Numerical Rating Scales (NRS) using pictures from the Shoulder Q developed for stroke survivors, to improve accuracy of rating (Turner- Stokes and Jackson et al. 2003), see Appendix B

Category 2 participants were unable to rate their pain on VAS scale were rated by the assessor using the Richie Articular Index (RAI) (Bohannon & Le Fort. 1986)

0 The patient has no tenderness OR visible discomfort

1 The patient complains of pain (voluntarily or when asked)

2 The patient complains of pain, winces

3 The patient complain of pain, winces and withdraws arm

Shoulder pain for Category 1 and 2 participants was always rated at the end of the assessment protocol. This was to ensure the hemiplegic arm was moved extensively prior to evaluation. This is because it is a known phenomenon that shoulder survivors tend to underrate their shoulder pain, if they are asked to rate their pain prior to the affected limb being moved (Nadler et al., 2018).

Defining Moderate to Severe Pain

Several studies have examined what defines mild, moderate and severe pain and what defines a minimal detectable change (Serlin et al 1995, Lingren et al. 2007, Kelly et al.2001). Pain rated as 4/10 on a 0-10, 11 point Numerical Rating Scale (NRS) has been shown to have a moderate impact on function (Serlin et al., 1995; Lingren et al., 2007). In addition, in cases of PSSP, a pain rating of greater than 4/10 has was always associated with an abnormal contrast enhanced shoulder MRI in terms of potential soft tissue pathology being present (Pompa et al. 2011).

A previous study of PSSP used a numeral rating of ≥5/10 to ensure pain is established so this was also set as the cut off for this study (Rajaratnam et al., 2007). For people unable to use Numerical scales, wincing with or without pain withdrawal on passive movement was used as marker of moderate to severe pain which corresponds to ≥2/3 on the Richie Articular Index (RAI) (Bohannon and La Fort, 1996). This study aims to examine if 10 degrees of external rotation restriction develops prior to these markers of moderate to severe pain.

Baseline Data collection

For Hypotheses 1 and 2 The following Data were collected

Markers of Hemiplegic Shoulder Restriction at baseline

a) Presence of 10 degrees of External Rotation Restriction (Yes/No)

b) Presence of 10 degrees of Glenohumeral Flexion and Abduction restriction (Yes/No)

c) Presence of 15 degrees of Shoulder Complex Flexion and Abduction restriction (Yes/No)

Every 3 Day upto 8 weeks Pain was monitored

a) Category 1 participants : Patient rating of pain on movement

b) Category 2 participants: Richie Articular Index assessor rating

For Hypotheses 3 – 4 the following Data were collected

Patient characteristics

a) Gender (Male/Female)

b) Age (Over/Under 65 years old)

c) Side of hemiplegia (Left/Right)

d) Whether the hemiplegia was on the dominant hand (Yes/No)

e) Type of Stroke (Haemorrhagic/Ischaemic)

f) Transfer status (hoist versus hoist not required): As a measure of full dependence. Due to the acuteness of the caseload this was more appropriate that transfers with or without assistance.

g) Diabetes (Yes/No)

Other baseline joint measurements

a) Subluxation: difference in Acromion to Humeral head distance (Non hemi side minus the hemi side)
b) Upper Arm Girth (cm)
c) Light Touch Sensation (Upper Arm and Palm Fugl -Meyer Score)
d) Proprioception (Thumb, Wrist, Elbow and Shoulder Fugl -Meyer Score)
d) Motor Activity of Shoulder Flexors, Abductors, Internal and External Rotators
e) Modified Ashworth Spasticity of Internal Rotators and Adductors

Baseline participant Rated Health, Depression and Anxiety

a) Self Rated Health on 100 scale
b) Depression rating (DISC score /10)
c) Anxiety rating (ASC score /10)

For Hypothesis 5 the following Data Were collected every 3 days upto 3 weeks post stroke

Motor power

Clinical power assessments will be conducted for the following movements
a) Shoulder Flexion
b) Shoulder Abduction
c) Shoulder Internal Rotation
d) Shoulder External Rotation range

For Hypothesis 6

Moderate to severe pain was defined as when category 1 participants rated their pain as ≥ 5/10 on movement or category 2 participants were rated aw ≥ 2/3 on the Richie Articular Index (RAI)

Participants who developed the levels of pain discussed had the following measures completed:

a) Pain ratings (category 1 or 2)

b) Passive Shoulder External Rotation, Abduction and Flexion

c) Modified Ashworth Scale of shoulder internal rotators and adductors

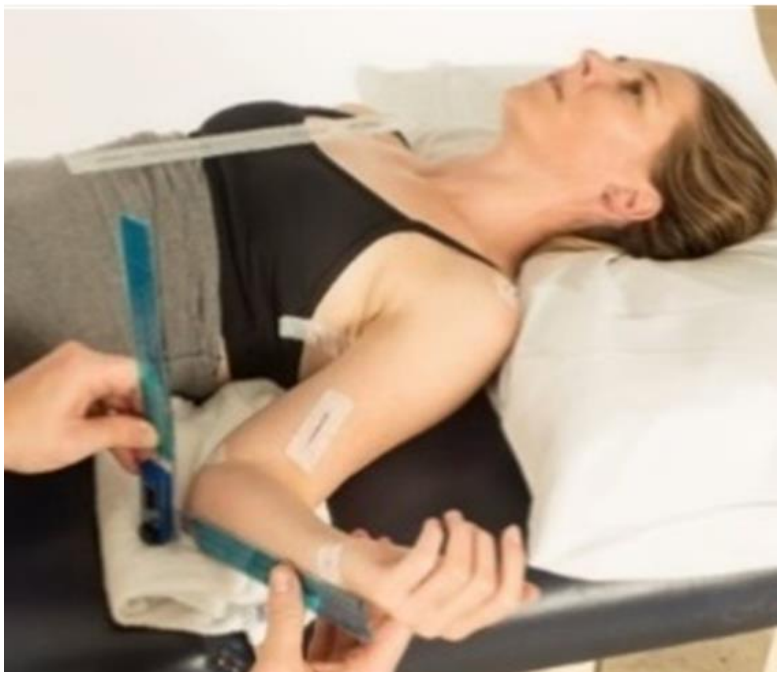
This will allow classification of participants as either having clinical signs of Frozen Shoulder and/or Proximal Spasticity in Shoulder Internal rotators.

Measuring joint angles

Passive range is measured clinically with a goniometer using standardised anatomical reference points and body positions (Norkin and White, 2016) (See Fig 14 below). As goniometers are commonly used by clinicians, this was used to establish the primary range outcome to ensure the external validity of this study (Denscombe et al., 2017).

Shoulder complex measurements of range involve allowing the scapula to move so the range measurement is a combination of glenohumeral and scapula-thoracic movement. Glenohumeral movement is measured by moving the humerus to the end of range whilst blocking scapula movement (Norkin and White, 2016). In the case of shoulder external rotation measurement there is minimal scapulothoracic movement, however, the scapula is not blocked so technically scapula complex movement is measured (Norkin and White 2016).

Fig. 14: Goniometry to measure Shoulder External Rotation

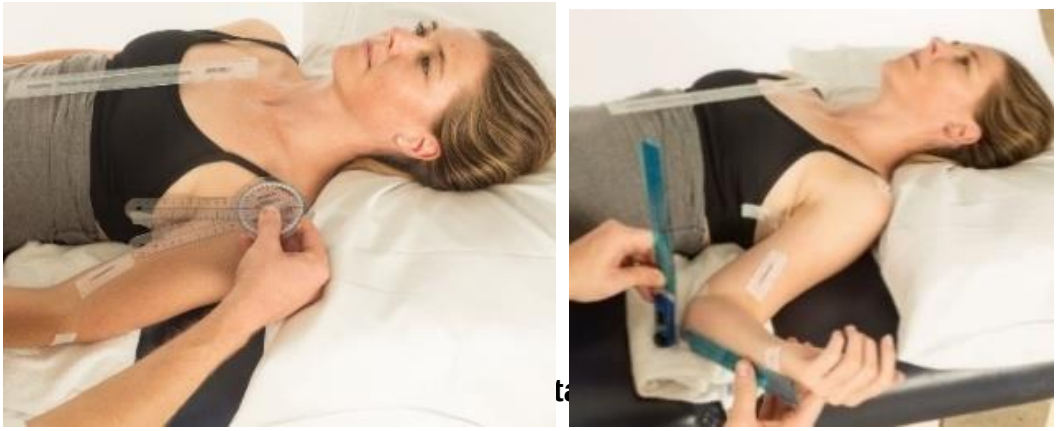


Passive External Rotation was measured in supine with one pillow head support and knee in supported slightly flexed position (see Fig 15). This maximum support position was to help reduce participant tone and guarding to allow more accurate passive measuring. If the participant was using an air mattress this was inflated to a maximum pressure setting.

Fig. 15: Standardised supine assessment position with one pillow behind head

Participants arms were then abducted to 20 degrees and the elbow supported with a small towel to help reduce muscle guarding (see Fig 16). The arm was then externally rotated to maximum passive range and the range was measured (see Fig 16 overpage). This was conducted for the non-hemiplegic arm and the hemiplegic arm. The difference in external rotation between the two measurements was calculated. This measurement procedure was modified from Norkin and White, 2016**.**

Fig.16: Measurement of Passive External Rotation in supine



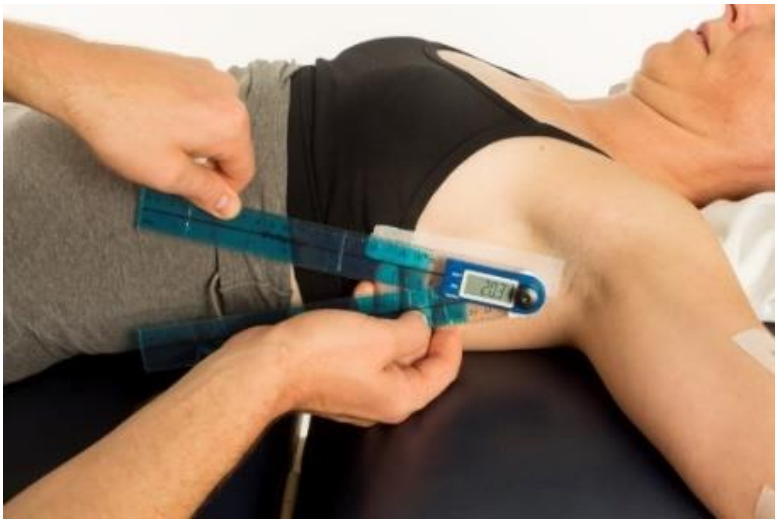
The following methodology was used to test the following hypothesis

Measuring Shoulder Flexion and Abduction

For shoulder flexion, passive range was measured relative to the mid axillary line (Fig 17&18). Measurements of the mid axillary line relative to horizontal were taken to aid standardisation of future measurement (B).

Fig. 17: Measuring Passive Shoulder Flexion relative to the mid axillary line

Fig 18: Measuring the mid axillary line relative to horizontal

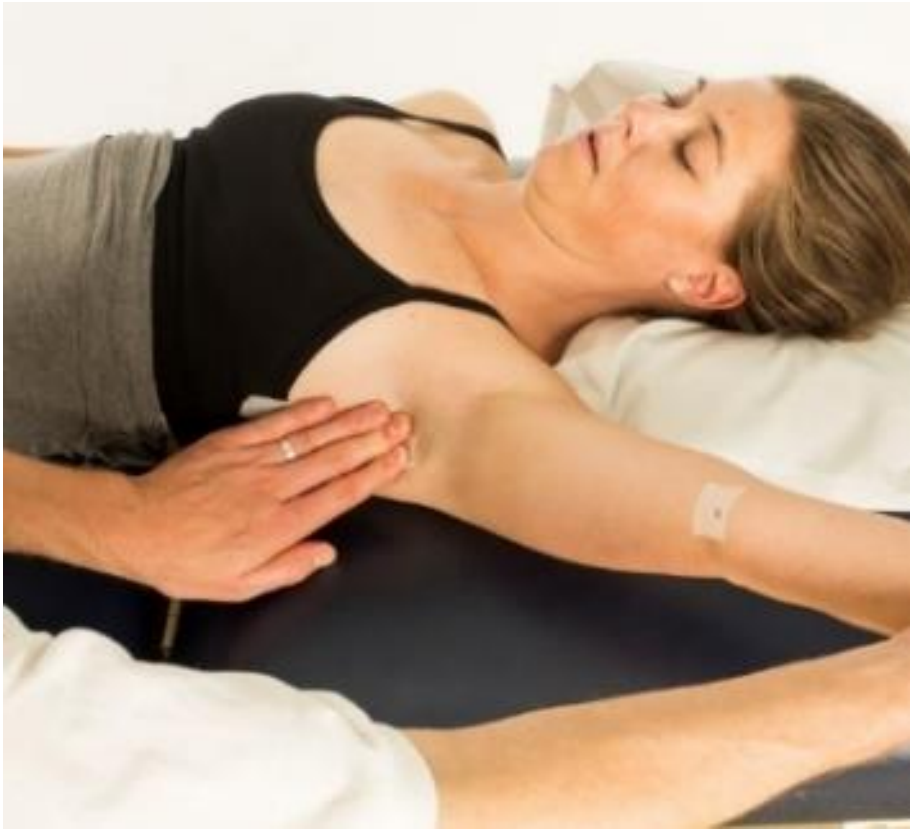


Shoulder abduction was measured relative to the line of the sternum (see Fig 19)

Fig. 19: Measuring shoulder abduction relative to sternum line

Glenohumeral Flexion and Abduction and Shoulder Complex Flexion and Abduction were measured in the same supine position as external rotation. Glenohumeral movements were quantified by measuring full passive range whilst the assessor blocked the scapula (see Fig 20)

Fig. 20: Blocking Scapula movement when measuring glenohumeral abduction



Measuring subluxation

It was not possible to measure subluxation in the standard upright seated position pictured in Fig 21 below, due to the acuteness the stroke survivors. Instead, all participants were positioned to 60 degrees high sitting with a slight knee bend, arms were unsupported by their side Fig 22

Fig 21: Standard Position for measuring subluxation

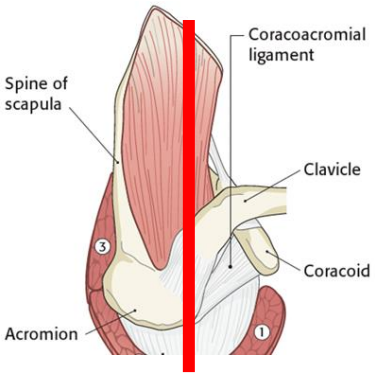
(Fig 20 taken from Fig 1, Kumar et al. 2014)

Fig 22: 60 degree high sitting position used in study 1

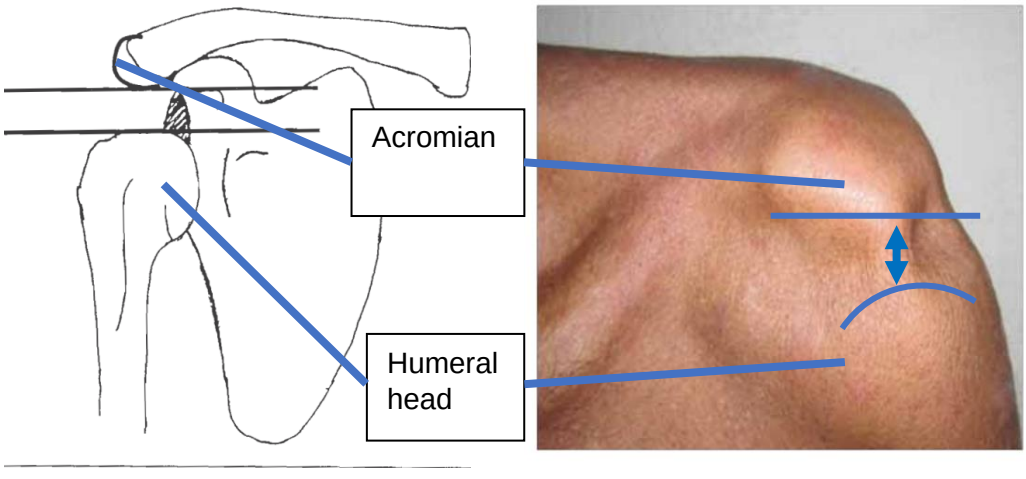
Vernier Calliper measurements were taken by palpating for the most anterior point of the acromion (See Fig 23) and then measuring the distance to the humeral head perpendicular to this point (See Fig 23). Palpation of the gap has been shown in a previous study of twenty subjects to correlate well with x-ray measurements of subluxation (r = 0.76 p =<0.001) (Hall et al., 1996).

Fig 23: Calliper method for measuring subluxation

Most Anterior point of the Acromian



Acromial to Humeral head distance

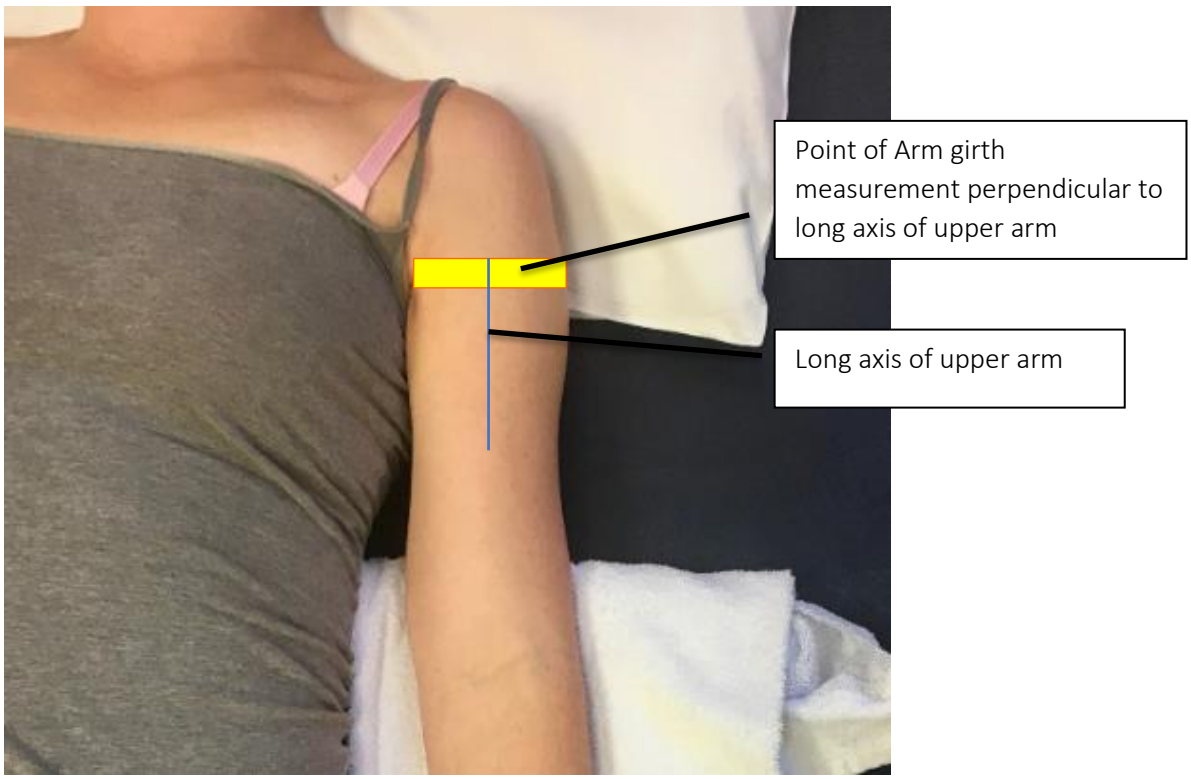


(Images taken from Fig 1 on page 529 Hall et al. 1996; and Fig Razaq et al. 2016)

Arm Girth assessment

To measure global muscle bulk, the circumference of the upper arm was measured with a tape measure at the upper most point of the axilla perpendicular to the long axis of the arm (see Fig 24). This methodology was previously used by Linn et al.1999 as a way of monitoring muscle atrophy over time. The mean value at baseline was for the previous study was 30.995 cm. Therefore, the dichotomous outcome of an Upper Arm Girth of ≥30cm being present or not will be used as a way of investigating if arm bulk has a relationship with outcome.

Fig. 24: Upper Arm Girth Measurement



Hemiplegic arm light touch sensation assessment

Light touch sensation was assessed proximally at the biceps muscle belly at the point where the mid arm girth was measured and distally at the palmer surface of the hand using the Fugl Meyer assessment criteria. *Scoring was as follows:*

(0) – Absent–- If the patient states that he does not feel the touch on the affected side, the score is absent.

(1) – Impaired–- If the patient states that he feels the touch on the affected side and the touch does not feel the same between affected and unaffected sides or the response is delayed or unsure, the score is impaired.

(2) – Intact–- If the patient states that he feels the touch on the affected side and the touch feels the same between affected and unaffected sides, the score is intact. (Sullivan et al., 2010)

Hemiplegic arm proprioception assessment

Proprioception was measured at the thumb interphalangeal joint, wrist, elbow and shoulder using the Fugl-Meyer assessment protocol (Sullivan et al. 2010). Each joint was held on the lateral aspects of the joint to minimize cutaneous feedback. Each joint was moved through a small amplitude (approximately 10 degrees for wrist, elbow shoulder and 5 degrees for the thumb joint). Each joint was moved 6 times Scoring was as follows:

(2) -Intact -participant was accurate 4 or more times

(1) -Impaired -participant was accurate less than 4 times

(0)- Absent- inaccurate with all movements

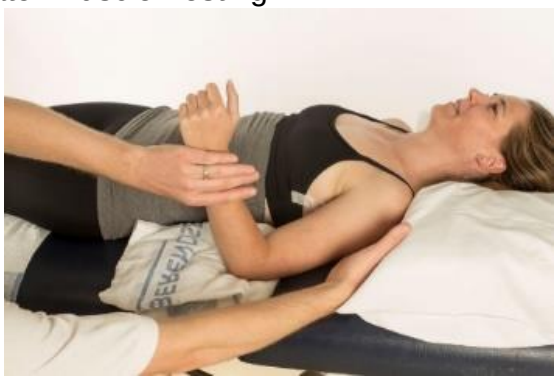
(Sullivan et al., 2010)

Hemiplegic arm strength assessment

All recruited participants had no effort against gravity at baseline, so the presence of active flickers or more in the movements of shoulder flexion, abduction, internal rotation and external rotation at 3 weeks (discharge) were compared for Late Pain (21–- 56 days) and No Pain (by 56 days) groups. In order to record motor changes in the upper limb, manual muscle strength testing was conducted for Shoulder Flexion, Abduction, External Rotation and Internal Rotation. All manual muscle testing were conducted in the passive range assessment position described above. Patients were instructed to try to complete the movement whilst the assessor palpated the musculature of interest. As participants all had significant upper limb weakness the dichotomous variable of no muscle activity versus flickers or more muscle activity (≥1 on the Oxford Muscle scale) was collected. Examples of muscle testing positions are shown in Fig 25:

Fig 25: Examples of manual muscle testing technique

External Rotator Muscle Testing



Internal Rotator Muscle Testing

Hemiplegic shoulder Spasticity assessment

Modified Ashworth Scale (MAS) scores were measured for shoulder internal rotator and adductor tone. The MAS has been shown to have good inter- and intra- rater reliability (Rajaratnam et al., 2007). The rating scores are shown overpage in Table 2 overpage. Spasticity was considered present with a score of 2 or more (≥2) on the MAS (Bohannan and Smith,1987). This was to ensure there was less chance of muscle guarding being interpreted as spasticity (Rajaratnam et al., 2007). Standardisation of measurement was achieved by participants being always positioned supine as with the passive measurements. 3 passive movements were conducted in the alignment established in the passive goniometry.

Spasticity assessments were conducted at the beginning of each review to minimise the impact of sensory modification on participants levels of spasticity (Thibaut et al. 2013). Speed was regulated by counting 1001,1002,1003 to ensure moving through full range took 3 seconds. Scoring was as below conducted on the 3rd movement. If the assessor was unsure about the rating on the 3rd movement, then a 4th movement was allowed to ensure ratings were accurate (Bohannon and Smith 1987). In addition, the 'angle of catch', which is when resistance is first felt at the speeds discussed above was also measured as a guide to spasticity severity (Patrick and Ada, 2006). The starting position for the measurement is when the limb is in the position that allows the effector muscle to be at its shortest length. For example, internal rotator catch would be measured from the point of full internal rotation with the palm on the abdomen. The arm is then moved at into external rotation until a catch is felt (Boyd and Graham, 1999). The angle of catch is the angle between the start point and the catch point. An earlier catch indicates more severe spasticity (Ashford et al., 2018). Angle of catch is used in the Tardieu scale and has been shown to have more specificity in identifying true spasticity

when compared to MAS (Patrick and Ada, 2006). However, full Tardieu angles require taking the angle of catch from the total passive range, which is problematic in cases of restricted passive range, so only angle of catch was recorded as an outcome in this study (Patrick and Ada, 2006).

Table 2: Modified Ashworth Scoring: (Bohannon and Smith 1987)

Grade	Description
0	No increase in muscle tone
1	Slight increase in tone, manifested by a catch or by minimal resistance at the end of the range of motion within the limb is moved
1^{+}	slight increase in muscle tone, manifested by a catch, followed by minimal resistance throughout the remainder (less than half) of the range of movement
2	More marked increase in tone but limb easily moved
3	Considerable increase in tone – passive movement difficult
4	Limb is rigid in flexion or extension, abduction or adduction

Measuring Mood and Anxiety

Category 1 participants were asked to rate their subjective mood and anxiety scores via the Depression Intensity Scale Circles (DISC) and Anxiety Scale Circles (ASC) see Appendix C (Turner-Stokes et al. 2005). Participants were also asked to self-rate their health on the vertical analogue scale extracted from the EuroQol (EQ) Questionnaire (Van Reenan and Janssen 2017).

Statistical Analysis

To test hypothesis 1, the primary analysis examined the relationships between the dichotomous outcome of pain versus no pain by 8 weeks and the presence or absence of 10 degrees of external rotation restriction at baseline.

Secondary analysis compared the dichotomous outcomes of Late versus Early pain and No Pain versus Late Pain. All variables discussed were defined as dichotomous outcomes.

Contingency tables were produced to examine observed versus expected frequencies for each test case in 2x2 tables to ensure suitability of statistical tests. The expected count is calculated from the total of each row multiplied by the column total and then divided by the total sample size. In order to meet the criteria for Chi Squared testing of a 2x2 table, no less than 20% of fields should have less than 5 expected data points (Howell et al.,2011). The majority of tests did not meet this cases assumption and so Fisher's exact test was applied to prevent type 1 errors in interpretation.

It was not possible to complete Log Linear analysis of Outcome (Pain vs No pain) to examine higher order interactions as greater than 20% of the expected frequencies had a count of less than 5, in the variables of interest which violated conditions for that analysis.

For continuous variables tests of normality were conducted using Kolmogorov-Smirnow and Shapiro Wilks statistics. In addition, when independent groups were uneven Levene's test of Homogeneity of variance was applied to ensure appropriateness of tests. When data was non-parametric Mann Whitney U was used to compare two groups. All tests were two sided and where possible bootstrapping was conducted as an additional robust test to prevent type 1 reporting errors.

Ethical Approval

NHS Ethic approval was given from London Dulwich, REC number 18-LO-0225. All participants and carers were given time to consider their involvement in the study and to ask questions to ensure informed consent. Ethical approval was granted for next of kins to consent in cases of reduced capacity which was required for the two Category 2 participants.

(4.4) Results

Subjects

A total of 2485 potential participants were screened between April 2018 and December 2020 within 2 weeks of their first stroke (see Consort Diagram Fig 26). Of these, 69 patients consented to participate in the study; Nine participants (13%) were lost to follow up as a result of transfer of care and a further 16 participants (23%) were excluded for other reasons (see Consort Diagram Fig 26). 12 participants were classified as low risk and do not form part of this study analysis.

79 participants met all inclusion accept 14 had already developed ≥5/10 pain. This represents 18% of potential participants. 32 'high risk' participants were recruited. After data collection they were divided into two groups:

i) Pain Group: 22 (69%) developed moderate to significant pain within 8 weeks

ii) No Pain Group: 10 (31%) participants did not develop pain by 8 weeks.

There was no significant difference at baseline between the Pain group and No Pain group for:

a) Days post stroke of baseline measurements: U = 130.50 (SE 24.42), (p= 0.41)

b) Age: t (30) = -0.89 (p= 0.38), see table 3 overpage.

Other demographics are addressed in hypothesis 3.

30 participants were classified as Category 1 and 2 participants were classified as Category 2:

Category 1 (n=30): participants who completed the Ability Q accurately and so could accurately rate pain on a Visual Analogue Scale.

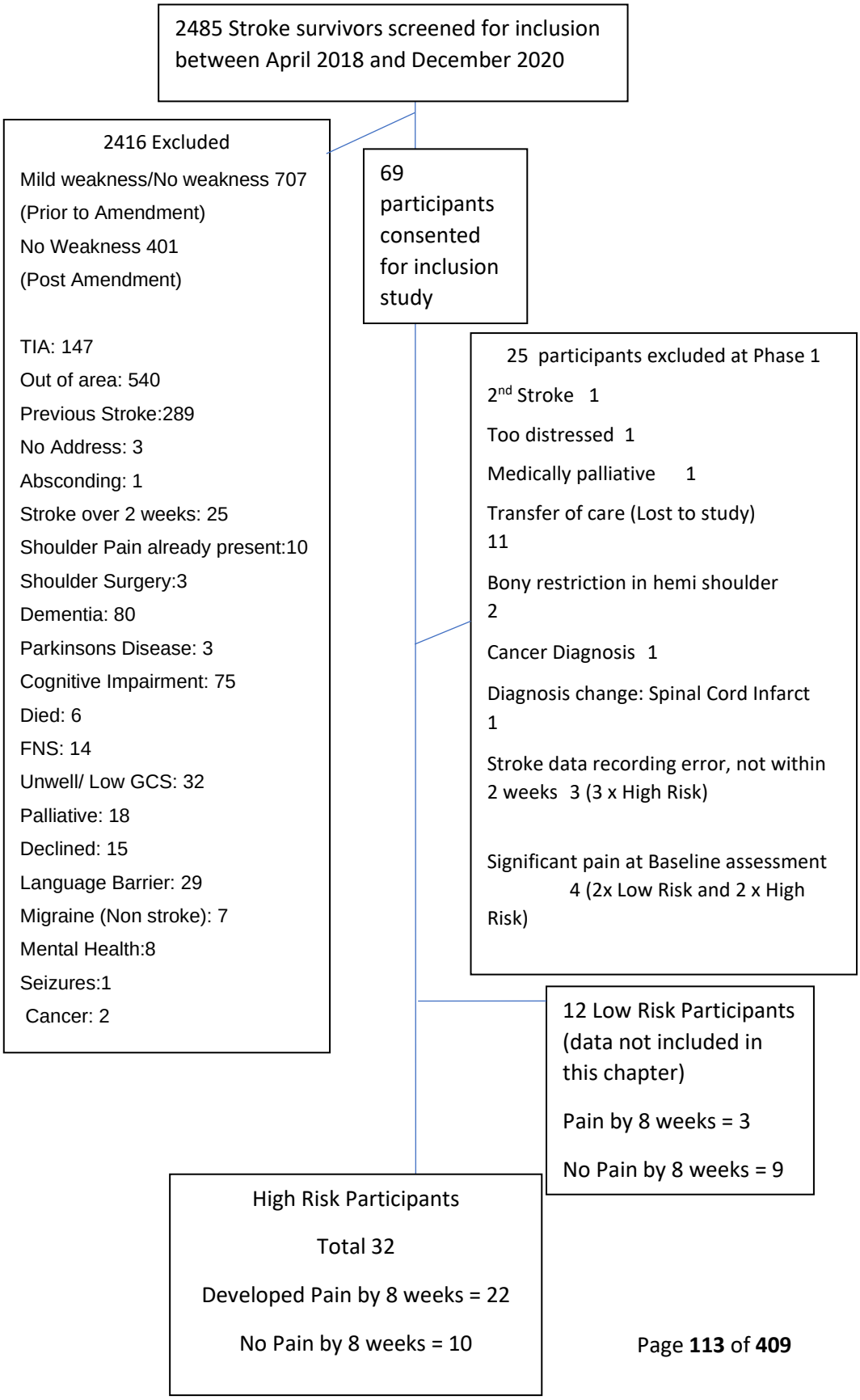
Category 2 (n=2): participants who made errors in the ability Q and so participated in a reduced protocol and their pain was rated using the Richie Articular Index (RAI).

Table 3: Study 1 Age and baseline times post stroke for Pain and No Pain groups

Baseline Demographics	**Pain (n= 22)**	**No Pain (n = 10)**
Age Range	34 – 93	42 – 85
Age (Mean)	67.64 (SE 18.29)	61.90 (SE 12.87)
Mean baseline post stroke (days)	8.45 (SE 1.01)	7.30 (SE 1.35)
Range of baseline time post stroke (days)	0 – 14	1 – 14

(SE = Standard Error)

Fig. 26: Study 1 Recruitment flow diagram



Results for Hypothesis 1

Hypothesis 1: *The development of moderate to severe pain on passive hemiplegic shoulder movement occurring within 8 weeks of stroke can be predicted by the development of at least 10 degrees of passive shoulder external rotation restriction within 2 weeks of stroke*

10 degrees of External Rotation restriction at baseline (within 2 weeks of stroke) showed a significant relationship with group (pain vs no pain) by 8 weeks post-stroke (Fishers Exact; p = 0.04). See 2x2 table 4 below:

Table 4: 2 x 2 Table: Participants in each category for baseline External Rotation restriction and Outcome (Pain vs No Pain) (Fishers Exact; p = 0.04)

Baseline Clinical Features (within 2 weeks of stroke)	**Pain by 8 weeks (n = 22)**	**No Pain by 8 weeks (n=10)**
10 degrees of External Rotation restriction **NOT present**	14	10
10 degrees of External Rotation restriction **Present**	8	0

Results for Hypothesis 2

Hypothesis 2 a) *At least 15 degrees of passive shoulder flexion and/or abduction within 2-weeks of stroke is a predictor of subsequent moderate to severe pain on hemiplegic shoulder movement within 8-weeks of stroke:*

There was no significant relationship between 15 degrees of shoulder complex flexion restriction (Fishers exact p = 1.00) and group (Pain vs No Pain) see table 5. There was a significant relationship between 15 degrees of shoulder abduction restriction at baseline and group (Fishers exact p = 0.04). See 2 x 2 table 6 overpage:

Table 5: 2x2 Table, Participants in each category: Baseline Shoulder Complex Flexion Restriction and Outcome (Fishers Exact, p = 1.00)

Variable	**Pain (n = 22)**	**No Pain (n= 10)**
No 15 degrees of Shoulder Complex Flexion Restriction at Baseline	20	10
15 degrees of Shoulder Complex Flexion Restriction at Baseline	2	0

Table 6: 2x2 Table: Participants in each category: Baseline Shoulder Complex Abduction Restriction and Outcome (Fishers Exact, p = 0.04)

Variable	**Pain (n=22)**	**No Pain (n=10)**
No 15 degrees of Shoulder Complex Abduction Restriction at Baseline	14	10
15 degrees of Shoulder Complex Abduction Restriction at Baseline	8	0

Hypothesis 2(b) *At least 10 degrees of glenohumeral flexion and abduction restriction will be a predictor of subsequent moderate to severe pain in the hemiplegic arm within 8 weeks post stroke*

There was no significant relationship between 10 degrees of hemiplegic shoulder glenohumeral flexion restriction, see table 7) (Fishers exact = 1.00) or 10 degrees of glenohumeral abduction restriction (see table 8) (Fishers exact =1.00) at baseline (within 2 weeks) and group (pain vs no pain).

Table 7: 2x2 Table: Participants in each category: Baseline glenohumeral flexion restriction and outcome (Fishers Exact, p = 1.00)

Variable	**Pain (n =22)**	**No Pain (n=10)**
No 10 degrees of Glenohumeral Flexion restriction at Baseline	20	10
10 degrees of Glenohumeral Flexion restriction at Baseline	2	0

Table 8: 2x2 Table: Participants in each category: Baseline glenohumeral abduction restriction and outcome (Fishers Exact, p =1.00)

	Pain (n=22)	**No Pain (n=10)**
No 10 degrees of Glenohumeral Abduction restriction at Baseline	16	7
10 degrees of Glenohumeral Abduction restriction at Baseline	6	2

Hypothesis 3 (a) *Proportions of demographics previously identified as risk factors will be different for pain versus no pain groups. In addition, mood and anxiety at baseline will be different for pain versus no pain groups*

There was no statistical difference between Groups (Pain vs No Pain) at baseline for the dichotomous variables of Gender, Age, Diabetes, Side of Hemiplegia (Hemi), Hemiplegia on dominant arm, Stroke Type or Transfer status (see table 9). There was no difference between groups for participant ratings of health, mood and anxiety at baseline (See table 10 overpage).

Table 9: Dichotomous Demographic Variables relationship with Outcome (Pain vs No Pain)

Dichotomous Variable	Conditions for Chi^2	N	Fishers Exact for relationship with Pain versus No Pain (p value)
Gender (Male/Female)	No	32	0.47
Number of participants over 65	No	32	0.71
Diabetes (Yes/No)	No	32	1.00
Side of Hemi (Left/Right)	No	32	0.24
Hemiplegia on dominant side (Yes/No)	No	32	0.37
haemorrhagic stroke (Yes/No)	No	32	0.41
Number of participants who were hoist transfer	No	32	0.12
Number of participants requiring Assistance of 2 to transfer	No	32	0.35
Number of participants requiring Assistance of 1 to transfer	No	32	0.35

Table 10: Baseline Self Rated Health, Mood and Anxiety and outcome (Pain vs No Pain)

Variable	Pain (n = 22)	No Pain (n =10)	Difference Test Statistic	P value
Self-Rated Health /100 (mean)	44.25 (SE 6.87)	47.78 (SE 6.19)	t(27) = 0.32	0.75
Depression (DISC) /10 (mean)	4.15 (SE 0.53)	4.44 SE 0.87)	U = 82.5	0.44
Anxiety (ASC) /10 (mean)	3.80	4.22	t(28) = 0.62	0.54

Results for Hypothesis 3

Hypothesis 3 (b) : *Baseline clinical joint measures of subluxation, arm girth, light touch, proximal proprioception and spasticity are additional predictors of pain by 8 weeks post stroke*

Subluxation

There was no significant difference between baseline Acromion to Humerus head distance difference (Hemi side minus Non-Hemi side) between the No Pain group (Mean 2.85mm, median 3.31mm) and the Pain group (Mean 3.62mm , median 3.25mm) was U = 121 (SE 24.6) (p = 0.66).

The relationship of other shoulder joint variables with outcome

The relationship of other baseline clinical measures with outcome are presented in Table 11 over page. As shown reduction of hemiplegic shoulder proprioception at baseline had a significant relationship with outcome (pain vs no pain) (Fishers exact p = 0.01). A 2x2 table of this variable is presented in Table 12 overpage.

Table 11: Baseline Clinical Joint measures (Pain vs No Pain Group)

Baseline Dichotomous Variable	Conditions for Chi^2	N	Fishers Exact for relationship with Pain versus No Pain (p value
Internal Rotator Tone 2 or more MAS	No	32	0.38
Adductor Spasticity 2or more MAS	No	32	0.64
Shoulder flexor activity	No	32	0.45
Shoulder abduction activity	No	32	0.25
External Rotator activity	No	32	0.57
Internal Rotator activity	No	32	0.24
Reduced Thumb proprioception	No	30	0.37
Reduced Wrist proprioception	No	30	0.66
Reduced Elbow proprioception	No	30	0.14
Reduced Shoulder Proprioception	No	30	0.01
Reduced Upper arm sensation	No	30	0.69
Reduced Palmar sensation	No	30	0.69

Table 12: 2x2 Table: Participants in each category: Baseline Shoulder Proprioception and Outcome (Pain versus No Pain) (Fishers Exact, p = 0.01)

Variable	**Shoulder Proprioception reduced**	**Shoulder Proprioception full**
No Pain (n=22)	1	9
Pain (n=10)	13	7

Results for Hypothesis 4

Hypothesis 4 (a): *Baseline demographic will be different for stroke survivors who develop moderate to severe pain on shoulder movement within 3 weeks (Early Pain) compared to those who develop pain between 3 – 8 weeks (Late Pain) post-stroke.*

Early and Late Pain

The early pain group was defined as developing within 21 days of stroke. The mean time of moderate to significant pain (≥5/10 on NRS scale) for the Early pain group was 16 days (Range 6 – 18 days) with 50% (6/12) experiencing some mild discomfort on movement (mean VAS 3.6/10) from an average of 15 days.

The late pain group was defined as developing pain from 21 -56 days post stroke. The mean time to moderate to significant pain for the late pain was group 39.9 days (Range 24 -56 days) with 40% (4/10) experiencing some mild discomfort on movement within the first 3 weeks (mean VAS 2.5/10) from an average of 17.75 days.

Demographic Analysis

Demographic data was divided into dichotomous variables for analysis; see table 13 overpage.

Gender showed a significant relationship with outcome (Fishers exact p= 0.04). As per table 14 overpage: a 2x2 table shows significantly more women were in the early pain group.

Stroke type (Haemorrhagic versus ischaemic) showed a significant relationship with outcome (Fishers exact p = 0.01). As per table 15 overpage: a 2x2 table shows significantly more Haemorrhagic strokes were in the late pain group.

There was a significant relationship between the presence of over 65 year old participants and group (Fishers exact p = 0.01). As per table 16 overpage: a 2x2 table shows significantly more participants over 65 were in the early pain group

Table 13: Baseline Dichotomous demographic variables relationship with outcome (Early versus Late pain)

Baseline Dichotomous Variable	Conditions for Chi^2	N	Fishers Exact for relationship with Pain versus No Pain (p value
Participants over 65 (Yes/No)	No	22	0.01
Gender (Male/Female)	No	22	0.04
Diabetes (Yes/No)	No	22	0.57
Side of Hemi (Left/Right)	No	22	0.38
Hemi on Dominant Hand (Yes/No)	No	22	0.69
Haemorrhagic Stroke (Yes/No)	No	22	0.01
Hoist Transfer at Baseline (Yes/No)	No	22	0.65
Requiring Assistance of 2 to transfer at Baseline (Yes/No)	No	22	1.00
Requiring Assistance of 1 to transfer at Baseline (Yes/No)	No	22	1.00

Demographic Variables

Table 14: 2x2 Table: Participants in each category: Relationship of Gender with outcome (Early versus Late Pain) (Fishers exact p =0.04)

Variable	Early Pain Cases	Late Pain Cases
Male	4	8
Female	8	2

Table 15: 2x2 Table, Participants in each category: Relationship of Stroke Type with outcome Late vs Early Pain (Fishers exact p = 0.01)

Variable	Early Pain Cases	Late Pain Cases
Ischemic Stroke	12	5
Haemorrhagic Stroke	0	5

Table 16: 2x2 Table, Participants in each category: Relationship of being over 65 with outcome Late vs Early Pain (Fishers exact p = 0.01)

Baseline Variable	Late Pain Cases	Early Pain Cases
Over 65 years Yes	8	2
No	2	10

Self-rated Health, Depression and Anxiety at Baseline

There was no significant difference between Early and Late pain groups for baseline between self-rate health for, depression or anxiety: see Table 17.

Table 17: Self rated Health, Mood and Anxiety for Early and Late Pain groups

Variable	Early (n= 12)	Late (n =10)	Statistic	P value
Self-Rated Health /100 (mean)	40.91 (SE 7.71)	48.33 (SE 12.42)	t(18) = 0.53	0.60
Depression (DISC) /10 (mean)	4.27 (SE 0.65)	4.99 (SE 0.93)	t (18) = -0.25	0.81
Anxiety (ASC) /10 (mean)	3.56 (SE 1.20)	4.00 (SE 0.86)	t(18) = -0.31	0.76

Hypothesis 4: (b) *Baseline clinical measures will be different for stroke survivors who develop moderate to severe pain on shoulder movement within 3 weeks (Early Pain) compared to those who develop pain between 3-8 weeks (Late Pain) post-stroke.*

Clinical Joint Measures (Early vs Late Pain)

A table of relationships between dichotomous joint variables and outcome (Early vs Late pain) is presented over page Table 18. Upper arm girth had a significant relationship with outcome (Fishers exact p = 0.03). As per table 19: a 2x2 table shows significantly more people with upper arms less than 30cm at baseline were in the early pain group.

Table 18: Baseline Dichotomous variables relationship with Outcome (Early versus Late pain)

Baseline Dichotomous Variable	Conditions for Chi^2	N	Fishers Exact for relationship with Pain versus No Pain (p value
Upper Arm Girth > 30cm (Yes/No)	No	22	0.03
Internal rotator MAS ≥2 (Yes/No)	No	22	0.20
Adductor tone MAS ≥2 (Yes No)	No	22	0.10
Shoulder flexor activity (Yes/No)	No	22	0.67
Shoulder abduction activity (Yes/No)	No	22	1.00
External Rotator activity (Yes/No)	No	22	1.00
Internal Rotator activity (Yes/No)	No	22	1.00
Thumb proprioception reduction (Yes/No)	No	22	0.57
Wrist proprioception reduction (Yes/No)	No	22	1.00
Elbow proprioception reduction (Yes/No)	No	22	0.34
Shoulder Proprioception reduction (Yes/No)	No	22	0.16
Upper arm sensation reduction (Yes/No)	No	22	0.64
Palm sensation reduction (Yes/No)	No	22	0.64
10 degrees of GHJ flexion restriction (Yes/No)	No	22	0.47
10 degrees of GHJ abduction restriction (Yes/No)	No	22	1.00
15 degrees of SHC flexion restriction (Yes/No_	No	22	0.48
15 degrees of SHC Abduction restriction (Yes/No)	No	22	0.68
10 degrees of SHC External restriction(Yes/No)	No	22	0.68

Table 19: 2x2 table showing participants in each category: Relationship of Upper Arm Girth and Outcome (Early versus Late Pain) (p = 0.03)

Arm Girth category	Early Pain Cases (n=12)	Late Pain Case (n=10)
Upper Arm Girth> 30cm	3	8
Upper Arm Girth < 30cm	9	2

Hypothesis 5 results

Hypothesis 5*: Participants who do not develop moderate to severe pain on hemiplegic shoulder movement by 8 weeks will have significantly more motor recovery and less development of passive external rotation restriction*

There was no significant difference between group (Late Pain versus No Pain at 8 weeks) for baseline shoulder flexion, abduction, internal rotation and external rotation motor activity (rating of ≥1 on Oxford Muscle testing scale, see table 20.

At 3 weeks there was a significant relationship between external rotation motor activity and group (p=0.02), but not for shoulder flexion, abduction ad internal rotation (see table 21). As shown in table 22: a 2x 2 table shows there were significantly more participants in the No Pain group that had external rotation recovery

Table 20: Relationship of motor activity at baseline with group (Late pain vs No Pain)

Baseline Dichotomous variable	Chi^2	N	p value
Shoulder Flexion activity (≥1 Flickers) (Yes/No)	No	20	0.37
Shoulder Abduction activity(≥1 Flickers) (Yes/No)	No	20	0.37
Shoulder IR activity(≥1 Flickers) (Yes/No)	No	20	0.37
Shoulder ER activity (≥1 Flickers) (Yes/No)	No	20	1.00

Table 21: Relationship of motor activity at 3 weeks with group (Late pain vs No Pain)

3 week Dichotomous variable	Chi^2	N	p value
Shoulder Fl Activity (≥1 Flickers) (Yes/No)	No	20	0.37
Shoulder Ab Activity (≥1 Flickers) (Yes/No)	No	20	0.37
Shoulder IR Activity (≥1 Flickers) (Yes/No)	No	20	1.00
Shoulder ER Activity (≥1 Flickers) (Yes/ No)	No	20	0.02

Table 22: 2x2 table showing participants in each category: Relationship of external rotator activity with group (Late vs No Pain) (p = 0.02)

	Late Pain	No Pain
No External rotation flickers or more	9	3
External rotation flickers or more	1	7

Hypothesis 6 Results

Hypothesis 6:

Participants who develop moderate to severe pain on movement will have clinical restriction patterns characteristic of Frozen Shoulder and will have associated spasticity in the internal rotators.

Frozen Shoulder

24% (5/21) participants showed either at least 50% external rotation restriction or at least 30% external rotation and abduction restriction combined (see table 23 overpage). Therefore, these participants could be clinically classified as having frozen shoulder. 81% (17/21) of participants who developed moderate to significant pain on shoulder movement within 8 weeks of stroke, had at least 5 degrees of external rotation restriction at pain. 71% (15/21) had at least 10 degrees of external rotation at pain.

Spasticity of Shoulder Internal Rotators

Clear signs of spasticity were defined as ≥2/4 on the Modified Ashworth Scale. 66% (14/21) had associated spasticity of their shoulder internal rotators and adductors 8 Early Pain and 6 Late Pain participants.

Table 23: Summary of Clinical characteristics of Shoulders that developed Pain

Variable	Early Pain (n= 12)	Late Pain (n = 9) (1 x missing)
50% External Rotation restriction	2	2
30% External Rotation and 30% Abduction restriction	0	3
Total	2	3
Abduction Restriction (At least 15 degrees MDC)	4	6
External Rotation Restriction (At least 10 degrees MDC)	8	7
Associate Night Pain	6	5
Associated Pain at Rest	3	4

MDC = Minimal Detectable Change

(Unable to complete clinical assessment of 1 participant after pain onset)

Pain severity and early signs of discomfort

Mean pain on movement was 6.5/10 for all category 1 participants (n=30) and the category 2 (n= 2) participants were all rated as 3 on the Richie Articular Index. It was not possible to get clinical measurements for one late pain participant.

50% (6/12) of early pain participants had some discomfort on movement at earlier assessments prior to moderate to severe pain (See Table 24). 50% of Early pain participants (6/12) had associated pain at night and 40% (3/12) had associated pain at rest.

40% (4/10) of late pain participants had some discomfort in the first 3 weeks post stroke. 56% (5/9) of late pain participants had associated night pain and (4/9) had associated pain at rest.

30% (3/10) of the No pain group had some discomfort in the first 3 weeks post stroke**.**

Table 24: Proportion of stroke survivors who developed mild discomfort on movement in Early, Late and No Pain groups.

Variable	Early Pain (n =12)	Late Pain (n=10)	No Pain (n = 10)
Number of stroke survivors with some discomfort on movement in the first 3 weeks post stroke	6 (50%)	4 (40%)	3 (30%)
Maximum discomfort (mean)	3.25 (SE 0.40)	2.50 (SE 0.46)	3.00 (SE 0.76)
Time from 1st Discomfort and significant pain (mean)	4.83 (SE 0.79)	30.00 (SE 8.82)	X

(4.5) Discussion

This cohort study examined the development of passive restriction in 32 stroke survivors recruited on average 8 days (range 0 – 14 days) post their 1st stroke. These restriction patterns were analysed against developing moderate to severe pain by 8 weeks post stroke. All participants had significant upper limb motor weakness with no effort against gravity on admission. The key finding of this study were:

Differences between Pain and No Pain Groups:

1) The presence of 10 degrees of passive shoulder external rotation or 15 degrees of passive abduction restriction within 2 weeks post stroke showed a significant relationship with developing moderate to severe pain by 8 weeks.

2) Reduced shoulder joint proprioception with 2 weeks of stroke (<2 on Fugl Meyer proprioception scale) is associated with developing moderate to severe pain within 8 week post stroke.

Differences between Early and Late Pain Groups:

Being over 65, being female, having arm an upper arm girth <30cm and having an ischaemic stroke were statistically more likely to be in the group that developed Early pain (within 3 weeks) rather than late pain (3 – 8weeks).

Differences between Late Pain and No Pain Group:

In this study we have discovered an important difference in the no pain group compared to the late pain group was the recovery of some shoulder external rotation motor activity (flickers or more) by 3 weeks.

Clinical characteristics of participants who developed pain

5) 85% of the stroke survivors who developed ≥5/10 pain on movement had at least 10 degrees of external rotation restriction. However, only 24% could be characterised as having clinical signs of frozen shoulder. 66% had associated spasticity in their internal rotators.

The primary findings of this study results show how external rotation and abduction restriction develop early in the shoulder and are present prior to moderate to severe pain. These clinical findings show a relationship with developing pain in the hemiparetic shoulder by 8 weeks post stroke. This aligns with the findings of previous studies that identify external rotation and abduction restriction as predictors of pain (Rajaratnam et al., 2007, Ada et al. 2020, Lingren et al. 2013). This strengthens the evidence base that these can be useful markers for clinicians to identify stroke survivors who may develop pain by 8 weeks and may help future with designing future intervention research.

In the case of abduction restriction there was a difference between pain and no pain groups when the scapula was allowed to move (shoulder complex movement), but not when scapula was blocked (pure glenohumeral movement. This could indicate shortening in muscle/structures that don't insert into the humerus such as serratus anterior. It is also possible that some muscles with axial origins such as

Pectoralis Major or Latissimus Dorsi do not reach their maximum potential length with the Scapula blocked and only reach this when the scapula is allowed to move (Wu and Bordoni et al., 2021). It is also important to acknowledge that activity and restriction of these muscle groups is complex as they are influenced by postural control/kinetic chain influences (Richardson et al. 2020). In an attempt to minimise these effects participants were always assessed in supine lying but it is impossible to exclude them completely.

66% of the subjects who developed pain showed spasticity in their internal rotators/adductors. However, it is difficult to come to clear conclusions about this finding without additional soft tissue scans. Future research should consider contrast enhance images to establish cases of true frozen shoulder, so pathological relationships with increased tone can be further understood.

Loss of proximal shoulder proprioception at baseline was significantly more associated with the group that developed pain. This aligns with the findings of a previous movement analysis study which found impaired proprioception in stroke survivors with PSSP (Niesson et al., 2009). It is possible this loss of proprioception could make the stroke survivor more susceptible to injury during movement, which could act as an inflammatory trigger for restriction processes (Niesson et al., 2009; Jump et al., 2021). However, in non-stroke subjects, shoulder pain has also been shown to potentially affect joint position sense (Ager et al., 2020). This often makes it difficult to establish which came first, the pain or the loss of joint position sense. In our study loss of proprioception was found prior to pain indicating loss of proprioception has a potentially causal relationship to PSSP in stroke survivors.

In regard to pathological processes, it is of interest that women, people over 65, people with ischaemic strokes and people with smaller arm girths were more likely to be in the early pain group within the first 3 weeks of stroke. It is possible these variables result in more rapid range loss and pain.

In regard to age, and upper arm muscle girth; muscles tend to atrophy at the rate of 1% a year from middle age (Wilkinson et al., 2018). Atrophy and tendinosis changes in muscle tend to make them more susceptible to injury, which could explain why older stroke survivors with reduced upper arm girth develop pain and restriction quicker (Bass et al. 2020). A large study of adults over 50 (n= 403) found that subscapularis develops fat infiltration, and its cross sectional area reduces quicker than more 'atrophy resistant' muscles such as Teres Minor and Deltoid (Raz et al., 2015). This could be a factor in the development of non-neural external rotation restriction in older people. However, links with atrophy and pain are still not clear and so this requires further investigation (Shah et al. 2008). Certainly, pre-stroke shoulder soft tissue health may be a factor in developing pain and restriction quicker after the onset of hemiparetic weakness post stroke (Holmes et al.,2020; Nadler et al. 2020).

In regard to gender, women have been shown to be more susceptible to developing shoulder pain later in life (Khosravi et al., 2019). Over all women generally have lower muscle and aerobic capacity compared to men and joint laxity may be influenced by sex hormones (Khosravi et al., 2019). Hypermobility and joint laxity has shown to be associated with higher prevalence of shoulder joint pain (Liaghat et al. 2022). This could be a factor in why women are more susceptible to shoulder pain later in life (Khosravi et al. 2019).

In regard to PSSP, an MRI study found significantly more muscle atrophy and subscapularis tendinopathy in women with PSSP (Shah et al., 2008). These factors may influence pain and restriction processes which is why women were found to develop pain quicker in our study.

It is important to note that variables such as arm girth and gender may not be independent of each other. Certainly it is an established phenomenon that women are more susceptible to muscle bulk loss with age (Kirchengast et al. 2009)

Early pain has also been shown to influence risk of developing more severe pain and restriction later (Nadler et al., 2020; Ada et al. 2020). In two stroke survivor cohorts (n=40; n=42) those who gave a numerical rating of pain above 0 at baseline were more likely to have moderate to severe pain at 6, 8 and 12 weeks post stroke (Nadler et al., 2020; Ada et al., 2021). It is possible early pain indicates inflammation processes are active which can trigger restriction processes such as frozen shoulder (Jump et al., 2021). In our study 45% (10/22) of stroke survivors who had discomfort greater than 0 on pain movement at baseline experienced moderate to severe pain by 8 weeks. 30% (3/10) of stroke survivors who did not develop pain by 8 weeks had some discomfort on movement (greater than 0) at baseline. This indicates some variability in outcome in regard to early discomfort predicting later pain. This is reflected in Odds ratios for baseline discomfort as a predictor ranging from 1.57 – 2.55 (Holmes et al., 2020; Anwer and Alghadir, 2020).

One factor that appears to ‘protect’ shoulders from developing moderate to severe pain could be the amount of motor recovery in the proximal shoulder. In our study the number of subjects who had recovery of external rotation activity (flickers or more) at 3 weeks was statistically significantly greater than subjects who developed moderate to severe pain between 3 to 8 weeks. It appears that pain at baseline in combination with a lack of motor recovery are factors clinicians need to be aware of when identifying people who may develop pain later. Shoulder Abduction power >2 (MRC) in the early stages after stroke has also been associated with not developing pain, indicating abduction and external rotation power are also useful clinical markers for clinicians to monitor (Nadler et al., 2020).

Analysis of clinical shoulder presentations for the stroke survivors who develop pain indicate that spasticity of the shoulder internal rotators may be a predominant driver (66%) of pain and restriction in this early phase. However, this is based on levels of restriction observed. Only 24% could be classified as having clinical signs of Frozen shoulder (Ranagan et al., 2020). Another study of 40 stroke survivors showed that hemiparetic arms with significant weakness developed on average 21% external range loss by 2 weeks and 50% by 6 weeks indicating possible frozen shoulder presentations (Ada et al., 2020). This highlights the need for future studies to include contrast enhanced MRI scans when restriction develops so the presence or absence of frozen shoulder processes can be clearly identified (Ya Ping Pong, 2009). In addition, protocols have used suprascapular nerve blocks as way of identifying restriction in the absence of spasticity (Fitterer et al., 2021). Our study only examined presentations upto 8 weeks post stroke. Other studies of cohorts 6 months and 1 year post stroke indicate that frozen shoulder may become more predominant, with proportions of around 50% being reported (Lo et al., 2003). It would be useful in future for recruited participants to be observed for upto a year post stroke to really understand the natural history of pain processes

Chapter 4 Study Limitations

As shown in the cohort diagram, this study highlights the difficulty with recruiting a cohort of participants with significant arm weakness in a hyperacute and acute setting. A large proportion of people did not meet the inclusion criteria and it was not possible to complete an analysis of excluded participant demographics. Therefore, the external validity and generalisability of these results are potentially questionable. The cohort diagram highlights the challenges of recruiting stroke survivors who are at high risk of developing PSSP (Price et al.,1999). In addition, 10 potential participants were excluded due to already having shoulder pain. On reflection it would have been useful to collect demographic information on these participants as they potentially represent a cohort who developed pain very quickly and it would have been useful to compare this cohort with the recruited participants.

In regard to the separation of groups according to pain developing within 21 days and over 21 days, this was picked as it related to usual acute stroke care periods. However as the lower end of the over 21 days group was 24 days there is still some uncertainty if the early and late pain groups truly represent separate populations.

Passive range was measured in supine, and external rotation was measured with the in arm in 20 degree abduction. As potentially different parts of the shoulder capsule are loaded when externally rotating in different amounts of abduction, a criticism of this could be that external rotation was not measured in different amounts of shoulder abduction (Rundquist et al., 2003). As the position of external rotation measurement was at 20 degrees abduction; this is stressing the anterior superior capsule

(structures such as coracohumeral ligament) whereas more abduction would have stressed the anterior inferior capsule (axillary pouch) so potentially in future conducting external rotation assessments at different amounts of abduction would be useful. However, a study of 21 non stroke subjects in supine using electromagnetic- tracking sensors of clinically applied forces found that humeral external rotation stiffness was not affected by shoulder abduction angles of 45, 90 and 180 degrees, so it's unclear if this is a true limitation (McQuade et al., 1999).

Classifying Frozen Shoulder was reliant on established clinical criteria; however, a more rigorous methodology would be to use contrast enhanced shoulder MRI (La Pompa et al., 2011). In addition, although check x rays were conducted in all cases where bone restriction was suspected it may have been useful to conduct this with all participants who developed pain to add rigour to the pain classifications. However, although this was originally planned and ethical approval granted, the research sites did not have capacity for this to be conducted on participants with PSSP.

Sample size: The sample size of this study was small which required Fisher's Exact assessments rather than a desired regression model approach. Although a 'statistically significant' relationship was found between developing pain and some clinical and demographic variables, there is a risk of applying these to the wider population without further research. This means this data provides useful targets for future research into mechanisms of pain onset.

Chapter 5: Investigating Subscapularis as a target for Botulinum toxin type A (BoNT-A) in the early treatment of hemiplegic shoulder after the onset of pain and associated internal rotator spasticity

Abstract

Purpose: To test the assumption that subscapularis spasticity is a key contributor to internal rotator and adductor muscle tone and to determine the effectiveness of botulinum toxin injection within the first 3 months of stroke to treat post stroke shoulder pain (PSSP).

Methods: A pilot study was conducted using ultrasound guided needle electromyography (EMG) assessments of people who had developed pain and restriction within first 2 months of stroke. A systematic review was conducted examining the effectiveness of botulinum toxin for post stroke shoulder pain associated with proximal shoulder spasticity with the first 3 months of stroke.

Results: 12 participants with PSSP were recruited. 11 had associated proximal spasticity of shoulder internal rotators (SpIR) and 1 had no clinical signs of shoulder spasticity. Four out of eleven participants with clinical signs of shoulder internal rotator spasticity showed EMG evidence of spasticity in the subscapularis muscle. No common patterns were observed amongst participants, with the pectoralis major muscle being the most common contributor to internal rotator spasticity (8/11, 73%). The systematic review identified no studies that had examined the use of botulinum toxin injection for the treatment of PSSP with associated proximal shoulder tone within 3 months of stroke.

Conclusion: This pilot casts doubt on the assumption that Subscapularis is the main contributor to SpIR. In this cohort there was variation in contributing muscles, with Pectoralis Major being the most consistent contributor. There is growing evidence of the effectiveness of botulinum toxin within 3 months of stroke to preserve range. However, to date there are no RCTs that examined the effectiveness of botulinum toxin in treating PSSP associated with proximal spasticity within 3 months of stroke.

(5.1) Introduction

Upper limb spasticity affects around 30% of stroke survivors who have hemiparetic weakness (Thibaut et al.,2013; Kuo and Li, 2018). As it is a sensorimotor controlled phenomenon, perhaps unsurprisingly weakness and sensory impairment appear to be key predictors of developing upper limb spasticity (Rosales et al., 2016). Upper limb spasticity can develop within days of central nervous system damage particularly in weak arms with sensory loss (Sommerfeld et al.,2004; Lindsay et al. 2021).

Spasticity of the shoulder internal rotator muscles (SpIR) and adductors is part of the upper motor neuron syndrome commonly seen in hemiparetic arms due to corticospinal system damage (Saikaley et al., 2020) and could be a key contributor to progressive loss of external rotation range observed in hemiplegic arms (Ada et al.,2020).

As well as restriction being driven by supraspinal and spinal sources, the reduced firing rate of motor units may also influence muscle contraction patterns (Thibaut et al, 2013; Gracies, 2005). The resultant muscle atrophy may then contribute to non-neural muscle stiffness (Thibaut et al., 2013). This stiffness can then drive more spasticity in a negative feedback loop (Thibaut et al., 2013).

Shoulder internal rotator spasticity and the contribution of Subscapularis

Botulinum toxin type A (BoNT-A) is a commonly used treatment for focal spasticity in the shoulder (Rossetto and Montecuco, 2003; Ashford et al, 2018).

As the most common pattern of proximal shoulder stiffness is restriction in external rotation and abduction; common target for botulinum toxin injection are the internal rotators; pectoralis major, latissimus dorsi, teres major and subscapularis.

A recent review identified randomised control trials that examined the use of botulinum toxin injected into proximal shoulder muscles in order to reduce shoulder pain and restriction (Weiner et al.,2018). A summary of the results with some additional recent studies is presented in table 25. As shown subscapularis and pectoralis major the most common treatment target. Often Subscapularis is cited as the main contributor to shoulder internal rotator spasticity (Choi et al, 2016; Yelnik 2019). This appears to be based on findings from healthy subjects indicating Subscapularis is the main internal rotation muscle. For example, (i) subscapularis contributes over twice the force of pectoralis major during internal rotation (Chang et al. 2000; Yelnik et al. 2019); (ii) it has the largest surface area of all the rotator cuff muscles and (iii) during forward flexion it generates the most force on the humeral head (Goetti et al. 2020; Bouaicha et al., 2016). Proportions of force generated as a total rotator cuff force; during shoulder flexion have been reported as 53%, 14%, 22% and 11% for the subscapularis, the supraspinatus, the infraspinatus and the teres minor respectively (Goetti et al. 2020; Bouaicha et al., 2016).

It is also possible that because the subscapularis is innervated by larger motor units compared to other shoulder internal rotators it is more susceptible to hyperexcitability after a stroke lesion (Haines & Milailoff, 2018). However, there is no direct evidence to support this theory.

It should also be noted that pre-botulinum toxin spasticity assessments rely on clinical measures rather than specificity identifying spasticity in certain muscle groups which may explain the variability of results present in table 25 (De Boer et al., 2008; Hecht et al.,1992).

Needle Electromyography (EMG)

One of the most rigorous methods of assessing true spasticity is examining the Hoffman (H) reflex and the Compound Motor Action potential (M) response (Palmari et al., 2004).

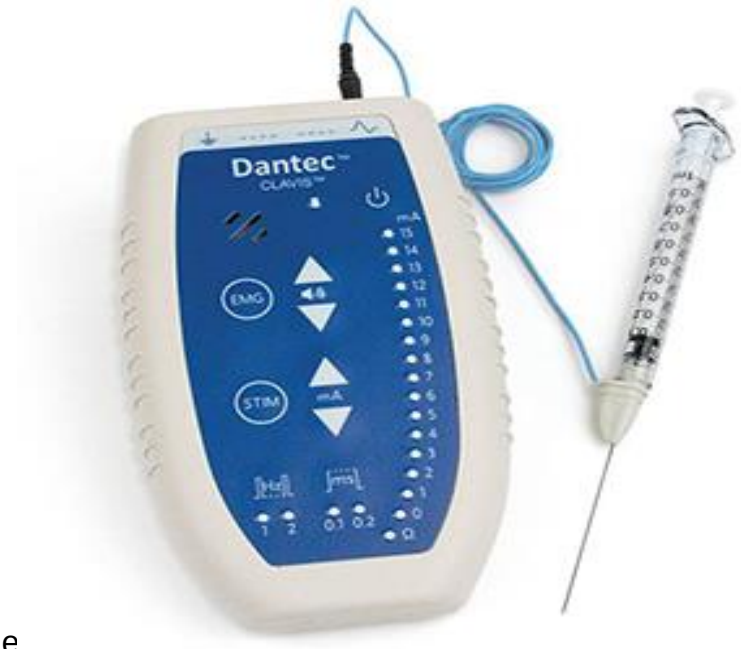
- The H-reflex is the time taken for monosynaptic reflex response after submaximal electrical stimulation of a combined motor and sensory nerve (Palmari et al.2004). The central nervous system response to electrical stimulation of peripheral afferent nerves (Palmari et al., 2004), testing the speed of the mechanical spinal reflex arc (Palmari et al. 2004).
- The M-response is the time taken for EMG evidence of muscle activity after electrical stimulation of a motor neuron.

The H/M ratio can then be compared to healthy control data to establish if spasticity (hyperexcitability) is present. This test requires controlled laboratory conditions and so is not commonly used in clinical practice. A practical solution to improving injection accuracy is the mobile needle Electromyography (EMG) device (See Fig 27 overpage), which measures muscle electrical activity generated by efferent nerve to muscle activity at the motor end plates (Walker et al., 2014). These devices also have an electrical stimulation function, so target muscles can be stimulated to ensure placement accuracy and been shown to improve accuracy compared to palpation alone (Picelli et al., 2012). The assessment procedure involves a stainless steel needle being inserted into the muscle of interest. For shoulder internal rotators the clinician then passively moves the shoulder from internal to external rotation at a standardised high speed. Spasticity activity is velocity dependant and auditory outputs from the EMG device help clinicians decide if spasticity is present (Walker et al., 2014).

Timing of Botulinum Toxin to date

There is still considerable debate about when botulinum toxins injections should be used after stroke. Early post-stroke recovery can be rapid (Hatem et al., 2018) and there is often concern about interfering with this process by paralysing recovering muscles. Perhaps as a result, most randomised control trials using botulinum toxin injection as the primary intervention for PSSP have concentrated on the chronic phase post stroke, ranging from 5.2 to 16.7 months post stroke (Saikaley et al. 2020) (see table 25 overpage). Lack of evidence base and concerns about side-effects of botulinum toxin used early after stroke are the likely reasons why are possibly why oral medication for spasticity is preferred in the first 3 months post stroke (Picelli et al., 2021).

Fig. 27: Example of a portable EMG device



The e ainst placebo or steroid injection is currently unclear in published literature (Saikaley et

al., 2020). This may be a consequence of the participants time post stroke in these trials. As shown in Table 25 overpage they are all over 5 months post stroke. It is now established that contracture in hemiplegic arms can develop within weeks of stroke (Allison et al., 2018). Cohorts over 5 months post stroke with hemiparetic weakness are likely to have some non-neural shortening in their shoulder soft tissue. This means that Botulinum toxin injections which target the neurological component of the restriction are therefore less likely to be effective.

There is now a significant need for randomised control studies (RCTs) to examine the use of botulinum toxin injection within early post stroke (within 3 months) to treat PSSP associated with internal rotator spasticity. When botulinum toxin has been used on the distal arm around 3 weeks post stroke (mean 18 days), it has proved to be effective compared to controls at reducing contracture (Lindsay et al. 2021). This indicates there is a case for early intervention on the proximal shoulder.

The case for early use of botulinum toxin injection is further strengthened by a study which examined 83 stroke survivors longitudinally (Picellie et al., 2021). Stroke survivors were classified as either < 90 days (less than 3 months) or > 90 days (>3months) post stroke. The study showed that botulinum injections in the upper and lower limb were more effective in improving range in patients treated within 3 months post stroke (Picelli et al. 2021).

The systematic review in this study will aim to identify if any control trials have been conducted within the first 3 months of stroke to treat PSSP with botulinum toxin.

Likely responders and the case for earlier intervention

Stroke survivors with more upper limb weakness with more severe strokes are at greater risk of developing severe and symptomatic spasticity (Rosales et al., 2016), ultimately increasing the risk of contractures and frozen shoulder over time. Botulinum toxin (BoNT-A) is most effective when restriction is purely neurological and so early intervention makes sense as this will be prior to the onset of non-neurological contracture (Rosales et al., 2016).

A meta-analysis examining the effectiveness of early use of BoNT-A included 6 studies treating the distal upper and lower limb (Rosales et al., 2016). This meta-analysis found that participants treated within 3 months of stroke showed a highly significant effect ($p = < 0.001$) on spasticity, compared to placebo injection controls (Rosales et al., 2016). Therefore, it of interest to find out how many control trials have been conducted to treat PSSP with associated internal rotator spasticity in stroke survivors less than 3 months post stroke.

Table 25: Summary of previous Botulinum Toxin studies for pain and focal spasticity in PSSP

Reference	Study Type (FU duration weeks)	Total Sample size	Clinical Spasticity Assessment Scale	Pain Assess-ment	Comp-arator	Time post stroke of patients (months)	Muscles injected	Dose (units)	Manu-facturer	Stat Dif. Proximal shoulder spasticity	Stat Dif. Pain VAS	Stat Dif. Passive range
Kong et al., 2007	RCT (12)	16	Ashworth	VAS	Saline injection	8.3	Pectoralis major and Biceps Brachii	500	Dysport	YES	NO	No
De Boer el., 2008	RCT (12)	21	Ashworth	VAS	Saline injection	9.1	Subscapularis	100	Botox	NO	NO	NO
Marco, 2007	RCT (24)	29	Modified Ashworth	VAS	Saline	5.2	Pectoralis major	500	Dysport	NO	YES	YES
Wu et al. 2019	RCT (12)	38	Ashworth	VAS	Steroid injection	5.7	Subacromial, sub deltoid bursa	100	Botox	NR	NO	NR
Lim et al. 2008	RCT (12)	22	Modified Ashworth	VAS	Steroid injection	8.7	Infraspinatus, pectoralis major and subscapularis	100	Botox	NO	NO	NO

NR = Not Recorded Mc Pain Q = McGill Pain Questionnaire Stat Dif = Statistical Difference VAS = Visual Analogue Scale

Table 25 continued: Summary of previous Botulinum Toxin studies for pain and focal spasticity in PSSP

Reference	Study Type (FU duration weeks)	Total Sample size	Clinical Spasticity Assessment Scale	Pain Assess-ment	Comp-arator	Time post stroke of patients	Reference	Study Type (FU duration weeks)	Total Sample size	Clinical Spasticity Assessment Scale	Pain Assess-ment	Comp-arator
Shaw et al., 2011	RCT (52)	189	Modified Ashworth	VAS	Therapy only	9.9	Pectoralis major	150 – 200	Botox	NR	YES	NR
Bravi et al., 2015	RCT (12)	21	Modified Ashworth	McGill pain Q	Saline injection	NR	NR	NR	Botox	NR	YES	NR
Marciniak et al., 2012	RCT (12)	21	Modified Ashworth	McGill pain Q	Saline injection	NR	Pectoralis Major and Teres Major	140 – 200	Botox	NO	NO	NO
Yelnik et al., 2007	RCT (4)	40	Modified Ashworth	VAS	Saline Injection	16.7	Subscapularis	500	Dysport	NO	YES	YES

NR = Not Recorded **Mc Pain Q = McGill Pain Questionnaire** **Stat Dif = Statistical Difference** **VAS = Visual Analogue Scale**

(5.2) Objectives and Hypotheses

The objective of this pilot study and systematic review was to answer two key research questions:

1) Is botulinum toxin effective in treating PSSP associated with proximal shoulder spasticity within the first 3 months of stroke?

2) Is subscapularis spasticity always present in PSSP cases where there is associated shoulder internal rotator and adductor spasticity?

Hypothesis for objective 2: In PSSP cases within 2 months of stroke and associated internal rotator spasticity, the subscapularis muscle will show signs of hypertonia

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(5.3) Methodology

Systematic Review Methodology

Review Protocol

A search protocol was developed using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

Search Terms and Inclusion criteria used the Population, Intervention, Comparator, Outcome and Study Design (PICOS)

Population: Adult stroke survivors (>18 years) who are within 3 months of stroke who have pain and restriction in their affected arm
Intervention: Focal injection of Botulinum Toxin into shoulder internal rotators/adductors.
Comparator: Placebo injection, Therapy only, steroid injection or other injection
Outcome: Improved passive range and reduced pain
Study Design: Randomised control trial

Studies were excluded that did not fit the above criteria or if the intervention was not clearly described to be a proximal shoulder injection of botulinum toxin for pain and restriction in the hemiplegic shoulder.

Search Strategy

The review was conducted from February 2020 to June 2020 on the following databases: PubMed, Ovid Medline, CINAHL, PEDro and OT-seeker by a Masters and PhD student.

Synonyms for words in the PICOS inclusion criteria were agreed prior to searching, so combinations of all potential options were included in searches: For example, in the case of Post Stroke Shoulder Pain: other commonly used terms were included in searches such as Hemiplegic Shoulder Pain (HSP), Post Stoke Upper Extremity Pain (PULP)

Once the search protocol and strategy were agreed, the Software package *Covidence* was used to ensure a systematic approach. This allows the adding of potential abstracts by all reviewers. Independent reviewers can either chose one of three options: Yes, No or Maybe for an article's suitability for inclusion into the study. In cases of conflicts a third reviewer can be used to resolve whether an article is rejected or retained. However, in this review there was no conflicts.

Pilot Study Methodology (Study 2)

The following methodology was employed to answer the study hypothesis: *In PSSP cases within 2 months of stroke and associated internal rotator spasticity, the subscapularis muscle will show signs of hypertonia*

Introductory note on participants

Subjects who developed pain in Study 1 within 8 weeks (2 months) consented to have needle Electromyography (EMG) investigations of their shoulder internal rotators and contrast enhanced MRI. However, after site capacity was removed for the enhanced MRI study this changed the scope of the project. Therefore, it was decided to present the EMG data as the pilot project below. NHS Ethic approval was given from London Dulwich, REC number 18-LO-0225. All participants and carers were given time to consider their involvement in the study and to ask questions to ensure informed consent. Some participants in this pilot did not meet the analysis criteria for study 1 however they were able to be included in this analysis

Participants

Stroke survivors were recruited from an acute stroke service according to the following criteria:

Inclusion Criteria

a) First ever stroke
b) Aged 18 years old or over
c) Have developed moderate to severe PSSP (≥5/10) within 8 weeks of stroke
d) Consents to Needle Electromyography (EMG) assessment

Exclusion Criteria

a) Pain in the shoulder (on the hemiplegic side) in the 6 months prior to stroke
b) History of surgery or orthopaedic fixation in hemiplegic shoulder
c) Passive bone restriction and/or injury. Whilst it was not possible to have plain x-rays conducted on all participants, any participant with a hard 'end feel', suspected trauma and or significant joint crepitus were x-rayed as per usual care.

d) Anticoagulation regime of stroke survivor means that EMG assessment is contraindicated

Clinical Measures of Passive Range and Spasticity

Passive Range

Passive External Rotation was measured in supine with one pillow head support and knee in supported slightly flexed position (see Fig 28). This maximum support position was to help reduce participant tone and guarding to allow more accurate passive measuring. If the participant was using an air mattress this was inflated to a maximum pressure setting.

Fig 28 Standardised supine assessment position with one pillow behind head (Study 3)

Participants arms were then abducted to 20 degrees and the elbow supported with a small towel to help reduce muscle guarding (see Fig 29). The arm was then externally rotated to maximum passive range and the range was measured (see Fig 29). This was conducted for the non-hemiplegic arm and the hemiplegic arm. The difference in external rotation between the two measurements was calculated. This measurement procedure was modified from Norkin and White, 2016**.**

Fig 29: Measurement of Passive External Rotation in supine (Study 3)

Spasticity Assessment

Spasticity is characterised by a velocity dependent increase in activity on passive stretch (Ashford et al. 2018). The Modified Ashworth Scale (MAS) was used to measure shoulder internal rotator spasticity.

The MAS is a validated spasticity outcome and has been shown to have good inter- and intra- rater reliability (Rajaratnam et al. 2007). Spasticity was considered present with a score of 2 or more on the MAS (Bohannan and Smith 1987). This was to ensure there was less chance of muscle guarding being interpreted as spasticity (Rajaratnam et al., 2007). See Table 26 for MAS grading overpage.

As discussed in the introduction, internal and external factors can influence tone. Therefore, standardisation of spasticity assessment was achieved by participants being always positioned supine as with the passive measurements. Efforts were made to ensure the participants were comfortable and clinical noise was at a minimum. Participants were not assessed if they were actively being treated for infection.

1) Spasticity assessments were conducted at the beginning of each review to minimise the impact of sensory modification on participants levels of spasticity (Thibaut et al. 2013)

2) 3 passive movements were conducted in the alignment established in the passive goniometry.

3) Speed was regulated by counting 1001,1002,1003 to ensure moving through full range took 3 seconds. Scoring was conducted on the 3rd movement. However, If the assessor was unsure at the end of the 3rd movement, then a 4th movement was conducted.

4) The resistance felt on assessment was scored according to validated Modified Ashworth Scale (See Table 26 overpage) (Ashford et al. 2018; Bohannon and Smith 1987).

'Angle of catch' was also measured, which is the angle from a position where musculature is in its most availably shortened to when resistance is first felt, when the limb is moved at speed (Patrick and Ada, 2006; Boyd and Graham,1999). For example, Internal rotator catch would be assessed from the stroke survivors' arm being internally rotated palm on abdomen to when a 'catch' is first felt as their arm is swiftly moved into external rotation (Ashford et al. 2018). An earlier angle of catch indicates greater hyperexcitability and so is an indicator of spasticity severity. This is why it is used in the Tardieu spasticity scale and has been shown to have more specificity in identifying true spasticity when compared to MAS (Patrick and Ada 2006).

Tardieu scale angles are calculated by taking the angle of catch from the total passive range, with larger Tardieu angles indicating more severe spasticity (Ashford et al. 2018). However, this is problematic in cases of restricted passive range, so in this study only angle of catch was recorded as an outcome (Patrick and Ada, 2006).

Clinical assessments of spasticity and range were conducted the day before EMG assessment. This is because spasticity is a mediated by sensory stimulation, so this ordering of assessments prevented clinical assessment movements potentially altering the participants EMG presentation (Thibaut et al. 2013; Ashford et al. 2018).

Table 26: Modified Ashworth Categorisation: (Bohannon and Smith 1987)

Grade	Description
0	No increase in muscle tone
1	Slight increase in tone, manifested by a catch or by minimal resistance at the end of the range of motion within the limb is moved
1^{+}	slight increase in muscle tone, manifested by a catch, followed by minimal resistance throughout the remainder (less than half) of the range of movement
2	More marked increase in tone but limb easily moved
3	Considerable increase in tone – passive movement difficult
4	Limb is rigid in flexion or extension, abduction or adduction

Needle EMG Procedure

Needle EMG Procedure

Needle EMG assessment was conducted the day after initial clinical measures were conducted to prevent sensory mediation of spasticity affecting results. The following procedure was conducted to standardise the assessment:

1) The stainless-steel EMG needle was inserted into the Subscapularis muscle via an anterior ultrasound guided approach by an experienced spasticity consultant. Confirmation of needle placement was provided by ultrasound.

2) As needle insertion causes pain, 10 seconds was left post insertion to allow insertional muscle guarding activity to dampen (Protocol after discussion with Anand Pandyan, 2018)

3) After stage 2 the arm was external rotated as per the clinical spasticity assessment described so the stretch response could be assessed in the Subscapularis muscle (Kim et al. 2005).

4) The consultant who was blinded to other clinical assessments indicated if there was a true stretch response i.e., spasticity or no clear signs of spasticity.

After the Subscapularis muscle was assessed, the spasticity consultant then conducted EMG assessments of all other shoulder internal rotators via a standardised palpation and insertion technique. This was so the contribution of other internal rotators could be assessed. This has become a validated method as position of motor end plates is fairly constant in the population as a whole (Walker et al., 2014).These assessments were not conducted using ultrasound guided techniques to prevent assessment burden for the participant. However, efforts were made using the EMG electrical stimulation function and via palpation to ensure needle placement and depth were accurate.

Ultrasound Assessment of Soft tissue

The standard clinical pathway for all the stroke survivors who developed pain was to receive an ultrasound scan by an imaging specialist consultant. This meant the number of soft tissue changes identified on these scans could be collected.

Although it is well established that age related shoulder soft tissue changes in asymptomatic people over 50 are common, a recent study has shown hemiplegia may accelerate changes (Grish et al., 2011; Idowu et al. 2017). Therefore, the number of reported soft tissue changes were counted in this study and as per a previous study protocol (Idowu et al. 2017). This previous study examined 45 stroke survivors and 90 age matched controls number of observations were classified as per below:

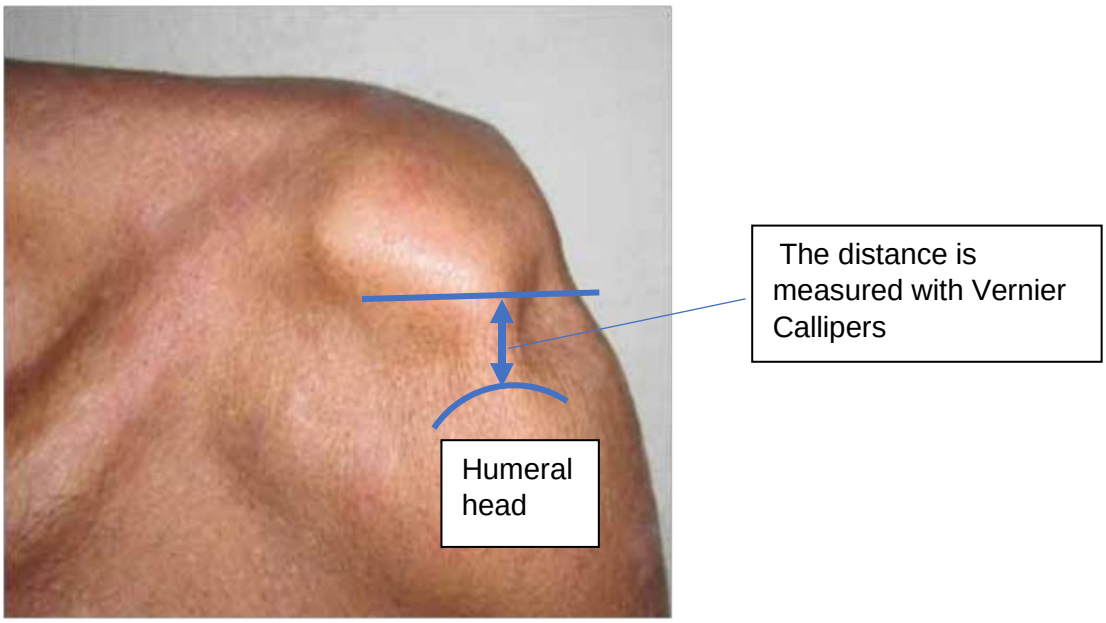
a) 0 = Normal
b) 1 -2 = Mild Damage
c) 3-4 = Moderate Damage
d) 5 -6 = Severe Damage

In this previous study 64.4% of stroke survivors showed moderate to severe damage in their hemiplegic shoulders compared to 2.2% on the unaffected side and 18.9% in age matched controls (Idowu et al., 2017).

Subluxation Assessment

Subluxation was measured as per the study 1 protocol using a Vernier Callipers. The distance from the Acromion to the humeral head was measured as per the Fig 30 below:

Fig 30: Subluxation measurement protocol



(Image taken from page 37, Razaq et al. 2016)

Ethical Approval

This study was originally part of study 1, NHS Ethics was granted from London Dulwich REC number 18-LO-0225 for needle EMG assessments of all participants who developed post stroke shoulder pain. In addition, ethics, site permission and capacity were granted to conduct additional enhanced MRI scans. It was hoped this would help to definitively understand soft tissue components of restriction. However, after study 1 of this thesis started and MRI scans had commenced, the site imaging department announced it no longer had capacity to complete the planned scans. Therefore, ultrasound reports conducted as part of participants standard care were collated in combination with EMG assessment as a pilot project.

Analysis Plan

The results of systematic review will be presented as a PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) Diagram. The results of the Pilot study will be presented as descriptive tables. Interpretative statistics were not required to answer the study questions.

(5.4) Results

Systematic Review

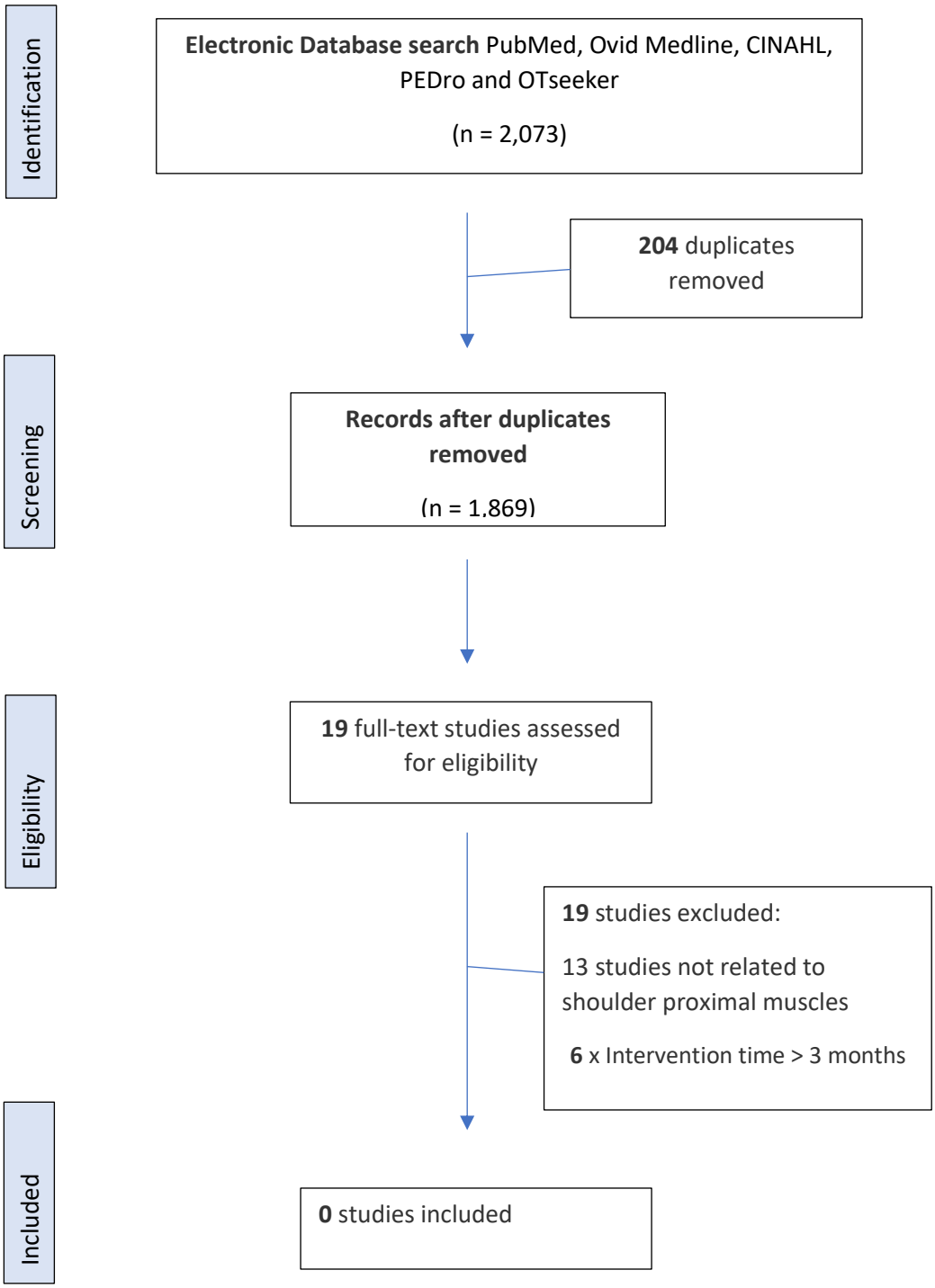
Review question; *What is the efficacy of botulinum toxin injection within the first 3 months stroke for PSSP and* associated spasticity of the shoulder Internal rotators?

Studies identified in the search

Initial searches identified 1,869 potential articles after the *Covidence* software had removed duplicates. 19 abstracts appeared to meet the inclusion criteria and were reviewed as full text articles. However, shown in the PRISMA diagram overpage no articles met the inclusion criteria Fig 31. 13 articles were rejected as they did not examine the effects of proximal shoulder muscle injection on pain and range. The remaining 6 articles were rejected as they were outside of the 3 months inclusion window.

This review indicates there are no current control trials that examine the use of botulinum toxin injection for PSSP with associated internal rotator spasticity within 3 months of stroke. This means the review was unable to answer the above question.

Figure 31 PRISMA flow chart extracted from *Covidence* showing stages of systematic review.



Pilot Study Results

27 participants recruited as part of study 1 developed PSSP (Fig 32). Anticoagulation regimes or consultant availability at different study sites were barriers to completing EMG assessments.

12 subjects were eligible for EMG assessment of internal rotators. 92% (11/12) of subjects had clinical signs of internal rotator spasticity (SpIR). This cohort developed pain at a mean of 32.5 days post stroke (SE 4.0) (range 15–- 56) and a mean age of 63.9 years (SE 4.8) (range 39 – 90). 1/11 of these participants had a history of diabetes. See Table 27.

The remaining participant without clinical signs of SpIR was an 84 year old man and developed pain at 8 days post stroke.

Characteristics of people who did not have EMG assessments and comparison with assessment cohort:

It was not possible to complete EMG assessments in 15/27 participants who developed PSSP. 2/15 participants were not available for clinical assessment once pain developed. The remaining 13/15 had clinical assessments when moderate pain developed (as part of study 1): 60% (9/13) had signs of internal rotator spasticity. Mean age of non-participants was 70.0 (SE 4.6) and time to pain was 22.7 (SE 3.3).

There was no statistical difference between participants that did or did not receive EMG assessments for age of participants $t(24) = -0.92$ ($p=0.37$), time of pain post stroke $U = 46.50$ ($p=0.06$) or number of participants with internal rotator spasticity Fishers Exact ($p = 0.32$).

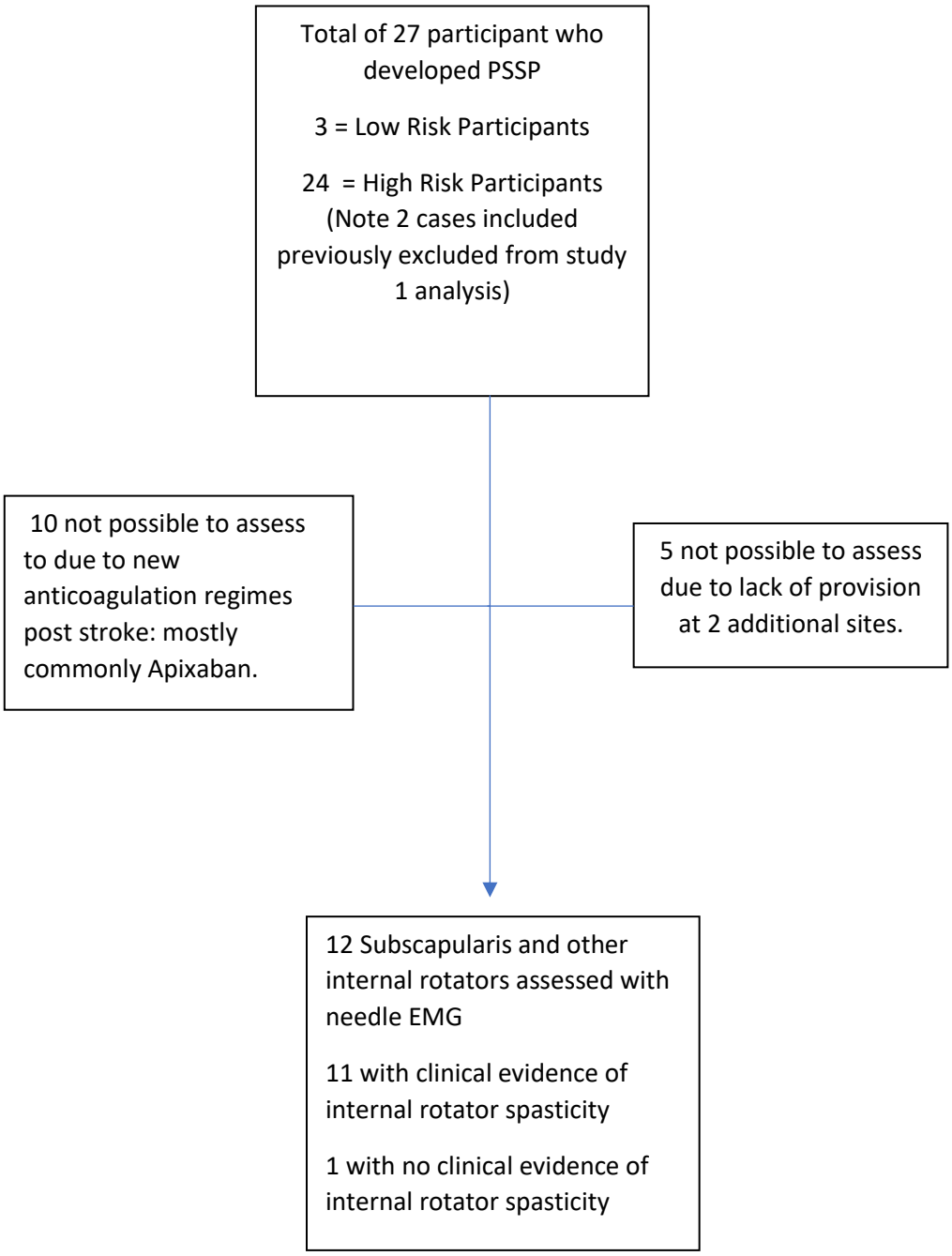
Table 27: Demographics of EMG pilot study participants (Study 2)

ID	Age	Gender (M= male, F = Female)	Time to pain (days post stroke)	Stroke type	Stroke area	Hemiplegic side
1	65	M	45	H	R Hemisphere	Left
2	47	F	23	I	R MCA	Left
3	68	F	49	I	R MCA	Left
4	54	M	33	H	R Hemisphere	Left
5	39	M	31	I	R MCA	Left
6	84	M	8	I	LMCA	Right
7	72	M	56	I	R MCA	Left
8	73	M	23	I	L MCA	Left
9	50	M	37	H	R MCA	Left
10	60	F	15	I	R MCA	Left
11	85	F	30	I	R MCA	Left
12	90	M	15	I	R PCA and MCA	Left

H = Haemorrhagic stroke, I = Ischaemic stoke

Angle of catch measured from hand placed on stomach

Fig 32: Consort Diagram for EMG pilot study (study 2)



EMG evidence of Internal rotator activity

36% (4/11) of participants with confirmed clinical signs of internal rotator spasticity had a needle EMG stretch response in the subscapularis muscle. This indicates that subscapularis muscle does not always show signs of hypertonia in cases of internal rotator spasticity.

The following proportion of participants with clinical evidence of spasticity in the internal rotators showed needle EMG stretch responses:

73% (8/11) in Pectoralis Major
36% (4/11) in Teres Major
36% (4/11) in Latissimus Dorsi **,** **see Table 28 overpage**

Therefore, although there was a very heterogenous picture, the most common contributor to internal rotator tone appears to have been Pectoralis Major in these cases.

Table 28: EMG stretch response results

ID	Pain on mvmt (/10)	ER Diff	Angle of Catch IR	MAS IR	Angle of Catch AB	Subsc SR	Pec Major SR	Teres Major SR	Lat Dorsi SR
1	5	58	47	2	30	YES	NO	YES	YES
2	8	23	95	2	130	YES	NO	YES	YES
3	8	101	25	2	30	NO	YES	NO	YES
4	5	91	18	2	40	NO	YES	NO	YES
5	5	30	34	2	115	NO	YES	NO	NO
6	5	-3	NO	0	0	NO	NO	NO	NO
7	8	47	40	2	115	NO	NO	YES	NO
8	8	13	104	1	156	YES	YES	NO	NO
9	8	40	75	2	87	NO	YES	NO	NO
10	10	75	25	2	60	YES	YES	NO	NO
11	9	38	45	2	52	NO	YES	YES	NO
12	5	10	41	2	67	NO	YES	NO	NO

ER Diff = External Rotation range difference between the hemiplegic and non hemiplegic, Subsc SR = Subscapularis EMG Stretch Response

Pec Major SR = Pectoralis Major EMG Stretch Response

Teres Major SR = Teres Major EMG Stretch Response

Lat Dorsi SR = Latissimus Dorsi EMG Stretch Response

MAS IR = Modified Ashworth Scale rating of Shoulder Internal Rotators

Additional Soft Tissue Changes and Subluxation

All 12 participants received ultrasound scans as part of their standard care. As shown in Table 29 overpage, the number of soft tissue changes recorded by an imaging consultant on ultrasound have been totalled and if a diagnostic impression was given by the specialist, this was recorded. 8 out of 12 cases were believed to have clinical signs of frozen shoulder with the remaining cases being either bursitis or rotator cuff tendinopathy (see table 29). 66% (8/12) of the hemiplegic shoulders had moderate to severe soft tissue changes (≥ 3 soft tissue changes recorded) reported on ultrasound.

4 participants had greater than 5 mm difference in Acromion to Humeral head distance on the hemiplegic side compared to the non-hemiplegic side. 8 cases had less than 5 mm difference. When cases with ≥5mm subluxation were analysed against cases with severe amounts of soft tissue changes, no statistical relationship was seen (Fishers Exact p = 1.00)

Table 29: Subluxation, ultrasound score and consultant diagnosis

ID	MAS IR	ER Diff	Acro to Hum head Hemi – Non Hemi (mm)	US Score	Ultrasound diagnosis
1	2	58	8.94	8	Frozen Shoulder
2	2	23	1.65	2	Subacromial subdeltoid Bursitis
3	2	101	3.59	3	Frozen Shoulder
4	2	91	2.09	3	Frozen Shoulder
5	2	30	3.31	6	Frozen Shoulder
6	0	-3	3.18	5	Supraspinatus and Long Head of Bicep tendinopathy
7	2	47	3.60	6	Frozen Shoulder
8	1	13	1.33	1	Frozen Shoulder
9	2	40	1.59	6	Rotator cuff tendinopathy and Subacromial subdeltoid Bursitis
10	2	75	6.06	5	Frozen Shoulder
11	2	38	6.19	1	Frozen Shoulder
12	2	10	5.86	2	Subacromial subdeltoid Bursitis

Ultrasound Scoring: (Number of soft tissue changes recorded) (Iduwu et al., 2017)

a) 0 = Normal
b) 1 -2 = Mild Damage
c) 3-4 = Moderate Damage
d) 5 -6 = Severe Damage

(5.5) Discussion

This review and pilot study have demonstrated the following:

1) There are currently no control trials examining botulinum toxin injection within the first 3 months of stroke to treat PSSP with associated Shoulder Internal rotator spasticity.

2) A small sample of 11 patients with shoulder internal rotator spasticity showed significant heterogeneity in which muscles were contributing to the restriction presentation. Therefore, assumptions that subscapularis is the key injection target could be inaccurate (Unlu et al., 2010, Choi et al., 2016; Singh et al., 2020). Pectoralis major was found to be the most consistent contributor to internal rotator spasticity (73%) in this cohort.

3) Ultrasound findings showed 66% of participants had moderate to severe amounts of soft tissue changes, which is comparable to a previous larger study (64.4%) (Idowu et al., 2017). In addition, imaging consultants classified 8 participants as having frozen shoulder based on clinical presentation and ultrasound findings.

This study showed there are considerable challenges to conducting needle EMG assessments of stroke patients within 2 months post stroke including site expertise and anticoagulation regimes. However, although the sample size of this study is small, it is clear that subscapularis spasticity is not the sole contributor to early SpIR and so it should not always be the target for BoNT-A injection. The critical factor in light of heterogeneity, seems to be expert assessment which will help to ensure approaches are specific to individual presentations.

The results of the systematic review have also indicated that although there is growing evidence that early use of BoNT-A injection can be useful, there is no trials to treat PSSP with associated SpIR within the first 3 months post stroke. This absence of evidence hampers clinicians using BoNT-A within the first 3 months for PSSP. In addition, clinician surveys have indicated that perceived barriers to earlier treatment are lack of availability of focal botulinum toxin clinics and clinician awareness of referral criteria (Picelli et al., 2017; Smania et al., 2013). Therefore, there is need for greater training of clinicians to ensure patient access to expert services.

Another factor identified as a barrier to the use of BoNT-A is the lack of standardisation of injection practices (Picelli et al., 2017). There is currently significant variation in products, dilution regimes and dosages applied (Ashford et al. 2018; Picelli et al. 2021). There is evidence that a fixed dose of 500 units (Dysport) diluted with 2.5ml saline was effective against control for treating elbow and distal upper limb spasticity with 3 months of stroke (Rosales et al., 2018; Picelli et al., 2021). Therefore, standardised approaches can be effective, so there is now a need for standardised approaches to be trialled in early PSSP cases associated with internal rotator tone, to better inform guidelines.

The ultrasound report findings indicate that hemiplegic weakness may make a stroke survivor more susceptible to soft tissue changes (Idowu et al 2017). These changes may be responsible for setting up a pro-inflammatory environment that in combination with arm disuse triggers frozen shoulder (Jump et al.2021). These, processes are likely to result in worsening of shoulder spasticity (Thibaut et al.,2013). This highlights the complex inter-relationship between soft tissue changes and spasticity in PSSP and so future research needs to consider both components when considering treatment protocols.

Review and Pilot Study Limitations.

Review

The review was limited to English language studies which means that some studies that met the inclusion criteria may have been missed. In addition, although efforts were made to expand the search as far as possible, there may be studies in the grey literature (posters and PhD theses not in peer review journals) which were missed by this review.

Pilot Study

There was no significant difference in terms of age, pain time post stroke and proportions of cases with SpIR between participants who had EMG assessments and those who did not. However, 55% (15/27) of subjects who were identified for EMG assessments could not receive assessments which represents a large proportion of subjects and could have biased results.

The most rigorous clinical techniques were used to ensure EMG needle placement accuracy in the subscapularis muscle including real time ultrasound imaging during insertion. For EMG needle placement of the remaining internal rotators anatomical landmarking, palpation and electrical stimulation without ultrasound imaging. This protocol was to prevent unnecessary participant burden. However, in future it may be beneficial to ensure all needle placements are ultrasound guided to optimise rigour.

Also as discussed, needle placement is a painful stimulus, and although efforts were made to reduce effects of this stimulus this may have influenced spasticity recording.

To prevent bias of EMG findings the specialist consultant conducting the assessments was blinded to the findings of the clinical spasticity

assessment. However, as equipment requires interpretation related to an auditory output, and as such there is potential for error.

The results of this study help to cast doubt on previous assumptions about ‘patterns’ of muscle over activity in cases of adductor and internal tone. However, firm conclusions about muscle relationship can’t be made, as only as a limited number of shoulder girdle muscle groups were assessed. Also, the sample size of the pilot study was very small and so further research is required to confirm findings.

Chapter 6: Factors that affect the outcome of hydrodilatation injection in stroke survivors with confirmed clinical diagnosis of frozen shoulder in their hemiplegic arm.

Abstract

Purpose: To evaluate the effectiveness of hydrodilatation injection for stroke survivors with suspected frozen shoulder in their hemiparetic shoulders. In addition, this project aims to understand factors that influence outcome and if improvements in passive range correspond with perceived pain relief.

Methods: Passive shoulder ranges and patient rated pain on movement were measured pre and post hydrodilatation injection. All subjects had clinical signs of frozen shoulder and were being assessed as part of QSUL from January 2018 to January 2020. Data were collected as part of a service evaluation (registered with NHNN 5-202122-SE),

Results: 41 stroke survivors had a clinical diagnosis of frozen shoulder and received a hydrodilatation injection, with a mean reported pain on movement of 7/10 (likely all in pain dominant phase of Frozen Shoulder). All received 40mg Triamcinalone Acetonide. Additional saline was added with a total injectate volume ranging from 20-55ml (mean 30.97ml (SE 1.53) for 34 case and the volume of injectate was not recorded for 7 subjects. There was a significant change in all passive range measures and pain outcomes within follow up period of 8 weeks post-injection. There was no significant change in outcome in subjects who received more or less than 30ml of additional saline. 3(/10) or more points improvements in patient rated pain corresponded with significant improvements in passive external rotation but not abduction and flexion.

Conclusion:.Hydrodilatation was shown to be effective for improving pain and passive shoulder range. Improvements in passive external rotation corresponded with measurable improvements in perceived pain. Volume of saline injectate did not appear to influence outcomes and it appears the timely use of steroid injection is key to improvements. Regression analysis showed age of stroke survivors significantly on range change post-injection. Time post stroke, gender, pain severity pre injection and restriction severity post-injection wasn't shown to significantly impact on outcome.

(6.1) Introduction

Hydrodilatation for Frozen Shoulder

Hydrodilatation is a treatment used for frozen shoulder that involves injecting steroid with additional saline (ranging 20-40ml) (Lewis, 2015). The additional saline is intended to distend the shoulder capsule to aid improvements in passive range and reduced pain (Lewis, 2015; Wu et al., 2017). Additional, saline distension compared to steroid alone has been shown to result in improvements in early and late pain compared to steroid alone (Challoumas et al., 2021). However, early and late range and functional changes are similar for both hydrodilatation and steroid alone (Challoumas et al., 2021; Wu et al. 2017). Currently there are no studies to date that examine hydrodilatation effectiveness for frozen shoulder in hemiparetic arms post stroke.

As discussed in the thesis introduction, moving the arm to end range positions are important in restoring joint homeostasis, once frozen shoulder processes are active (Lubis and Lubis, 2013). This helps to explain why the addition of post-injection exercises improve functional outcomes when compared to injection alone in recent reviews (Challoumas et al., 2021). It is often challenging for stroke survivors with significant hemiparesis to move their arms to end range positions after injection treatments. It possible therefore that the additional saline in hydrodilatation is important to distend and stress the joint capsule in stroke survivors to the aide the restoration of joint homeostasis. Stroke survivors could represent a separate cohort the general population when considering the efficacy of hydrodilatation injection. This service evaluation will examine effectiveness in this population but it will also look at factors that influence outcome.

Previous injection studies in the Post Stroke Population

As discussed, no studies to date have examined the effectiveness of hydrodilatation injection in treating PSSP. However, steroid is the drug used in hydrodilatation and several studies have examined the use of steroid alone. Four Randomised Control Trials (RCTs) studies found no significant difference between steroid injection compared to therapy alone, Suprascapular nerve block, botulinum toxin or saline placebo injection when examining pain and range improvements as outcomes (Saikaley et al.,2020). Two studies found a significant effect of steroid compared to lidocaine injection or Transcutaneous Electrical Stimulation (TENS) (Saikaley et al.,2020). This shows that the effectiveness of steroid injection for PSSP as a blanket diagnosis is unclear.

An important limitation of the discussed studies to date is the clinical characteristics of the subject's shoulder pain were poorly defined. For example, to have a clinical presentation of frozen shoulder, the subject should either have at least 50% of restriction in external rotation compared to the other side or at least 30% restriction in two out of 3 movements; abduction, external Rotation or internal rotation (Rangan et al., 2020; Wu et al., 2017). Also, it is possible that different phases of Frozen Shoulder, such as pain dominant or restriction dominant phases will respond differently to steroid injection because these likely represent different levels of inflammatory activity (Lewis et al., 2015). Therefore, even within cohorts with frozen shoulder it is important to define whether they are in a pain or restriction dominant phase.

Factors that may affect hydrodilatation outcome

In the general population the following variables have shown a relationship with hydrodilatation injection outcome:

1) **Gender:** Women are 2.7 times more likely to have a poor hydrodilatation outcomes (Torrence et al. 2017)

2) **Pre injection levels of pain**: Patients with a VAS score >10/15 (equivalent of 6.6/10) are 1.9 times more likely to have poor outcome (Torrence et al.,2017).

3) **Pre injection passive range:** Passive external rotation less than 0 degree had a 2.4 times more risk of poor outcomes (Torrence et al.,2017).

4) **Volume of injectate**: In non-stroke subjects with frozen shoulder the volume of the injectate appears to be related to treatment outcome, with a volumes ≥30ml being more effective (Torrence et al, 2018). In fact, subjects who received <30mls were 1.86 times more likely to require subsequent arthroscopic capsular release following hydrodilatation injection (Torrence et al.,2018). Meta-regression of 7 control studies found that injectate volume >30ml fluid improved range of movement (Saltychev et al.,2018), though the effect size was small (Cohen's d=0.3).

In addition, to these variables it is possible that **age** related joint changes such as tendinosis and arthritis may make a stroke survivor more susceptible to a pro inflammatory joint environment, therefore age is also a variable of interest. Time post stroke may also influence if someone has developed permanent joint restriction otherwise known as contracture (Alison et al., 2018).

(6.2) Hypotheses

Hypothesis 1: Hydrodilatation injection is effective in improving shoulder passive external rotation, abduction and flexion range and pain on movement in stroke survivors with clinical signs of frozen shoulder.

Hypothesis 2: Stroke survivors who receive less than 30mls of injectate will have worse outcomes in terms of passive external range change and self-rate pain change compared to stroke survivors who receive ≥30ml of injectate.

Hypothesis 3:

a. Gender, age, time post stroke will all influence changes in passive shoulder external range post-injection

b. Stroke survivors with <0 degrees of passive shoulder external rotation (no movement past neutral) at baseline will have poorer outcomes compared to those with ≥0 passive external rotation.

c. Stroke survivors who rate their pain on movement as < 6.6 on a 11 point Numerical Rating Scale will have poorer outcomes compared to those who rate their pain ≥6.6/10.

(6.3) Methods

What indicates true change?

This evaluation will examine changes in passive shoulder external rotation, flexion and abduction range and patient reported pain on movement as markers of improvement. As discussed in the introductory chapters, this would indicate a true influence on the underlying frozen shoulder pathology (Jump et al., 2021).

Minimal Detectable Change in clinical measurement

The following range values represent minimal detectable values in clinical assessments of passive joint range that would indicate, true change and not just measurement error. Standard errors of measurements were calculated from standard deviations for measurements conducted on 168 asymptomatic shoulders. 3 measurements were conducted for each movement at two points 7 days apart by a single assessor (Dougherty et al. 2018).

i) Shoulder Complex External Rotation: 9 degrees (Salamh et al., 2012; Dougherty et al., 2018).

ii) Shoulder Complex Flexion and Abduction: 15 degrees (Dougherty et al., 2018)

iii) Glenohumeral Flexion and Abduction (blocking scapula movement): 10 degrees (Dougherty et al., 2018)

Pain Scales

For a 11 point numerical pain scales (0 – 10); the minimal change that would indicate a true change in the patient's pain perception is 3 points change (Walsh et al., 2021; Michener et al., 2011)

Service Evaluation

A service evaluation was registered with Queen Square 5-202122-SE, so pre and post hydrodilatation clinical data can be harvested from clinical notes from January 2018 to January 2020 for stroke survivors with a clinical diagnosis of frozen shoulder. Clinicians completed outcomes in a standardised upright sitting position, see below (Fig 33).

Fig 33: Assessment Position for Clinical Measures (Hydrodilatation Evaluation)

The following data was collected from clinicians' notes

1) Shoulder Passive Range changes (measured with a goniometer)

2) Patient rated pain changes (Pain on movement rated on a 11 point 0-10 Numerical Rating Scale)

3) Volume of injectate

4) Age and gender

5) Time since stroke when injected

6) Stroke type (Haemorrhagic/Ischaemic, side of hemiplegia)

Clinical diagnosis of frozen shoulder in hemiplegic arms

Frozen shoulder was confirmed if patients presented pre injection with at least 50% reduction in passive shoulder external rotation range in hemiplegic arms or patients (Rangan et al.,2020) or 30% reduction in shoulder external rotation and shoulder abduction combined (Sharma et al., 2016).

Post-injection follow up measurements

Follow up time in previous studies is very variable from 1 week to 3 years (Rymaruk & Peach, 2017). However, current practise guidelines indicate that patients should be followed up as quickly as possible to encourage mobilisation into tolerable range (Smith & Funk, 2020). A caveat to this is the potential for early steroid flare, an acute irritation that can occur after steroid injection (Fawi et al., 2017). This means the upper limb service aims to follow up patients from 48 hours post-injection. However, as a result of service pressures patients are sometimes followed up several weeks after the injection. Early changes after shoulder hydrodilatation have previously been defined as upto 8 week post-injection (Rymaruk and Peach, 2017). Therefore, we set 8 weeks as the cut off for collecting service follow up data.

Statistical Analysis

Tests of normality were conducted using Kolmogorov-Smirnow and Shapiro Wilks statistics. The patient population characteristics were then described accordingly. When independent groups were uneven, Levene's test of Homogeneity of variance was applied to ensure appropriateness of tests. All tests were two sided and where possible bootstrapping was conducted as an additional robust test to prevent type 1 reporting errors.

Testing hypothesis 1 required repeated measures analysis. When parametric analysis was appropriate, results were adjusted according to the grand mean of pre and post-injection scores to prevent inflated error bars and to prevent type 2 errors (Field et al., 2018).

To test hypothesis 2 outcome range changes were split according to who received 30ml or more of injectate versus those that received less. Parametric t or Mann Whitney U tests were used to compare groups according to data distributions.

For hypothesis 3 passive external rotation change was the dependent variable. Hierarchical Linear regression was conducted with the variables of interest. Initial collinearity checks indicated that age and stroke type (haemorrhagic vs ischaemic) showed significant collinearity. As age is an important theoretical variable, this was chosen in preference to stroke type. Age, gender and time post stroke were the independent variables in the final regression analysis.

The analysis involved inputting age first, then age x gender followed by age x gender x time post Stroke and significance values for improvements in the model were then interpreted. As there were 3 variables in the model, a sample of 41 was sufficient for this analysis (Field, 2018).

Variables for hypotheses 3b and 3c could not be include in the regression model discussed due to potential problems with collinearity of variables. The sample was therefore divided into groups according to the cut offs of pre injection external rotation (< 0 and ≥ 0 degrees of passive external rotation) and pre injection patient rated pain (<6.6 and ≥ 6.6/10), which allowed simple t test comparison of passive external rotation range change between groups.

(6.4) Results

105 patients who were assessed for inclusion onto a Regional Upper limb program presented with pain on movement and joint restriction (see consort diagram Fig 34 overpage).

41 patients were followed up within 8 weeks of injection and had pre and post-injection clinical measures of passive range and pain completed (see table 30 overpage)

93% (38/41) of suitable patients had at least 50% external rotation restriction compared to their unaffected side pre-injection. The remaining 3 had at least 30% movement restriction in external rotation and abduction. Therefore, all participants could be classified as having clinical signs of frozen shoulder.

All 41 participants received hydrodilatation injection. All received 40mg Triamcinalone Acetonide after the injection site was initially numbed with 5mls of 1% lidocaine solution. Additional saline was added with a total injectate volume ranging from 20–- 55ml (mean 30.97ml (SE 1.53) for 34 case and the volume of injectate was not recorded for 7 subjects. Demographics are presented below.

Comparison of included versus excluded participants

There was no significant difference between age of stroke survivors included in the analysis mean 59.46 (SE 1.46) compared to those lost to follow up 63.22 (SE 1.55). Not all data on the excluded participants available but in the data available, these was no significant difference between proportions of hemiparetic side between the included participants and the participants lost to follow up χ^2=0.42 (p=0.66). There was no significant difference between proportion of men and women in the included participants compared to the participants lost to follow up χ^2=0.33 (p=1.00).

The four non stroke survivors were excluded from this analysis.

Table 30: Number of included vs not included participants against side of paresis

	Left Hemiparesis	Right Hemiparesis
Included participants	27	12
Lost to follow up	32	19

Table 31: Number of Included vs not included participants against Gender

	Men	Women
Included participants	26	15
Lost to follow up	43	26

Impact of Covid -19 on project

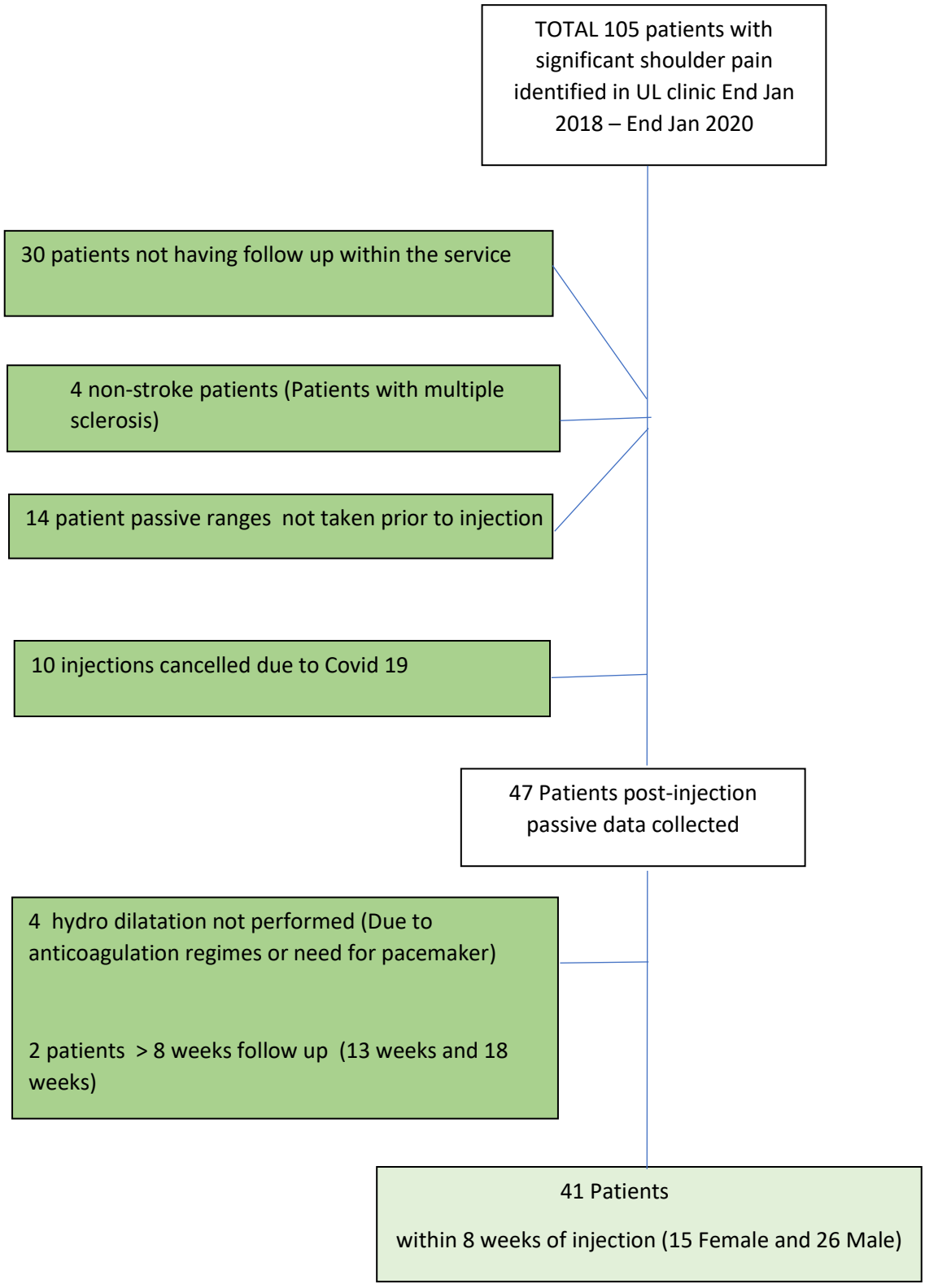
Unfortunately, due to the outbreak of Covid-19, 10 patients who had pre injection clinical measures did not receive hydrodilatation injection and so were excluded from the analysis.

Table 32: Service evaluation participant demographics (Hydrodilatation Evaluation)

Demographics	**Numbers, means and ranges (n =41)**
Males/ Females	26/15
Left/Right Hemiplegia	27/12
Haemorrhagic Stroke/Ischaemic Stroke	6/35
Time Baseline post stroke (mean months)	11.13 (SE 1.31)
Range months post stroke (months)	0.3 – 42.8
Time to Injection post stroke (mean months)	12.63 (SE 1.36)
Range (months)	1.8 – 43.6
Pain on Movement (mean NRS)	7.08 (SE 0.30)
Pain Range (NRS)	3.0 – 10.0
Subluxation (score 1 = ½ finger width)	0 – 3
Subluxation score Mean	0.9 (SE 0.15)
Subluxation Median	1.00
Age range	38 – 82
Age mean	59.46 (SE 1.46)
Age median	59.00

SE = Standard Error

Fig 34: Hydrodilatation service evaluation consort diagram



Results for Hypothesis 1:

Hypothesis 1: *Hydrodilatation injection will have a significant effect on improving shoulder passive external rotation, abduction and flexion restriction and patient reported pain on movement. Pain change and external rotation change will show a close relationship.*

There was a significant improvement in passive external rotation, abduction, flexion and pain as shown in the table and graphs overpage

Table 33: Pre and Post-Injection Mean Passive Range and Pain with Difference statistics (Hydrodilatation Evaluation)

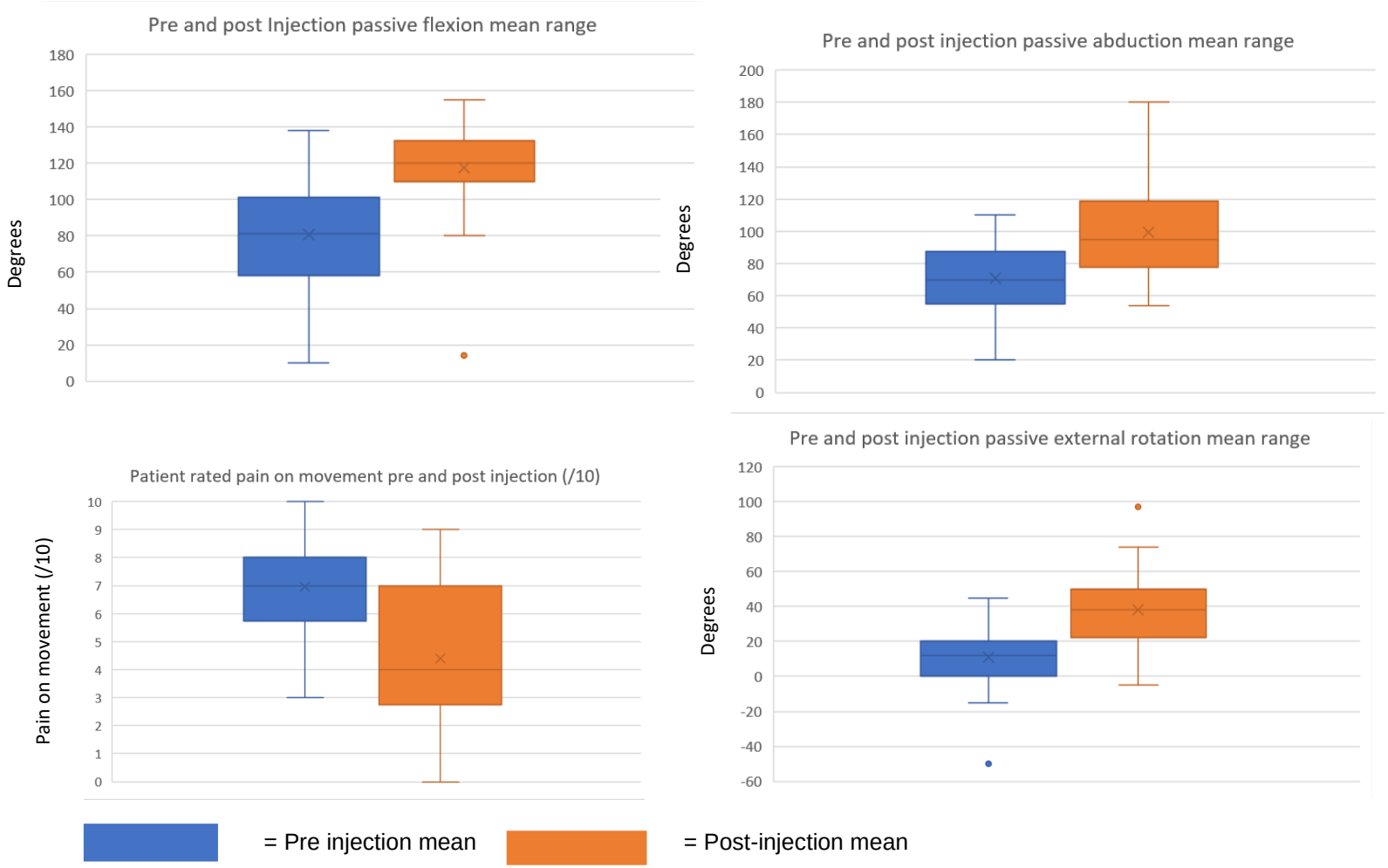
Variable	Mean Pre inj	Mean Post Inj	Mean Change	Diff Test Statistic (Pre vs Post)	Diff p value
Passive ER	10.95 (SE 2.67)	38.05 (SE 3.02)	27.63 (SE 3.23)	t = -9.00	P =<0.001 Cohens d= 1.27
Passive ABD	71.05 (SE 3.30)	99.15 (SE 4.19)	28.10 (SE 4.18)	t =-6.73	P =<0.001 Cohens d = 1.05
Passive FL	80.54 (SE 4.97)	117.59 (SE 3.82)	37.05 (SE 4.46)	t = -8.31	P =<0.001 Cohens d = 1.3
Pain (NRS)	7.08 (SE 0.30)	4.46 (SE 0.47)	2.46 (SE 0.56)	W= 42.00	P =<0.001

ER = External Rotation, ABD = Abduction, FL = Flexion,

NRS = Numerical Rating Scale. Pre inj = Pre injection,

Post Inj = Post-Injection, Diff = Differ

Graph 1 – 4: Box plots of Pre and Post-Injection Passive Shoulder Range and Pain



The relationship between range change and pain

Post-injection range was divided into two groups:

(i) People with ≥3 points change in pain on movement

(ii) People with < 3 points change in pain on movement

There was a significant relationship between passive external rotation change and pain groups t (32) = 2.47 (CI 3.01, 31.48) (p = 0.02), cohens d = 0.86 as well as passive Abduction change t(32) = 2.90 (< p = 0.01) (CI 6.9, 39.1) ,cohens d = 1.0 and pain groups. However there was passive flexion change did not show a significant relationship between pain group U = 144.00 (p = 0.90), see table 32 overpage.

Table 34: Passive range change with or without 3 points self reported pain change on movement post-injection (Hydrodilatation Evaluation)

Range change variable (Post-Injection – Pre jection)	**3 points Change Pain NRS (n=20)**	**LESS than 3 points Change Pain NRS (n =14)**
Passive External Rotation Mean Change	38.14 (SE 6.99)	20.90 (SE 3.23)
Passive Abduction Mean Change	43.57 (SE 6.74)	20.60 (SE 4.66)
Passive Flexion Mean Change	39.29 (SE 8.07)	34.95 (SE 5.90)

Hypothesis 2: *Stroke survivors who receive less than 30mls of injectate have worse outcomes in terms of passive external rotation range change and patient rated pain change compared to patients who receive ≥30ml of injectate.*

Participants were split according to the volume of injectate injected:

I) Group A: 17 participants had 30ml or more injectate

ii) Group B: 17 participants had less than 30 ml injectate

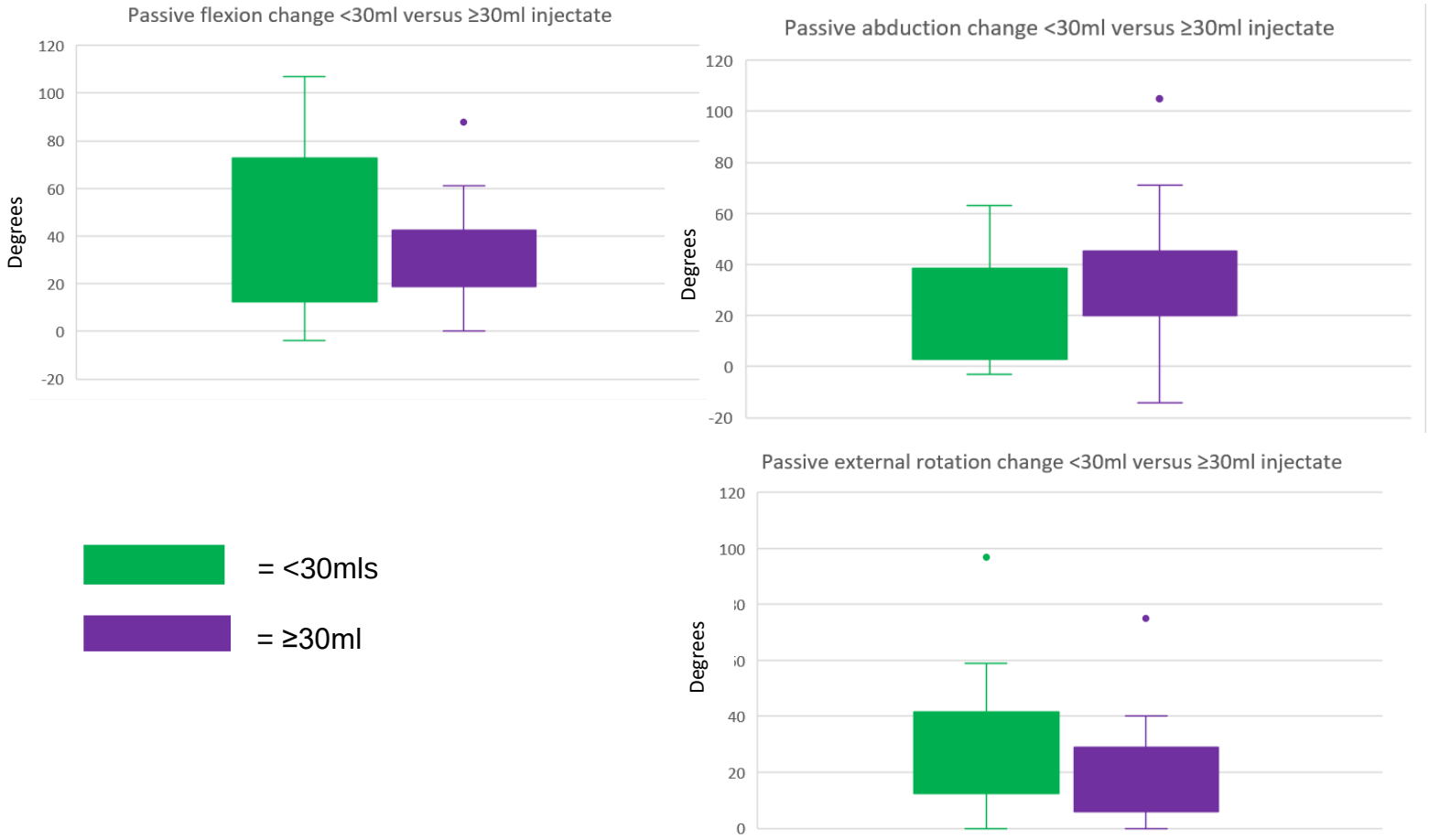
Relationship of volume injected on range and pain change

The was no difference between groups for external rotation, abduction range change or flexion range change (see Table 33).There was no difference between groups for number of participants with at least 2 points change on the Numerical Rating Scale (NRS) or 4 points changes on the NRS. (See Box Plots over page)

Table 35: Passive Range and Pain Change for Groups A and B

Change variable post-injection	**Group A ≥30ML (n =17)**	**Group B <30ML (n=17)**	**Test Statistic**	**P value**
Mean Passive External Rotation Change	21.71 (SE 4.52)	31.35 (SE 5.60)	U = 105.00	0.27
Mean Passive Abduction Change	35.53 (SE 6.61)	23.94 (SE 4.89)	t(32)=-1.41	0.17
Mean Passive Flexion Change	34.76 (SE 5.32)	38.59 (SE 8.13)	U=148.50	0.89
At least 2 points improvements in NRS (number of participants)	10	8	χ^2= 0.56	0.46

Graphs 5 – 8: Box plots of passive range change for <30mls and ≥30mls of injectate



There were no significant differences between groups for pre injection passive shoulder external range, passive shoulder abduction and passive shoulder flexion. There was also no significant difference in patient rated pain on movement pre injection between groups See table 34 below:

In 7 cases the clinician did not report the volume injected. There was no significant difference in age (mean 56.45 (SE 3.83)), F=0.88 (p =0.42) or time post stroke (11.16 months (SE 1.63)), KW = 0.14 (p =0.93) between the 7 missing cases and the analysis groups.

Table 36: Pre-Injection Range and Pain for Groups A and B

Pre-Injection Variable	**≥ 30ML injectate (n =17)**	**< 30ML Injectate (n = 17)**	**Test statistic**	**P value**
Mean passive external rotation	11.06 (SE 4.80)	10.35 (SE 4.02)	U = 162.00	(p=0.55)
Mean passive abduction	71.88 (SE 4.18)	71.29 (SE 4.63)	t (32) = -0.94	(p=0.93)
Mean passive flexion	87.71 (SE 7.03)	77.47 (SE 7.72)	U= 169.00	(p=0.40
Pain NRS (mean)	7.43 (SE 0.39)	5.73 (SE 0.72)	U = 152.50	(p=0.09)

Hypothesis 3:

3a Gender, age, time post stroke and type of stroke (ischaemic versus haemorrhagic) will influence the amount of passive shoulder external range and perceived pain changes post-injection.

Only age significantly improved the model as a predictor of external rotation change F=7.26, (p 0.01), with a beta value = -0.85 (-0.17 -1.7) (p=0.03). Addtion of gender and time post stroke of injection did not significantly improve the model with p values of p =0.61 and p =0.45 respectively. 16% of variance in external rotation change was explained by age (R = 0.41 and R^2=0.16), with the following model formula:

ER change = - 0.85(age).

3b. Stroke survivors with <0 degrees of passive shoulder external rotation at baseline will have poorer outcomes compared to those with ≥0 passive external rotation.

There was no significant difference in external rotation range change in stroke survivors with less than 0 degrees external rotation at baseline (mean 34.00 degrees (SE 10.2)) compared to stroke survivors with 0 degrees or more external rotation at baseline (mean 26.54 degrees (SE 3.4)), t (39) = 0.811 (p=0.41)

3c. Stroke survivors who rate their pain on movement as < 6.6 on a 11 point Numerical Rating Scale will have poorer outcomes compared to those who rate their pain ≥6.6/10.

There was no difference in outcome in people with pain on movement scores ≥ 6.6/10 at baseline (30.17 degrees SE 5.04) compared to pain scores below (22.80 degrees SE 3.16) $t(32) = 1.24$ ($p=0.23$).

(6.5) Discussion

This project evaluated clinical data for 41 subjects pre and post hydrodilatation injection who all had clinically confirmed frozen shoulder. The main findings were: Hydrodilatation injection resulted in clinically meaningful changes in passive shoulder flexion, abduction and external rotation. There was a significant difference in external rotation range change between stroke survivors with more than 3 points improvements in perceived pain on movement compared to those with less than 3 points change. There was no significant difference between abduction range change and flexion range change and the two pain groups. This indicates that improvements in external rotation range appear to be most related to improvements in patient comfort on movement.

Volumes of injectate above and below 30ml was not related to changes in passive external rotation, abduction or flexion or changes in patient rated pain on movement.

Age explained 16% of external rotation range change variance post-injection. A beta value of -0.85 indicating that reduction in external rotation range change post-injection. This means in real terms that a 50 year old receiving this injection would expect 26 degrees more of external rotation range change post-injections compared to an 80 year old. This result is particularly interesting in relation to the results of study in Chapter 4. It appears that age may impact on the speed of onset of pain and may also limit outcomes of interventions. As discussed earlier this may relate to joint and muscle changes such as oesteoarthritis and age related tendonosis.

Stroke survivors who reported pain on movement ≥6.6/10 (Pain severity) or were unable to move past neutral passively into external rotation at baseline did not have significantly worse external rotation range outcomes compared to stroke survivors with less pain and restriction at baseline.

These findings help support the clinical use of hydrodilatation for treating frozen shoulder in the hemiplegic arm. However, having more or less than 30mls of injectate did not seem to influence outcomes. One might then argue that timely provision of steroid appears to be the important factor and the addition of saline to distend the joint capsule may not be significantly important to outcomes (Wu et al.,2018). A caveat to this inclusion, is that the sample size of this study is not as large as studies that have found an effect of saline volume (Torrence et al., 2018).

A recent meta-analysis of hydrodilatation in the general population, estimated a numbers needed to treat figure of 12 patients (Saltychev et al.,2018). It appears that early pain changes might be a benefit of hydrodilatation versus steroid alone (Challoumas et al., 2021). These meta analyses represent as much larger sample base compared to this service evaluation. A larger sample study is required of stroke survivors with Frozen Shoulder examining hydrodilation versus steroid injection to confirm if there is any added benefit of saline distension.

The apparent effect of age on outcome is useful for clinicians to know and may relate to the findings of study 1 in this thesis. In study 1 stroke survivors over 65 years old were more likely to develop PSSP and restriction earlier, possibly due to accelerated fibrosis (Jump et al. 2021). Another consideration is that age tends to result in muscle sarcopenia and this process is accelerated in hemiplegia in combination with decreases in muscle fibre length (Gray et al., 2012). It is possible therefore, that being over 65 years old makes a patient more susceptible to developing more permanent muscle shortening, otherwise known as contracture (Kwah et al., 2012).

However, a previous study looking at predictors of muscle contracture in the hemiplegic elbow and wrist did not find a significant effect of age, and only found muscle strength predicted contracture by six months post stroke (Kwah et al., 2012).

Another explanation for reduced treatment effects with age is age related joint changes. Age related increases in bone turn over results in higher levels of arthritis, with estimates of 30-50% of adults over 65 suffering arthritis, which would result in joint restriction and less change after treatment injections (Loeser, 2010).

Finally in our study pain severity and amount of external rotation restriction present prior to injection was not found to influence outcome in this evaluation. 98% (40/41) of the stroke survivors in this service evaluation reported pain on movement as ≥5/10. This indicates that the majority of the cases in this study were in the pain dominant early phase of frozen shoulder. Therefore, is also possible that hydrodilation needs to be examined across different phases of frozen shoulder in stroke survivors to establish optimal timing of injections.

Conclusion

The findings of this evaluation align with recent systematic review conclusions in the general population, that hydrodilatation can be effective for the treatment of frozen shoulder. However, the previously used dichotomous variable of <30mls versus ≥30mls which has been shown to have a possible effect on outcome in the general population did not show an effect on the stroke survivors in this cohort. Therefore, it is unclear if the addition of saline to distend the shoulder joint capsule is important to outcome. External rotation change was found to be related to meaningful changes in pain and external rotation change was found to be influenced by age. This is useful for clinicians when considering expected change post-injection and when deciding which clinical measures to focus on during treatment outcomes.

Hydrodilatation Service Evaluation Limitations

A key limitation to this evaluation is there is no control as a comparator, so it is difficult to make definitive conclusions about the usefulness of hydrodilatation compared to steroid alone in stroke survivors. In addition, the potential powerful placebo effects of an injection cannot be fully evaluated.

This evaluation looked at changes within an 8 week follow up period post-injection However, without longitudinal follow up it also unclear if changes are maintained. Therefore, future studies examining the effectiveness of hydrodilatations should use a control and examine changes at 6months and year to identify if there is lasting effectiveness in this cohort.

The cohort in this service evaluation were all at least 3 months post stroke and previous steroid injection studies to date have all had cohorts at least 6 months post stroke (Saikaley et al., 2020). It is possible that these subjects may have developed joint contractures, particularly in very weak shoulders which may have influenced the efficacy of the distension treatment. It would be useful for future studies to examine if the addition of saline distension in frozen shoulder is more effect when applied more acutely post stroke.

Chapter 7: Scapula axial rotation strategies of stroke survivors with a clinical diagnosis of frozen shoulder in their hemiplegic arm.

Abstract

Purpose: To investigate Scapula axial rotation initiation strategies in subjects with frozen shoulder in their hemiparetic arm compared to their non-hemiparetic arms. In addition, we examined if clinical measures of active Glenohumeral external rotation showed a relationship with dynamic scapula axal rotation range.

Methods A non-invasive wireless inertial measurement system (Kinetikos, Xsens Technologies,*Coimbra,Portugal)* was used to measure scapula axial rotation during standardised shoulder complex elevation.

Participants: 11 stroke survivors (mean 19.2 months post-stroke) with post-stroke shoulder pain (mean symptom time 17.4 months) and frozen shoulder had shoulder kinematics measured as part of a specialist upper limb clinic assessment.

Results: Hemiparetic arms with frozen shoulder showed a mean difference of 12 degrees more scapula external rotation during forward flexion initiation compared to their non-hemiparetic sides. Non-hemiparetic shoulders showed more variation in Scapula axial rotation strategies during a full elevation cycle. Dynamic scapula axial rotation range during forward shoulder flexion showed a significant positive relationship with clinical measures of active humeral external rotation range.

Conclusion: Increased scapula retraction as an initiation strategy may be a compensation for reduced external rotation range in hemiparetic shoulders with frozen shoulder. The relationship of dynamic scapula axial rotation range with active glenohumeral external rotation range may indicate why external rotation recovery is protective. Dynamic scapula axial movement adjustments likely ensure optimal length tension relationships. It is possible that this could have an effect on reducing injury

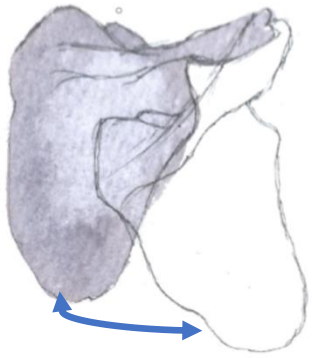
(7.1) Introduction

Scapula movements require anticipatory feed-forward muscle control to ensure optimal length-tension relationships between scapulothoracic muscles and humeral elevators (Da Baets et al., 2014). Dynamic Scapula axial rotation adjustments aim to maintain optimal length tension relationships in shoulder musculature (Da Baets et al., 2014). Scapula movements during dynamic shoulder movement are summarised in Fig ** overpage.

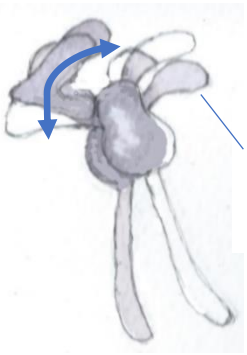
Currently there is no clear relationship between Scapula movement changes and shoulder pain in the general population (Hogan et al. 2020; Da Baets et al., 2014; McQuade et al., 2016). Scapula compensations as a result of reduced descending motor control after stroke likely alter normal length tension relationships which may contribute to soft tissue irritation (Beer et al., 2007; Niesson et al., 2008), This is because Scapula axial rotation positions that deviate too far from neutral have been shown to reduce an individual's ability to generate isometric elevation force compared to more neutral positions (Smith et al., 2002) This may then have a role in injury which can trigger frozen shoulder and restriction processes (Ludewig et al., 2009; Jump et al., 2021; Niesson et al., 2008). In addition, when Frozen shoulder results in Glenohumeral restriction it is possible Scapula rotation compensations may further exacerbate non-optimal length tension relationships (Ludewig et al, 2009; Smith et al., 2002).

Fig. 35: Scapula Movements

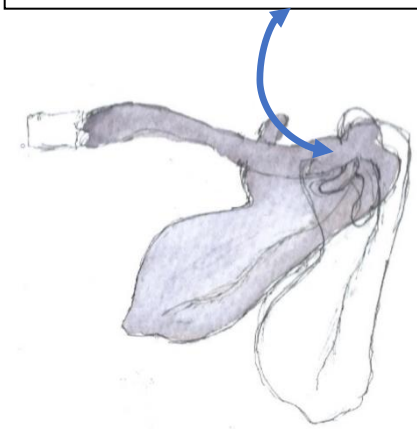
a: Upward/ Downward Rotation (posterior view)



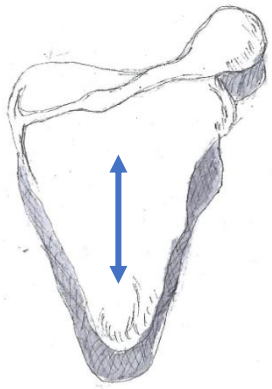
b: Anterior /Posterior tilt (side view looking at Glenoid)



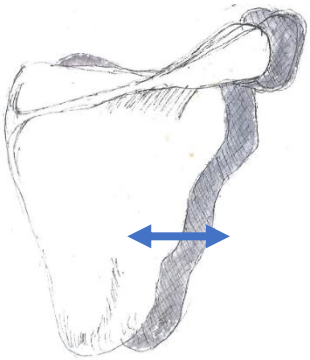
c: Axial Rotation: Internal/External Rotation (view from above)



d: Elevation/ Depression (posterior view)



e: Abduction/ Adduction



Results from study 1 in this thesis indicate recovery of external rotation power in the first 3 weeks after stroke appear to reduce the risk of developing pain and restriction in the hemiparetic arm. It is possible that the ability to generate proximal rotation torque (rotational force) allows for dynamic scapula rotational adjustments during forward flexion (Beer et al. 2007; Da Baets et al. 2014). To test this, it is of interest to establish is dynamic scapula axial rotation range has a relationship with clinical measures of external rotation range.

Another reason for understanding dynamic scapula movement changes is that efficient scapula movement has been proven to impact on upper limb function (Kim et al., 2017). It has been shown that axio-scapula muscle strength impacts on hand and gait function in stroke patients in a small control trial (Kim et al., 2017). Humeral elevation, Scapula upward rotation and Scapula axial rotation range have been shown to predict 65% of variance in stroke survivor upper limb Fugl Meyer scores (Rundquist et al., 2012).

Verbal and sensory cues by therapists can alter shoulder recruitment strategies both positively and negatively and so it is important for therapists to understand how pathology affects movement so appropriate cues are given (Shin et al., 2018; Larsen et al., 2018).

Joint Kinematics

The shoulder joint has multiple degrees of freedom and visual assessments of the shoulder complex has been shown to have limited diagnostic accuracy (Wassinger et al., 2015). For example, visual assessment of scapulothoracic movements in 12 subjects without neurology was found to have a diagnostic accuracy 49.5%, specificity 60% and sensitivity 35% (Wassinger et al., 2015).

Due to the limitations of visual assessments, joint kinematics using computerised tracking systems have gained in popularity (Hussain et al., 2018). Kinematics is defined as the study of relative movements of different joints of the body (Hussain et al., 2018). Sensors placed on anatomical landmarks allow 3-dimensional (3D) tracking of joint movements. This sensor information is interpreted by a computer model coded from many subjects, often with use of bone pin data (Picerno et al.,2019). Pins are inserted into the bones of the articulating joints so true movement can be tracked along with surface landmarks and sensor information. This data is used to ensure computer models interpret sensor information as accurately as possible in relation to true joint movements (Picerno et al., 2019). Non-invasive wireless inertial measurement systems are therefore accurate solutions for clinical kinematic measurement which are more desirable and practical than invasive research bone techniques (Seth et al., 2016; Hajizadeh et al., 2019). This validation study involved 1 subject (Seth et al., 2016).

As the *Kinetikos* system is fairly new to the market it was difficult to ascertain exact values around not discussed in the Seth article. This was due to concern about competitors . In a verbal discussion between *Kinetikos*, they explained the maximum error were around 3.5 degrees (as per similar studies with similar equipment) (Niessen et al., 2008, Verbal discussion Ricardo Matias 2019).

Scapula movement changes due to hemiparetic weakness

Firstly, it is useful to understand what scapular changes occur purely as a result of the onset of weakness after stroke**.** In hemiparetic arms, reduced ability to forward flex the humerus against gravity appears to result in more scapula upward rotation (Rundquist et al., 2012). It is possible that higher proportions of scapula upward rotation are a compensation for reduced proximal external rotation force (torque) production (Joshi et al., 2011). This was demonstrated in non-stroke subjects where the external rotators were fatigued by a repeated exercise protocol, which resulted in increased scapula upward rotation during elevation (Joshi et al., 2011).

Research examining proximal shoulder torque (rotational force) generation at different arm speeds in hemiplegic arms, found a person's ability to generate proximal arm torques was reduced with increased arm speed (Lum et al., 2004). This is a likely reason why stroke survivors self-select slower arm speeds when elevating their hemiparetic arms (Lum et al. 2004).

Scapula Movement changes in painful hemiparetic shoulder

Scapula upward rotation changes in painful hemiparetic shoulder

The impact of shoulder pain and restriction on scapula movement is currently unclear. A significant increase in resting and active scapula upward rotation (n=27) has been found in participants with hemiparetic shoulder pain compared to the unaffected arm and compared to controls during forward elevation (Niessen et al., 2008). In contrast another study (n=21) found upward rotation reduced in patients with PSSP compared to controls (Hardwick and Lang, 2011). Both studies reported passive external rotation restriction in their affected arm, though it was not clarified if there were clinical signs of frozen shoulder (Niessen et al., 2008; Hardwick and Lang, 2011). However, participants of the two studies represented different time points in relation to chronicity post stroke; one cohort was on average 3 months post stroke whereas the other cohort were a mean of 7 months post stroke (Niessen et al., 2008; Hardwick and Lang, 2011).

Scapula upward rotation has been the focus of kinematic studies of PSSP to date. This is possibly because it is the easiest movement to measure and measurements of scapula upward rotation are associated with the lowest measurement errors (Da Baets et al., 2014; Price et al.,1999).

Scapula upward rotation initiation patterns have previously been defined as follows:

1) **Scapula lead:** where there is more scapula upward rotation during movement initiation on the affected side compared to the unaffected side (Price et al.,1999). Participants with shoulder pain in there hemiparetic arms predominantly displayed a scapula lead strategy 4/6 (67%). This relationship was replicated in a further 17 stroke survivors which found hemiparetic shoulders with pain showed greater upward rotation at rest and during elevation compared to the non-hemiplegic side (Niesson et al. 2008). This may be explained by electromyography (EMG) muscle activation data (Da Baets et al. 2014). Pain in hemiparetic shoulders has been shown to delay lower trapezius and serratus anterior muscle activity during forward arm flexion compared to hemiparetic arms without pain (Da Baets et al., 2014).
2) **Scapula lag:** where participants show less scapula upward rotation in the affected side during movement initiation. This groups had a significantly lower arm motricity scores and significantly higher proportion of participants with subluxation 5/8 (63%) (Price et al., 1999). Therefore, scapula lag is possibly the result of non-optimal length tension relationships during movement.
3) **Scapula symmetry:** where participants shoulder upward rotation is similar on both arms during movement initiation: These participants had higher arm motricity scores and a higher proportion of participants who could perform shoulder shrug 12/16 (75%) compared to the lead (50%) and lag (25%) groups (Price et al.,1999).

It is now of interest to establish if these movement categories can be reproduced in a cohort with clinical signs of frozen shoulder in their hemiparetic arms.

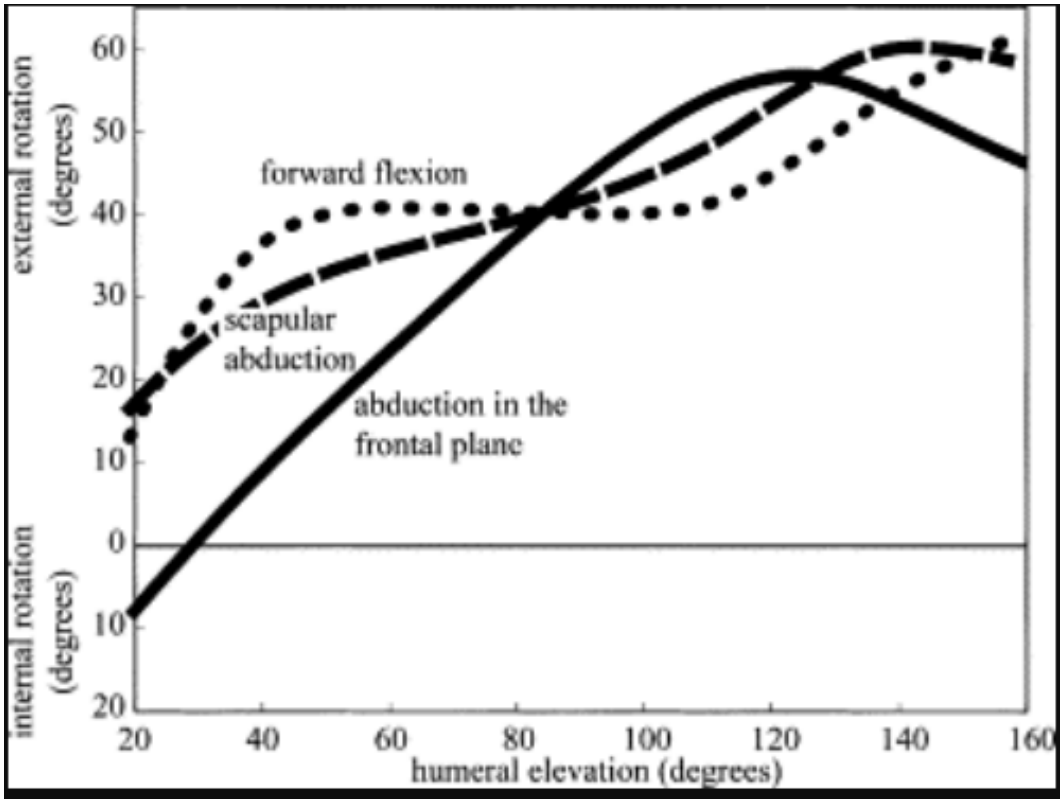
Scapula axial rotation changes in painful hemiparetic shoulder

Healthy shoulders show variation in axial rotation according to the plane of elevation. In respect to this shoulder movements are often standardised in study protocols to forward flexion in the scapula plane (Meskers et al 2005 and Lixandra et al. 2017). This helps to isolate changes that may be the result of pathology or weakness.

During forward shoulder flexion healthy shoulders without neurology appear to demonstrate a pattern of progressive scapula external rotation, followed by a slight reversal into internal rotation around 70 degrees of elevation followed by further external rotation towards the end of elevation see Fig. 35 overpage (Stokdijk et al., 2003; Ludwig et al. 1996; Ebaugh and Spinelli, 2010). It appears this rotation strategy works in combination with the humeral head which is also externally rotating during elevation as 35 degrees of Humeral external rotation relative to the scapula is required to clear the Glenoid Tuberosity of the Scapula Acromion (Browne et al., 1990).

Paretic shoulders at 110 forward shoulder elevation have been shown to be more retracted (external rotation and adduction) compared to healthy controls (Meskers et al.,2005). However, only 3 of the subjects had pain on movement (3/10) (Meskers et al., 2005). In contrast two other studies where all subjects had pain found no difference in Scapula axial rotation during elevation between hemiparetic and non-hemiparetic shoulders (Niesson et al. 2008; Lixandra et al., 2017). Unfortunately. it was unclear if these subjects had significant passive joint restriction in their paretic shoulders. These studies also represent different cohort as the subjects of one were a mean of 7.7 months and 60 months post stroke respectively (Meskers et al., 2005; Lixandra et al., 2017).

Fig. 36: Combined scapula external rotation patterns in three elevation planes for 30 normal subjects (forward flexion, abduction in the Scapular plane, and pure sideways abduction)



(Taken from Fig 6: Stokdijk et al., 2003).

It is now of interest to investigate if common Scapula axial rotation strategies exist in a cohort with defined shoulder pathology. In this study we examine a cohort who all have Frozen Shoulder in their hemiparetic arm; according to clinical restriction criteria (Rangan et al., 2020). This includes passive shoulder external rotation and abduction restriction, with associated pain (Rangan et al, 2020).

Scapula Initiation Strategies

In shoulders with pain, it appears that ‘scapula excursions’ are present in resting positions and initiation strategies that then influence further movement during arm elevation (Babyar et al., 1996). This has also been shown in shoulders with PSSP (Niesson et al.,2008). However, clinical pain presentations have not been well described. Understanding axial rotation and upward rotation initiation strategies in hemiparetic shoulders with clinical signs of frozen shoulder will help to define the effects of this pathology on movement patterns.

Effects of Covid-19 Pandemic

The initial aim of this evaluation was to analyse scapula movement patterns in a cohort with frozen shoulder and known external rotation restriction. Initially, it was hoped to analyse movements pre and post hydrodilatation injection. This would help to unpick the effects of pain and restriction versus weakness alone. However, due to the pandemic the cohort’s injection treatments were cancelled and so only initial analysis was completed.

(7.2) Aims and Hypotheses

The primary aim of this study was to identify common scapula axial rotation initiation and movement strategies in hemiparetic arms with clinical signs of frozen shoulder during active forward flexion.

In addition, the relationship between active glenohumeral external rotation range and dynamic scapula axial rotation range was examined. This study will test the following hypotheses:

Hypothesis 1: (Scapula axial rotation hypotheses)

a) Hemiparetic shoulders with clinical signs of frozen shoulder will show significantly more scapula external rotation during forward flexion initiation compared to the non-hemiparetic side.

b) Non-hemiparetic shoulders will show a mixed axial rotation scapula strategy during elevation compared to hemiparetic shoulder shoulders with frozen shoulder which will be more fixed into external rotation.

c) Total dynamic scapula axial rotation range during arm flexion will correlate positively with clinical measures of active Glenohumeral external rotation range in hemiparetic and non-hemiparetic shoulders

If these hypotheses are correct, it will clarify if there are common Scapula axial rotation compensations in hemiparetic shoulders with frozen shoulder restriction. It will also confirm that Scapula axial rotation performance is influenced by active external rotation ability. Although the study cohort will have already developed pain and restriction it will give some understanding about why external rotation recovery is important in preventing pain.

Hypothesis 2: (Scapula upward rotation hypotheses)

2a) Proportions of scapula upward rotation during shoulder flexion will show an inverse relationship with clinical measures of active external rotation range

b) Ratios of Scapula: Humeral movement will decrease with increased total elevation ability

2c) Hemiparetic shoulders (without subluxation) with painful frozen shoulder will demonstrate a 'scapula lead' movement initiation strategy: more upward rotation compared to the non-hemiplegic side as a result of pain and restriction.

2d) Hemiplegic shoulders with a measurable subluxation will demonstrate a 'scapula lag' movement initiation strategy (regardless of pain and restriction): less upward rotation compared to the non-hemiplegic side as a result of non-optimal length tension relationship

If hypothesis 2a is true, it will confirm the relationship between active external rotation ability and Scapula upward rotation compensations. If hypothesis 2b is true, it will confirm the findings of previous research that proportion of upward Scapula rotation decrease with total shoulder elevation ability (Rundquist et al., 2012). If hypotheses 2c and d are true it will help confirm the findings of a previous study that indicate upward rotation initiation strategy is influenced by pain, weakness and glenohumeral joint alignment (subluxation).

(7.3) Methods

Subjects

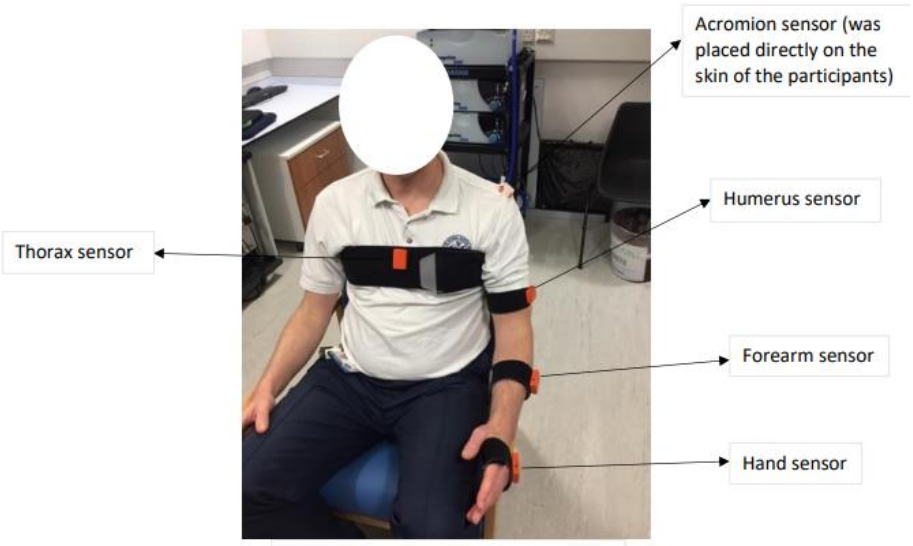
A London upper limb service was trialling the use of widely used non-invasive kinematic kits in order to get more accurate information on patients' active arm movement. Initially this service evaluation aimed to collect clinical measurements and scapula kinematic data conducted on stroke survivors who attended the clinics with clinical signs of frozen shoulder. As discussed the original aim was to collect data pre and post hydrodilatation injection to examine the impact of the treatment on movement patterns (Evaluation reference 5-202122-SE). However, as a result of the Covid-19 pandemic only pre injection measurements were collected.

Measurements

3D kinematic scapula data was collected for scapula flexion movements in the scapula plane using a non-invasive wireless inertial measurement system called Kinetikos (Xsens Technologies*, Coimbra, Portugal*) . The *Kinetikos* equipment used in this study very small errors have been reported, with a value of 2mm found when comparing bone pin data and model positioning outcomes (Seth et al., 2016).

The inertial measurement sensors (IMU) use a 3-axis gyroscope, accelerometer and magnetometer as well as a barometer to measure speed, rotation and elevation of scapula relative to humeral elevation. The sensor data is transmitted to a wireless station; the Awinda Master which is then uploaded to a software model developed by Seth et al. 2016. The sensors were placed as per Fig 36**.**

Fig. 37: Kinetikos sensor placement



Prior to testing the sensors were calibrated with the Elbow at 90 degrees (measured with a goniometer) and the forearm placed in a mid-prone position as pictured in Fig 29. This complied with the manufacturer instructions (Kinetikos, Xsens Technologies,*Coimbra,Portugal,* Kinetikos, 2018). These are fixed onto the skin with medical tape. Once calibrated the device signalled an error message if there was excessive movement at a sensor or sensor slippage.

The testing procedure

Participants were seated on a standard chair with a backrest and without arm rests. As the system and model were developed using shoulder flexion in the scapula plane in a palm down, elbow extended position (see Fig 37 below), this was chosen as the test movement (Seth et al., 2016). In addition, other studies of hemiplegic arm kinematics have used this movement (Lixandrao et al.,2017; Hardwick and Lang, 2011).

Fig. 38: Standardised shoulder flexion movement

Scapula plane was standardised as 45 degrees to the lateral Acromion. A laser pointer was used to position a target of a tennis ball on top of an extended microphone stand. This target gave participants the line of elevation to follow to ensure standardisation of repeated movements. Participants were also given a towel lumbar support to ensure an upright thoracic posture. Towel support was given at the lumbar spine in the chair to promote an upright posture.

Participants arms were initially moved passively within the scapula plane to ensure patient comprehension of the elevation task, and to aid standardisation. Participants were instructed to lift their arm as far as possible, as comfort allows and then lower fully 5 times. Each elevation was counted off by the assessor to allow the participant to keep track, however, no cues for speed were given. 5 repetitions were chosen to ensure reliability of findings (Seth et al., 2016).

Additional Clinical Measures

In addition to the 3D Kinematics, additional clinical measures were taken by therapists. All measurements were conducted in clinic in an upright sitting position as per Fig 38 below:

Fig. 39: Assessment Position for Clinical Measures (Study 2)

(Taken from Fig 1, Kumar et al. 2014)

The following data was harvested from service data for analysis:

1) Passive and Active Range of Shoulder Complex Flexion, Abduction and External rotation (measured using a goniometer in upright siting)

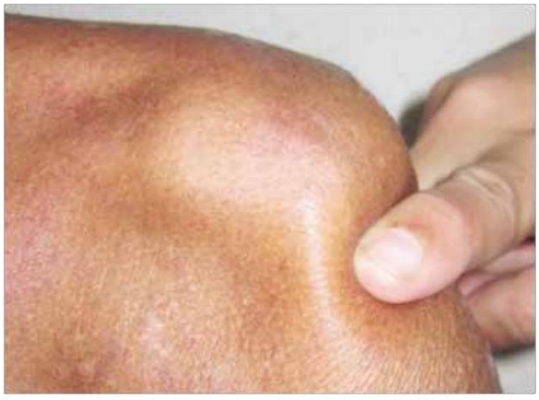
2) Finger breath measurements of subluxation

3) Proximal shoulder Proprioception measures using the Fugl Meyer

Subluxation measurements

A validated and reliable clinical assessment of subluxation is the finger palpation technique (Hall et al,1999). The space below the acromion is palpated with the arm hanging by the patients' side as per Fig. 39. Spacing is recording as follows: Less than Half a finger = 0, Half a finger = 1 point, 1 finger = 2 points etc. This means that ½ finger difference compared to the unaffected side is the minimal detectable change, using this methodology: The presence of subluxation was defined as any palpable gap more than ½ finger in this study.

Fig. 39: Example of palpation method for subluxation assessment



Proprioception measurements

The Fugl Meyer Proprioception assessment was conducted at the proximal shoulder measure (Sullivan et al., 2010). The shoulder joint was held on the lateral aspects to minimize cutaneous feedback. The shoulder was initially moved through a small amplitude (approximately 10 degrees). The shoulder joint was moved 6 times, Scoring was as follows:

(2) -Intact -participant was accurate 4 or more times

(1) -Impaired -participant was accurate less than 4 times,

(0)- Absent- inaccurate with all movements.

Statistical analysis plan

To test Hypothesis 1a To calculate rotation ranges; peak rotation in each direction were averaged across the 3 middle elevations cycles for both hemiparetic and non-hemiparetic sides. Kendall's tau non-parametric correlation analysis was conducted when comparing the relationship of clinical measures of active external rotation and dynamic axial rotation range. As the sample size was only 22, boot strapped confidence intervals were calculated, as even though Kendall's tau is preferred for small samples there is still the potential for type 1 errors (May & Looney, 2020). One reassuring factor for studies using similar equipment is that intra-individual variability is reduced due to the accuracy of the measurements resulting in effects size predictions of around 0.7 (Niessen et al., 2008). This in combination with a minimal desired detection measure of 3.5 degrees, calculates a power of 0.8 (Niessen et al., 2008). Manufacturers of this device advised that this power was appropriate for the equipment in this study and when *G*Power* is used with 0.8 effect size, a sample of around 15 – 19 is required for the correlation coefficients calculated in this study (Verbal discussion with Kinetikos 2018).

For Hypothesis 1b To establish scapula resting and initiation positions scapula axial positions were sampled prior to movement and at 5 degrees humeral elevation for both non-hemiparetic and hemiparetic shoulders. 5 degrees was selected based on previous research with similar equipment indicating 3.5 degrees was minimal detectable change that might not be related measurement error (Niesson et al., 2008).

For Hypothesis 1 c Whole scapula axial rotation strategies were observed throughout elevation cycles so they could be described and classified.

To test hypothesis 2a: Kendall's tau nonparametric correlation analysis was conducted when comparing the relationship between clinical measures of external rotation range and proportions of scapula upward rotation measured with the *Kinetikos* system. (Justification as per above).

For hypothesis 2b: Proportions of scapula upward rotation were calculated for subjects in the follow three criteria

1) Total shoulder elevation <45 degrees

2) Total shoulder elevation 45 -90 degrees

3) Total shoulder elevation > 90 degrees.

For hypothesis 2 c and d: 5 degrees was set as a parameter for clinical difference in upward rotation at initiation, Scapula upward positions were sampled at 5 degrees humeral elevation to allow classification to either Scapula lead, lag or same, as per below:

1) Scapula lead was defined as ≥5 degrees more scapula upward rotation on the hemiparetic side compared to the non-hemiplegic side
2) Scapula lag was defined as ≥5 degrees more scapula upward rotation on the non-hemiplegic shoulder compared to the hemiplegic arm
3) Same was define as <5 degrees difference in scapula upward rotation between the non-hemiplegic and hemiplegic arm.

For continuous variables tests of normality were conducted using Kolmogorov-Smirnow and Shapiro-Wilks statistics. In addition, when independent groups were uneven Levene's test of Homogeneity of variance was applied to ensure appropriateness of tests. When data was non-parametric Mann Whitney U was used to compare two groups. All tests were two sided and where possible bootstrapping was conducted as an additional robust test to prevent type 1 reporting errors.

For analysis of 2x 2 tables; Contingency tables were produced to examine observed versus expected frequencies for each test case to ensure suitability of statistical tests. The expected count is calculated from the total of each row multiplied by the column total and then divided by the total sample size. In order to meet the criteria for Chi Squared testing of a 2x2 table, no less than 20% of fields should have less than 5 expected data points (Howell et al.,2012). Fisher's exact test was applied to prevent type 1 errors in interpretation when conditions for a Chi Squared test were not met.

(7.4) Results

Participants

11 stroke survivors had wireless inertial measurements completed of shoulder flexion in the scapula plane on their hemiplegic and non-hemiplegic side (see demographics table 35 overpage).

All participants had pain in their hemiparetic shoulder (Numerical Rating Scale /10 mean = 6.12, range 4 -10/10). 73% (8/11) patients had associated night pain and all participants rated some level of low mood and 10/11 patients rated some level of anxiety (see table 36 overpage). 82% (9/11) had at least 50% reduction in passive shoulder external rotation range, and the remaining two had at least 30% reduction in shoulder external rotation and shoulder range. This meant all had a clinical diagnosis of frozen shoulder in their hemiplegic arms.

All participants had additional spasticity in their internal rotators and adductors, all scoring 2/4 for tone in these muscle groups. All participants had full proximal shoulder proprioception as measured with the Fugl Meyer assessment (2/2). 55% (6/11) patients had at least half a finger width subluxation. See clinical measures of active range in table 36 overpage.

All patients were able to forward flex their arms to at least 10 degrees against gravity on their hemiparetic side and complete 5 total elevation cycles on each arm (see Appendix for all elevation cycle data). There was a small amount of variation in elevation amplitudes in hemiplegic arms with lower total elevation ability indicating some effect of fatigue in some cases.

See Demographic Table 35 overpage:

Table 37: Stroke survivor demographics for scapula kinematics evaluation

Variable	Participants (n = 11)
Age	61.45 years (SE 2.08)
Gender	10 female, 1 male
Hemiplegic Side (R/L)	3 /8
Paretic arm (Dominant /Non Dominant)	8/3
Time post stroke (mean)	19.23 months (SE 4.05)
Time with PSSP (mean)	17.44 months (SE 4.09)

SE = Standard Error

Table 38: Summary of Clinical characteristics of 11 stroke survivors

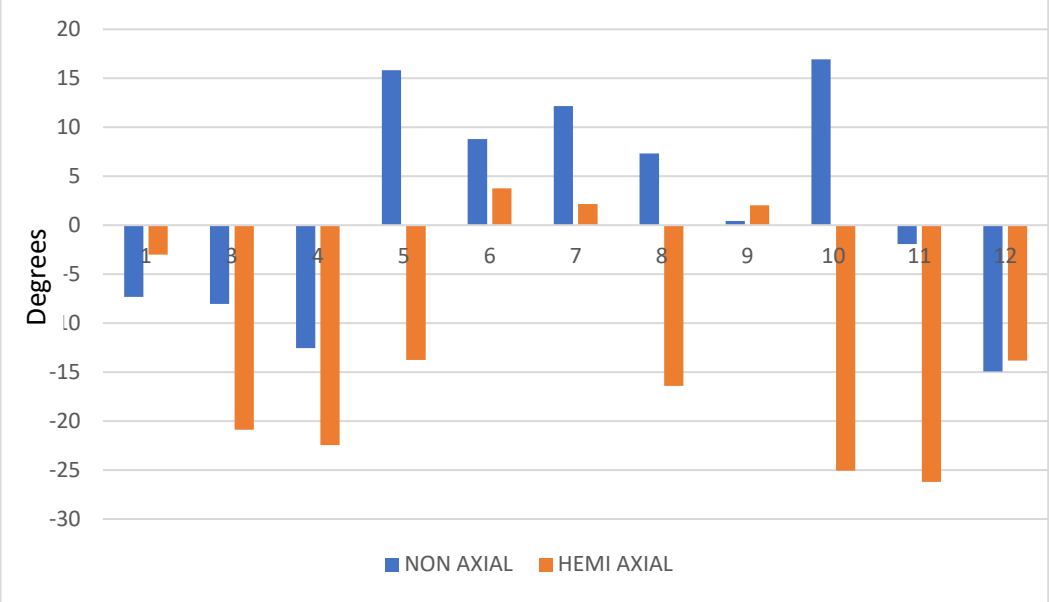
Hemiparetic Arm		Non – Hemiparetic Arm	
AROM/PROM External Rotation on hemiparetic side (mean)	1˚(SE 5.43) / 26˚ (SE 5.13)	AROM/PROM External Rotation on non-hemiparetic side (mean)	57˚ (SE 4.82)/ 72˚ (SE 3.62)
AROM/PROM Abduction on hemiparetic side (mean)	57 ˚ (SE 3.0)/ 94˚ (SE 8.44)	AROM/PROM Abduction on non- hemiparetic side (mean)	144˚ (SE 4.22)/ 158˚ (SE 4.52)
AROM/PROM Flexion on hemiparetic side (mean)	59˚ (SE 6.63) / 85˚ (SE 7.24)	AROM/PROM Flexion on non-hemiparetic side (mean)	145˚ (2.71)/ 155˚ (SE 3.62)
Hemiparetic subluxation (mm)	4 (SE 0.90)	N/A	
Pain on movement (mean NRS /10)	6.3 (SE 0.90)	N/A	

Results for Hypothesis 1:

Hypothesis 1a) *Hemiparetic shoulders with clinical signs of frozen shoulder will show significantly more scapula external rotation during forward flexion initiation compared to the non-hemiparetic side.*

At 5 degrees elevation the Scapula's on the hemiparetic side showed significantly more external rotation (relative to their starting positions) -16.54 degrees (SE 2.14) compared to the non-hemiplegic side - 4.50 degrees (S.E. 2.27), U= 577 (p = <0.001). Individual case axial rotation angles are presented in graph 10, showing 9/11 cases in the hemiparetic shoulder were more into scapula external rotation at 5 degrees flexion elevation.

Graph 9: Scapula axial rotation at 5 degrees humeral flexion



Positive values = relative internal rotation

Negative values = relative external rotation

NON AXIAL = Non hemiplegic arm Axial Rotation

HEMI AXIAL = Hemiplegic Arm Axial Rotation

X axis = individual cases

Coupling of Axial rotation and relative abduction

At 5 degrees of shoulder elevation; 7/8 of the hemiparetic shoulders and 4/5 of the non-hemiplegic shoulders showed coupling of scapula external rotation and adduction (Retraction) forward arm flexion initiation. 3/4 of hemiparetic shoulders and 3/5 of the non-hemiplegic shoulders showed coupling of scapula internal rotation and abduction (Protraction) during forward arm flexion initiation.

Starting positions

There was no statistical difference between axial rotation starting position hemiplegic side (mean -6.35 degrees, SE 2.06), non-hemiplegic side (mean -8.40 degrees, SE 4.03), $t(20) = -0.452$ ($p = 0.66$).

Hypothesis 1b*)* *Non-hemiparetic shoulders will show a mixed axial rotation scapula strategy during elevation compared to hemiparetic shoulders with frozen shoulder which will be more fixed into external rotation*

Three axial rotation strategies were identified during humeral elevation in this cohort: i) External rotation ii) Internal rotation and iii) Mixed during elevation cycle (described below with examples)

1) External (E): Progressive Scapula external rotation with shoulder complex elevation and then reversal on lowering (see Case A overpage ID 1 – hemiparetic shoulder)

2) Internal (I): Progressive Scapula internal rotation with shoulder complex elevation and then reversal on lowering (See Case B overpage (ID- 7 hemiparetic shoulder)

3) Mixed (M): Initial progressive scapula internal rotation followed by a reversal to external rotation during mid-range elevation (see Case C overpage ID- 7 non-hemiparetic shoulder)

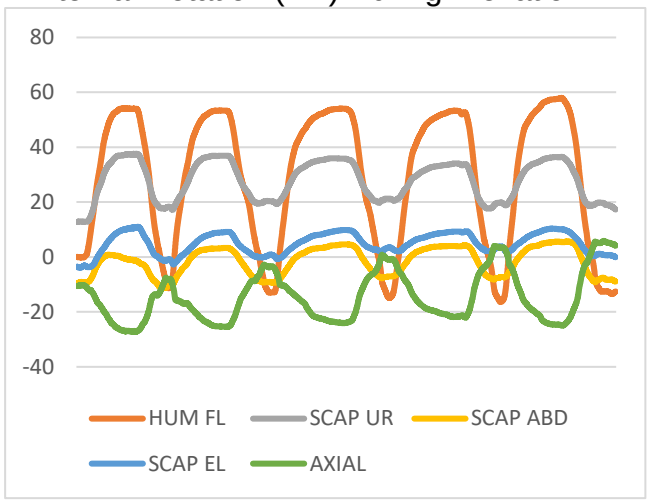
Hemiparetic arms with frozen shoulder showed a predominantly external rotation (E) scapula strategy during elevation 64% (7/11), with 4/11 displaying an internal strategy (see table 29). There was no predominant strategy in the non-hemiparetic shoulder; 36% (4/11) were mixed, 36% (4/11) external and 27% (3/11) internal. Examples of each strategy are displayed in Graphs 6,7 and 8 overpage. In addition, elevation cycles for all cases are presented in Appendix. Hemiparetic shoulders stayed in one rotational strategy with less dynamic axial rotation adjustments.

Table 39: Scapula axial rotation strategies during humeral elevation in the scapula plane (Letters as per definitions overpage)

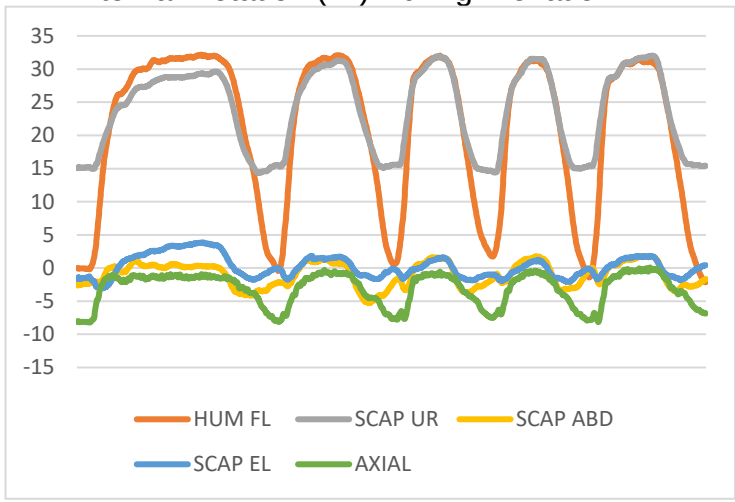
ID	Non Hemiparetic arm	Hemiparetic arm with Frozen Shoulder
1	M	E
3	E	E
4	I	E
5	M	E
6	I	I
7	I	I
8	M	I
9	E	I
10	M	E
11	E	E
12	E	E

Graph 10,11 & 12: Examples of different scapula axial rotation strategies over 5 elevation cycles in the scapula plane

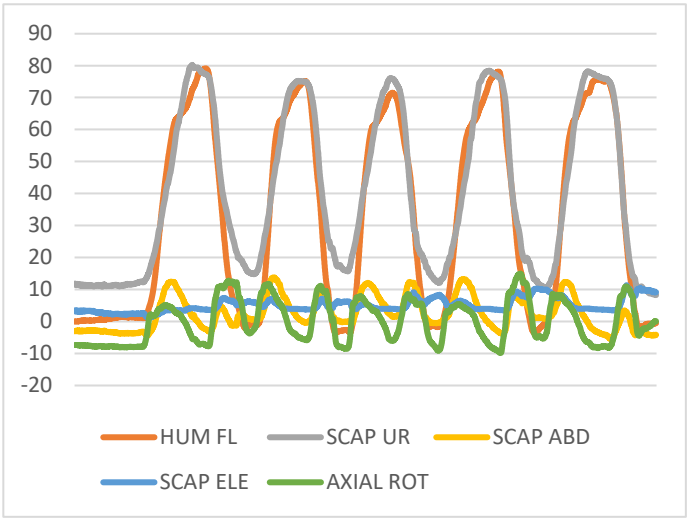
A: External Rotation (ER) During Elevation



B: Internal Rotation (IR) During Elevation



C: Mixed Rotation During Elevation: Initial IR with elevation and then ER at the end of shoulder flexion range



Hum FL = Humeral Flexion

Scap UR = Scapula Upward Rotation

Scap ABD = Scapula Abduction Positives values = Abduction

Negative values = Adduction

Scap EL = Scapula Elevation

AXIAL = Axial Rotation Negative values = External Rotation

Positive values = Internal Rotation

Y Axis = Degrees

Case A X axis = Total time for 5 elevation cycles = 49.45 seconds

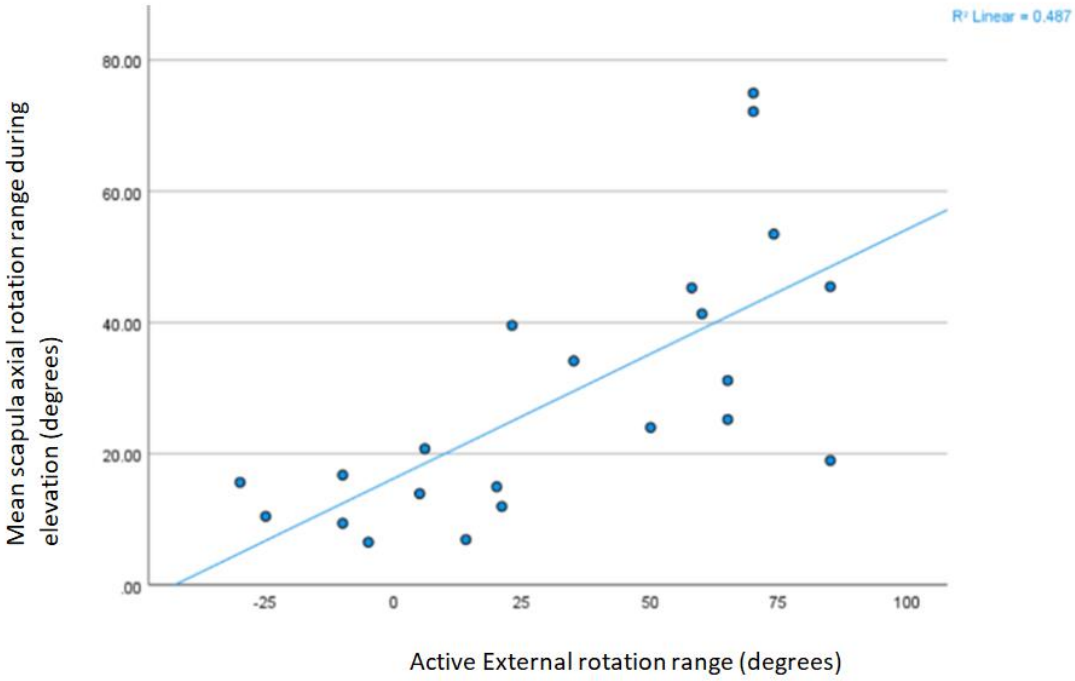
Case B X axis = Total time for 5 elevation cycles = 23.99 seconds

Case C X axis = Total time for 5 elevation cycles = 34.33 second

Hypothesis 1c) *Total scapula axial rotation during elevation will correlate positively with clinical measures of active external rotation range.*

Total scapula axial rotation range during active elevation measured with the inertial measurement system showed a positive relationship with clinical measures of active glenohumeral external rotation range. Non-parametric (Kendall's Tau) correlation analysis for these variables was significant Ƭ = 0.55 (p=<0.01) (CI 0.36, 0.72). (See Graph 9).

Graph 13: Scatter plot of dynamic axial rotation range (y axis) versus clinical measures of active external rotation (x axis)

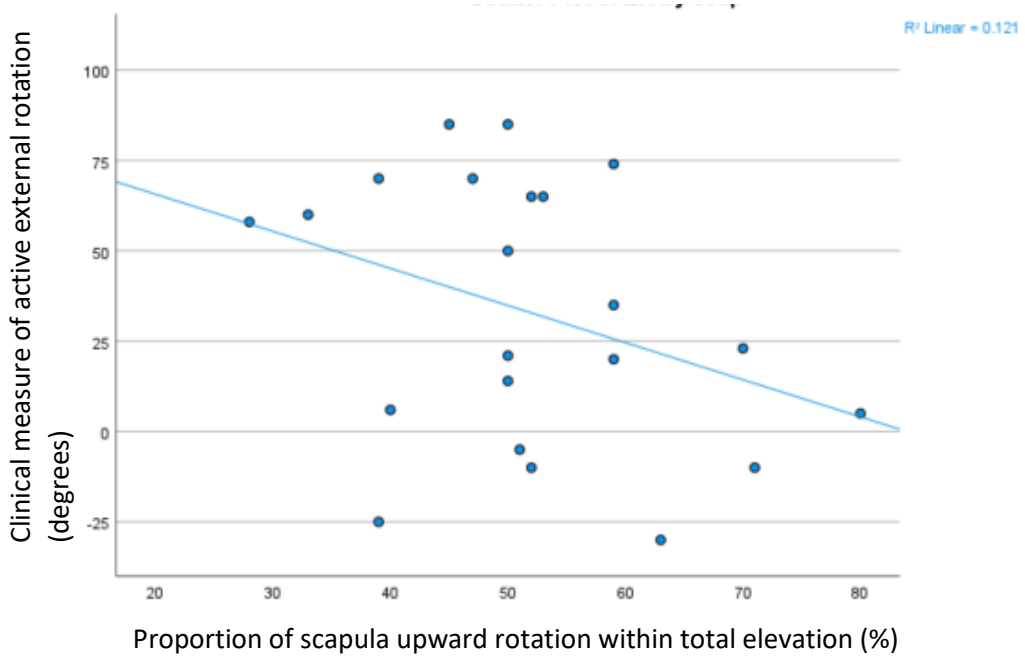


Results for Hypothesis 2

Hypothesis 2*a) Proportions of scapula upward rotation to total elevation will show an inverse relationship with clinical measures of active external rotation range.*

There was no clear relationship between active external rotation and proportion of scapula upward rotation as shown by Graph 14. Non-parametric correlation analysis was non-significant Kendall's Tau Ƭ = - 0.22 (p = 0.16) (CI - 0.5, 0.11).

Graph 14: Clinical measures of Active external rotation range (y axis) against proportion of scapula upward rotation in total elevation (x axis)



Hypothesis 2b) *Ratios of scapula: humeral movement will decrease with increased total elevation ability*

Proportions of scapula upward rotation decreased with total elevation ability:

1) For 4 subjects with total shoulder arm elevations under 45 degrees, scapula to humerus rations were 2.0: 1

2) For 4 subjects with total shoulder arm elevations from 45 – 90 degrees, scapula to humerus movement ratio were 1.3 : 1

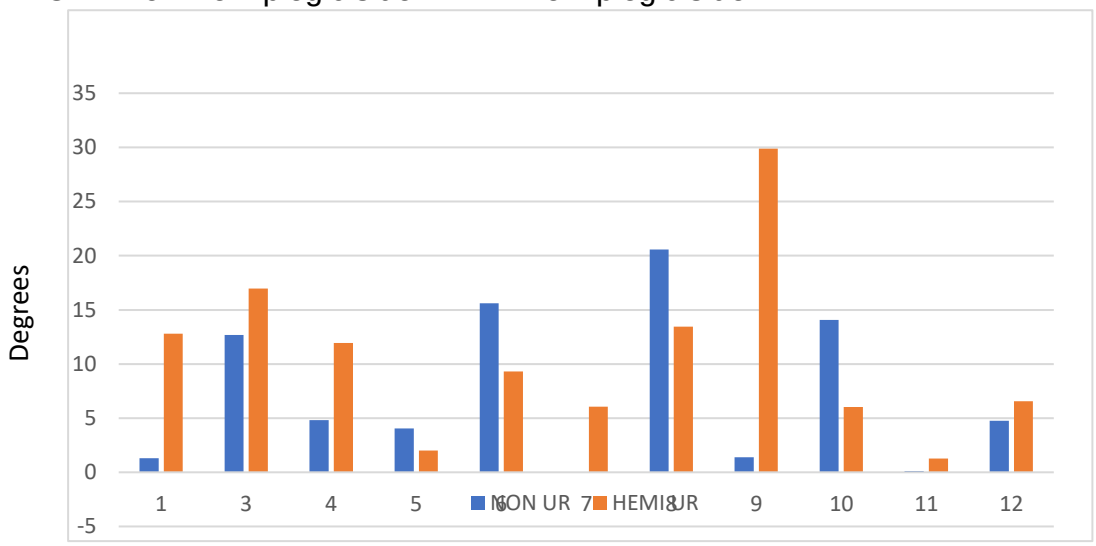
3) For 12 subjects with total shoulder arm elevations over 90 degrees elevation, scapula to humeral movement ratio were 0.86 : 1

Hypothesis 2b) *Hemiparetic shoulders (without subluxation) with painful frozen shoulder will demonstrate a 'scapula lead' movement initiation strategy: more upward rotation compared to the non-hemiplegic side as a result of pain and restriction.*

There was no predominant lead upward rotation strategy in this cohort at 5 degrees of humeral elevation (Graphs 15). At 5 degrees of humeral elevation 45% (5/11) of hemiparetic shoulders with frozen shoulder demonstrated a scapula upward rotation 'lead' (more) strategy, 27% (3/11) demonstrated scapula 'lag' (less) and 27% (3/11) demonstrated scapula symmetry (same amount) compared to the non-hemiparetic arm. Scapula lead initiation did not have a significant relationship with pain severity on movement (coded ≥5/10), (Fishers exact = 1.00).

Graphs 15: Scapula upward rotation initiation positions at 5 degrees humeral elevation (y axis = Degrees) (x axis = case IDs).

NON =Non Hemiplegic side **HEMI**=Hemiplegic side



Starting Position

There was no difference in starting position scapula upward rotation between the hemiparetic (mean = 12.41 (SE 0.90)) side and non-hemiplegic side (mean = 12.18 (SE 1.05)), U =53.00 (p = 0.62).

2c) *Hemiplegic shoulders with a measurable subluxation will demonstrate a 'scapula lag' movement initiation strategy (regardless of pain and restriction): less upward rotation compared to the non-hemiplegic side as a result of non-optimal length tension relationship*

Scapula lag did not have a significant relationship with the presence of subluxation (Fishers exact = 0.55)

Table 40: Scapula initiation positions on hemiparetic (Hemi) arm relative to non-hemiparetic side

ID	Maximum Active External Rotation	Maximum Hemi Active Elevation	Scapula Upward Rotation strategy on Hemi arm	Subluxation (Palpable space between acromion to humerus at least ½ finger)	Pain on Movement ≥5/10
1	6	90.6	Lead	NO	YES
3	-25	106.9	Lead	YES	NO
4	20	62.2	Lead	NO	YES
5	-30	44.1	Same	YES	YES
6	-5	55.0	Lag	NO	YES
7	10	62.9	Lead	NO	YES
8	5	30.1	Lag	NO	NO
9	23	69.9	Lead	YES	NO
10	21	66.6	Lag	YES	YES

11	-10	39.3	Same	YES	NO
12	-10	26.1	Same	YES	YES

(7.5) Discussion

3D Kinematic data was collected during shoulder elevation in the scapula plane for 11 stroke survivors on their hemiparetic and non-hemiparetic side. All subjects had PSSP in their hemiplegic arm and a confirmed clinical diagnosis of frozen shoulder. This evaluation aimed to examine if consistent axial and upward rotation Scapula initiation strategies existed amongst this cohort with PSSP and confirmed clinical signs of frozen shoulder. The data suggest the following:

1) Hemiparetic shoulders with pain and clinical signs of frozen shoulder showed significantly more scapula external rotation on humeral flexion initiation compared to their non-hemiparetic shoulders. This was generally coupled with adduction in a retraction movement pattern.

2) Three global axial rotation strategies were identified during full humeral elevation in this cohort: i) External rotation ii) Internal rotation and iii) Mixed during elevation cycles. Hemiparetic shoulders demonstrated predominantly external rotation strategies (64%, 7/11). Only non-hemiplegic arms demonstrated mixed Scapula rotation strategies; possibly due to greater available dynamic axial range.

3) Clinical measures of glenohumeral active external rotation showed a statistically significant relationship with dynamic scapula axial rotation range during elevation

4) Ratios of scapula: humeral elevation appears to decrease with total elevation ability which aligns with findings of a previous study (Rundquist et al., 2012).It also showed an inverse relationship with active external rotation range, but possibly due to sample size this relationship was not statistically significant

5) In this cohort; there was no consistent upward rotation strategy ‘scapula lead’ or ‘scapula lag’ in the hemiparetic shoulders compared to the non-hemiparetic side.

Retraction as a predominant scapula strategy

These findings in a small cohort of stroke survivors indicate hemiplegic arms with frozen shoulder tend to predominantly move into scapula retraction during movement initiation possibly due to reduced external rotation range and reduced proximal torque generation. This aligns with the finding of a previous study with a cohort that was 7.7 months post stroke with 3/10 subjects having pain (Meskers et al.,2005) . However, it is in contrast to two other studies that had cohorts that were 13.7 months and 60 months post stroke that did not find a difference in axial rotation between hemiparetic shoulders with pain and non-hemiparetic shoulders (Niessen et al. 2008; Lixandra et al., 2017). As the subjects in this study were on average 19 months post stroke, it is possible that scapula movement strategies are the result of interacting factors related to motor recovery stage, levels of pain and the amount of passive restriction which may explain the variation in these results. In this cohort, all subjects had frozen shoulder and it is possible that scapula retraction during elevation is the predominant compensation for this pathology. It would be useful in future to attempt to examine subjects who are at a similar motor recovery stage with frozen shoulder, so the effects of frozen shoulder can be isolated. This is a small sample study and the individual profiles at 5 degrees elevation indicate there is variability which needs further investigation with a larger sample.

A factor that was beyond the scope of this small evaluation was considering Thoracic posture. It has been found that Thoracic flexion postures predominantly result in scapula external rotation (Yabata and Fukui et al., 2022). In stroke survivors who are likely to have trunk impairment it is possible that this is resulting in increased thoracic flexion which is another driver of increase scapula external rotation during initiation of movement.

Observed variation in Axial Rotation strategies

One clue as to why there is such variation in scapula strategies in this cohort is found in previous studies examining the effect of different cueing strategies on scapula control (Hsiang-Ling 2016). Measurements pre and post 'conscious control' by the patients resulted in measurable changes in scapula rotation (Hsiang-Ling 2016). Therefore, different subjects may have responded differently to our standardisation cues in this study resulting in altered axial scapula rotation. Another factor as discussed, could be the variation in chronicity of the subjects. Our cohort ranged from between 4 – 41 months post stroke. Although clinically participants fell into Brunnstrom levels 2 and 3 variations in time post stoke may have resulted in different levels of entrainment of scapula strategies, as well as variations in changes to muscle anatomy (Da Baets et al., 2014; Gray et al., 2012). Variations in participants upper limb functional history prior to stroke may have also influenced the range of strategies observed.

In this study all participants had the same levels of proprioception and internal rotator tone via clinical measures. However, the elevation cycles shown for each subject shown in Appendix (), indicate that there was variation in subjects' ability at being able to return fully to their starting point on their hemiplegic arm, (see hemiplegic arms of case 3 and 4). In future it may be useful to analyse patients' ability to return to a starting point as an additional proprioceptive check and it would be interesting to understand how this affects Scapula performance.

In this cohort only some non-hemiplegic arms showed mixed rotational strategies during elevation. A study of subjects who had not suffered a stroke found steep external rotation gradients in the first 50 degrees followed by plateauing and slight rotation reversal and then further external rotation towards the end of range elevation (Stokdijk et al., 2003). Therefore, a mixed rotational scapula strategy with larger axial rotation ranges appears to be part of normal scapula rotation movement.

Previous studies have indicated that motor weakness can exist on the paretic and non-paretic side after stroke (McCrea et al., 2003; Wist et al., 2016). Mixed axial rotation strategies appear to result from greater available axial rotation range and could indicate a stroke survivor has experienced more motor recovery compared to simpler rotational strategies.

Dynamic Axial Rotation

In this small cohort study we have shown there is a relationship between glenohumeral joint active external rotation and dynamic scapula rotation range during elevation. This indicates that a lack of ability to generate proximal torque (or rotational force), influences an individuals' ability to make dynamic Scapula movement changes throughout elevation (Lum et al.,2004). This could give some indication why active external rotation recovery in study 1 of this study may be protective of a subject developing pain.

Scapula dyskinesis, possibly as a result of different activation times of muscles such as Subscapularis and Lower Trapezius have not been shown to directly influence pain (Hogan et al., 2020; Da Baets et al., 2014). However, it is possible that the lack of ability of a scapula to make dynamic adjustments results in abnormal stresses and non-optimal length tension relationships which results in the development of injury (Paine and Voight et al., 2013)

Scapula upward rotation strategies

In our study 4/11 subjects (45%) with pain demonstrated a Scapula lead strategy which is in contrast to the findings of previous study that found 4/6 (64%) showed a Scapula lead. In addition, our study found no differences in resting upward rotation between hemiparetic and non-hemiparetic side. This is contrast to a previous study that found greater upward rotation in the painful hemiparetic side compared to the non-hemiplegic side (Niesson et al., 2008). The variation shown in this study cohort and conflicting results of other studies indicates that pain does not appear to have a clear relationship with upward rotation strategy. However, it is important to note that in this study cohort all participant had restriction associated with frozen shoulder, so this may represent a separate cohort to these previous kinematic studies

A clear influence on upward rotation range is total elevation ability. In our study we were able to demonstrate that ratios of scapula upward rotation increase with decreasing total elevation ability as per a previous cohort study of 16 stroke survivors (Rundquist et al., 2011). The previous study showed higher proportions of scapular movement at lower elevations with ratios of 4.1:1 compared to 2.0:1 in our study (Rundquist et al.,2011). It is possible that this previous study had subjects with less passive restriction compared to this study which may explain differences in proportions of scapula upward rotation. It is also possible proportion of upward rotation may be an interaction of motor recovery and the presence or absence of joint pathology. Evidence to support this is found in kinematic studies of non-stroke subjects with external rotation restriction due to frozen shoulder. These found inverse relationship between proportion of scapular upward rotation and active external rotation range (Fayad et al., 2008; Babyar et al. 1996). In this study we found a similar inverse relationship, but possibly due to the sample size, this relationship was not statistically significant. In future, it would be useful to complete a study with a larger sample so regression analysis could be conducted dynamic scapula axial rotation and upward rotation. This would allow different influences on strategy clarified.

Study Limitations

1) Limitations of the Measuring system: Although the 3D measurement system has proven accuracy (see Appendix for sensor accuracy data), the software model was developed with bone pin data of only one subject (Seth et al.,2016). Therefore, it is possible that the process of rendering sensor data into movement outputs may result in error due to anatomical variance in the population. One particular limitation of this equipment is there is only one sensor located on the scapula (on the Acromion), whereas another study looking at upward rotation had several sensor points (Price et al.,2000). Therefore, the software model makes several inferences about the scapula **from the relative position of one sensor.**

2) Lack of Control: This study cohort all had the same pathology which was causing their PSSP and comparisons were made to their unaffected side. Two studies with controls found that movement patterns in the hemiparetic and non-hemiparetic arms showed more similarity than controls (Meskers et al. 2005; Lixandrao et al. 2017). This fits with building evidence that both hemiparetic and non-hemiparetic limbs can be affected by stroke (Yalcin et al. 2012). The lack of age matched controls means it is hard to establish what is 'normal' versus adapted movement.

3) Elevation protocol: All participants were standardised to elevate their arm 45 degrees to the lateral Acromion and a visual target was provided. However, anatomical variation in scapula plane may have resulted in the participants being cued to relatively internally or externally rotate based on the way the assessment was standardised. It is hoped that by comparing the non-hemiparetic to the hemiparetic side for each subject, the effect of this would be cancelled out, but it could be a cause of some the variation observed. In addition, recent expert discussion has recommended that upper limb movement analysis should involve a functional drinking task with 15 repetitions (Kwakkel et al., 2019). However, as this study was specifically interested in scapula movements it was decided to use an elevation task that would involve maximum scapula movement. In addition, 5 repetitions were used as this cohort had significant upper limb weakness and 15 repetitions would likely result in problems with fatigue.

4) Fatigue: may have been a factor in altered performance, however as shown in the elevation cycles in Appendix D, it appears once a subject establishes a scapula rotation strategy this appears to be repeated throughout the 5 cycles on their affected and unaffected arm. However, larger sample studies are required to establish if this a generalisable phenomenon.

5) Sample size: Even though potential effect sizes are enhanced by the accuracy of the equipment, this cohort is still too small to make large generalisations.

6) Postural variation: An under investigated factor is the effect of Thoracic posture and Thoracic movement on how the scapula moves (Da Baets et al., 2014). Recent research indicated that flexed thoracic postures increase scapula external rotation (Yabata and Fukui et al., 2022). In future it would be useful to look at the Thoracic and Trunk outcomes; such as the Trunk Impairment Scale so they can be considered in relation to scapula performance.

Grouping: Although movements were standardised and multiple repetitions were measured for each subject, this pilot study was conducted with a small sample. Therefore, it is possible that some of the groupings described in relation to axial rotation strategies may just represent intrasubject variability. Further work needs to be conducted at separate time points to establish if scapula axial rotation strategies are constant across time.

Scapula movements in isolation: This reductionist approach of looking at scapula movement in isolation may not be as useful as considering the whole scapula position throughout functional movement. In future consideration of 3D Euler angles may give more insights into true scapula change

Conclusions

This project highlights that dynamic scapula performance and humeral external rotation range are linked. There is significant heterogeneity of scapula axial rotation strategy even within a cohort with similar pathology and restriction profiles. However, the ability of the scapula to dynamically adjust during elevation improves with active humeral external rotation range ability. This gives a possible clue as to why external rotation movement recovery is protective of developing pain.

It would be useful for future research to collect sufficient sample for a regression analysis to examine factors that influence scapula axial rotation and upward rotation strategies. This would help to build a model that incorporates some of the clinical complexity of individual presentations, including thoracic postural variations. Such a model would be useful for clinicians as it would aid clinical reasoning in treatment approaches to aid scapula control. In future scapula analysis pre and post an intervention such as a steroid injection may help to unpick the effects of pain and restriction versus weakness.

Chapter 8: Investigating proportions of Kinesiophobia and influencing factors on arm disuse behaviours in people with lasting pain and frozen shoulder in their hemiplegic arm

Abstract

Purpose and Participants: To identify proportions of maladaptive kinesiophobia in a cohort of stroke survivors with lasting shoulder pain (>2months) and clinical signs of frozen shoulder the proportion that have developed maladaptive levels of Kinesiophobia (fear of movement). In those who have high levels of fear of movement qualitative methods have been used to understand individual experiences that have influenced moving the painful arm

Methods: Multiple methods cohort study: A validated questionnaire Tampa Scale of Kinesiophobia (TSK) was used to measure Kinesiophobia. Participants with ≥37 TSK scores were interviewed as this indicates maladaptive levels of fear of movement. A semi structured topic guide was used using the theory of planned behaviour as a framework (Azjen, 2013).

Results: 25/41 (61%) of participants scored ≥37 on the TSK indicating maladaptive levels of fear of moving their affect limb. 21/25 (84%) of these subjects were interviewed. Thematic analysis of the transcripts was conducted to answer the following questions:

1) *What Influenced fear of movement of their affected arm?* Themes identified were 1a) Negative interpretation of symptoms and 1b) Perceived poor pain management.

2*) What factors other than fear influenced arm movement behaviours in their affected arm?* Themes identified were 2a) Redundant Appendage: perception that arm was redundant due to lack of rehabilitation recovery 2b) Negative influences on self-management (internal and external factors) 2c) The demotivating transition from acute to community care.

Conclusion Kinesiophobia appears to be common in stroke survivors with lasting pain (> 2months) and clinical signs of frozen shoulder. It is difficult to understand if this fear of movement contributed to the chronicity of these subjects' pain. This study has identified individual factors that may have contributed to maladaptive behaviours.

(8.1) Introduction

Post Stroke Shoulder Pain (PSSP) can often resolve a few months after onset (Gamble 2002). However, there is a significant cohort of stroke survivors who develop shoulder pain that lasts for months to years (Lingren et al.2018). Long term PSSP is often associated with passive joint restriction and one of the main causes of this restriction is frozen shoulder (Saikaley et al. 2021).

Recent frozen shoulder models suggest that a pro-inflammatory environment driven by many potential triggers can disrupt normal modulation of fibroblast activity resulting in progressive fibrosis of the shoulder joint capsule (Jump et al. 2021). However, subjects with frozen shoulder who move into 'tolerable pain' regularly can restore joint homeostasis and stop the pathological process of progressive joint fibrosis (Lubis and Lubis, 2013). Therefore, although movement avoidance is a normal adaptive response to an initial injury, it appears that people who develop maladaptive ongoing fear avoidance of shoulder movement could be preventing joint recovery in cases of frozen shoulder (Martinez-Calderon et al. 2018; Lubis and Lubis, 2013). In fact, a tendency to somatise (excessive thoughts related to physical symptoms) might be a risk a factor in causing frozen shoulder and so long term pain (Chiaramonte et al. 2020).

A recent qualitative study of thirteen community dwelling stroke survivors who suffered from shoulder pain for 5-54 months described four themes of coping styles;

1) Managing shoulder pain by adopting various practical and cognitive strategies

2) Practical modification to solve daily life problems

3) Changed movement patterns and specific actions to mitigate the pain

4) Learning how to deal with the pain mentally (Lingren et al.,2018)

Although it is important not to generalise these findings to the entire chronic post stroke shoulder pain population, it is interesting that several of these strategies could be described as adaptive or compensatory. The theme 'Changed movement patterns' included participants who expressed that they had reduced their arm movement to reduce their pain. This is important because as discussed, current understanding indicates that regular movement helps main joint homeostasis and is likely to help pain in the long term (Jump et al. 2021; Lubis and Lubis 2013). In addition, stroke survivors who develop learned non-use of their affected limb may be limiting their ongoing stroke recovery (French et a. 2014).

Another important consideration is that lack of movement may lead to further sensitisation and increased chronicity of pain (Dean et al., 2013). This is because central sensitisation appears to be the result of amplification of signals from low threshold mechanoreceptors within the central nervous system (Dean et al. 2013). This amplification of signal is likely due to a complex interaction between several biological, psychological and social factors (Gifford et al.,1998). However, regular joint movement may have role in reducing the summation effects centrally resulting in reduced perceived pain in the long term (Dean et al., 2013)

As discussed in Chapter 3, a phenomenon that that has been established in larger cohorts of people with chronic musculoskeletal pain is the concept of 'Kinesiophobia' where people with pain have developed maladaptive fear avoidance of moving their affected limb (Das et al., 2013).

The Tampa Scale for Kinesiophobia (TSK) has been created and validated to measure the levels of Kinesiophobia (fear of movement) in people suffering from pain (Goubert et al.,2004; Miller et al.,1991).The TSK is a 17 item questionnaire, comprised of 17 statements with which participants can select their level of agreement on a 4 point Likert scale. Four items have inversed coding, and total scores range from 17 to 68, with a lower score indicating less fear of movement (Vlaeyen et al, 1995).

A cut-off value of ≥37 has been established, with scores equal and above indicating a person has developed maladaptive levels of fear of movement (Bränström et. al., 2008;Vlaeyen et al., 1995; Wasiuk-Zowda et al. 2017). High TSK scores have been shown to be a key predictor of greater perceived disability regardless of the upper limb musculoskeletal problem in the general public (Das et al., 2013).

The psychometric properties of the TSK have validated for fear of movement and fear of re-injury across many musculoskeletal conditions (Roeloefs et al 2011). In addition, it has specifically been validated for use in shoulder pain conditions and correlates well with Shoulder Pain and Disability Index scores (Minken et al. 2010).Particularly items 1,2,9 and 11 related to activity avoidance had particularly stable psychometric properties in relation to shoulder pain (Minken et al.,2010).

There has been limited studies examining Kinesiophobia and TSK scores in stroke survivors (Wasiuk-Zowda et al., 2021; Sethy et al.,2017). Only a single case study looked at Kinesiophobia in a stroke survivor with chronic regional pain in their hemiplegic arm (Sethy et al., 2017). This is the first investigation into levels of Kinesiophobia in stroke survivors with suspected post-stroke frozen shoulder.

(8.2) Objectives and Hypotheses

As discussed, in stroke survivors with likely frozen shoulder it is important to understand if they are fearful of movement and to understand factors that have influenced this fear. It is also important to understand what has driven reduced arm movement other than fear, so clinicians can better understand the complex interaction of different factors resulting in overall reduced arm movement.

Objective 1 To establish the proportion of stroke survivors who have developed maladaptive levels of Kinesiophobia in a cohort that has developed suspected frozen shoulder in their hemiplegic arm and have experienced pain for longer than 2 months.

Hypothesis 1: Maladaptive levels of fear of movement exists in some stroke survivors who have experienced lasting PSSP (≥2 months) with a likely diagnosis of frozen shoulde**r**

Objective 2

The second objective of this study is to understand the lived experience of people with maladaptive levels of fear of movement (a score of ≥37 on the TSK) to answer the following questions:

1) What influenced fear of hemiplegic arm movement?

2) What factors other than fear have influenced reduced arm movement in the hemiplegic arm?

Although this qualitative work will not be directly generalisable, it will be beneficial for rehabilitation staff to understand what influences maladaptive behaviours that reduced movement in the affected arm of stroke survivors with lasting PSSP. The results may indicate how education of people who have upper limb weakness post stroke may be directed to prevent movement avoidance. It is also hoped this work will inform future projects aimed at the psychological influences on disability in people that have developed post stroke shoulder pain (PSSP).

(8.3) Methods

The objectives were addressed with a cohort study using the following mixed methodology:

Participants

Participants were recruited from a specialist upper limb service assessment clinic. Sampling was via a convenience sample of stroke survivors who attended the assessment clinic between the dates February 2019 and February 2020. Appropriate stroke survivors were identified by assessing clinicians (A consultant neurologist, a consultant physiotherapist and a consultant occupational therapist) according to the following criteria:

Inclusion Criteria

Adults (>18 years) who have experienced a stroke with hemiplegic weakness in the specialist upper limb assessment clinic.

Participants have at least 50% passive restriction in External Rotation or at least 30% restriction in abduction, external rotation or internal rotation (indicating frozen shoulder)

Adults developed post stroke shoulder pain (PSSP) in their hemiplegic arm that has lasted ≥2months

Able to participate in a telephone or online platform interview depending on their preference and or communication supports needs.

Exclusion Criteria

History of orthopaedic surgery or fixation in the shoulder on the hemiparetic side prior to their stroke

Severe aphasia (receptive or expressive) (determined by clinical clinic team)

Cognitive impairment that means that they are not able to discuss their condition history (determined by clinical clinic team)

Kinesiophobia Questionnaire

All recruited participants completed the 17 item Tampa Scale for Kinesiophobia (TSK). The questionnaire was implemented by the consenting researcher reading out questions and ensuring participants understood the Likert scoring. See Appendix E; As shown scoring for items 4, 8, 12, 16 are reversed.

Participants were informed that the study was specifically focussed on arm movement behaviours which were defined as ‘Any activity that involves you or someone else moving your affected arm’. We explained that questions around ‘Exercise’ in the questionnaire would relate to them moving their affected arm. In addition, any question about pain was relating to their shoulder pain. For Item 6 ‘My accident has put my body at risk for the rest of my life’, participants were asked to substitute the words My stroke to ensure the items relevance to their circumstances.

Interviews of participants with high TSK scores

All participants who scored ≥ 37 on the TSK were approached for interview. These interviews were semi structured and were conducted either face to face, via phone or via an online platform according to preference and/or communication needs. The interviews were audio recorded.

Some participants preferred to be interview with either a carer or a partner present and in these cases the additional person was encouraged to give opinions when participants felt they could add extra detail to discussion. Each participant was also prepared for the interview using a standardised script; see Appendix F.

The script orientated the participant to the researcher's role, and clarification was given that answers would not influence their onward care. Key points in the patient information leaflet were restated including the primary aims of the study. The following statement was read to the participant 'During the interview I will refer to movements of the arm affected by your stroke, which can mean any arm movement by yourself or someone assisting' This was to clarify that any movement of the affected arm was relevant to the discussion.

The Interview Topic Guide

The topic guide for the interview was designed using The Theory of Planned Behaviour as framework to help develop questions (Azjen, 2013). This established theory dictates that there are three main drivers of a person's behavioural intentions:

1) Behavioural Beliefs: These are the perceived consequences of behaviours by an individual

2) Normative Beliefs: These are beliefs about the normative expectations of others and can be experienced as perceived social pressures or social persuasion

3) Control Beliefs: These are the perceived presence of factors that may facilitate or impede a persons desired behaviour

Open questions were written in regard to these 3 factors (see Appendix F), and in consideration of the two qualitative research questions:

1) What influenced fear of hemiplegic arm movement?

2) What factors other than fear have influenced reduced affected arm movement?

Also, as this study is interest in information given by health professionals; a further question was added:

Was there any specific advice, information or treatments you received from health care professionals that affected how you manage your painful arm?

Finally, a sign off question was included below to ensure participants felt they had been given enough opportunity to express what they felt is important about the topic:

Is there anything that has been missed or that you wanted to talk more about?

The topic guide was designed to ensure questions were open and not leading with the use of generic prompts such as ‘What made you think this?’, ‘Can you give more information’ (Drever 2003). Probes where an interviewer attempted to dissect more specific topics raised by a participant were more discretionary according to the direction of the interview (Drever 2003).

Analysis Methods

Questionnaire Data

The raw score of the Tampa Scale for Kinesiophobia were used to classify participants as high or low TSK scores using the cut-off value of 37 as discussed. In addition, two subscales have been identified by previous researchers in the TSK with items fitting into the following two categories:

1) Activity Avoidance

2) Somatic Focus (Roelofs et al., 2011)

Two additional items were asked to assess the impact of mood on arm activity levels. Likert scales as per the TSK were used so participants could show levels of agreement with the following statements:

1) When I feel sad my shoulder pain is worse

2) When I feel sad, I move my arm less

Qualitative Interview Data

The COREQ (COnsolidated criteria for REporting Qualitative research) checklist has been used to report the Qualitative components of this study (Tong et al.,2007). The interviews were transcribed by a trusted transcription agency and inductive thematic analysis was conducted. Inductive thematic analysis is where no predetermine theory is used to guide the analysis due to how little is known about fear avoidance in this cohort (Braun and Clarke, 2014).

A theme can be defined as a pattern across interview responses that expresses a central organising concept. It is likely to be composed of subthemes which express aspects of the overarching main theme (Brain and Clarke, 2014)

The following analysis structure is recommended by expert guidelines (Braun and Clarke 2014):

1) Data Immersion: Reading interview transcripts several times, listening to recordings and reading notes

2) Generating initial codes

3) Searching for themes

4) Reviewing themes

5) Defining and naming themes

6) Reporting

The researcher aimed to take a contextualist approach which is a concept that is anchored between essentialism and constructionism (Braun and Clarke 2006). This approach aims to acknowledge the influence of broader social context whilst also reporting on the individuals experience as a truth (Braun and Clarke 2006).

There has been significant recent debate about the concept of saturation in qualitative research. This is where researchers establish that no further new concepts are being introduced by new participants and so the topic is 'saturated'. However, this relies on the belief that a topic can be truly saturated which goes against a more constructionist research stance (Braun and Clarke, 2014). As this study is taking a pragmatic contextualist epistemological standpoint it was decided to compete initial coding 3 months prior to ending recruitment. Then after initial coding was completed 3 further interviews were to test the saturation of the data. This approach as being suggested by researchers with a contextualist standpoint (Francis et al, 2010).

As per the COREQ guidelines further information about the researcher's reflexivity in this process of interviews and approaches to analysis have been presented in the results section.

Ethics

This study was approved by an NHS Ethics committee. REC identification number 19/NS/0070 (North of Scotland). In addition, local capacity was approved by hospital Research office. All participants were given information about the study via a Patient Information Sheet. Both the potential participant and their accompanying partners or carers were given an opportunity ask questions prior to them consenting. Participants were given an option to consent after this initial contact or to take more time as required, to ensure they did not feel pressurised to participate. If interpreter services were required, then it was possible to organise one via telephone or an online platform service.

(8.4) Results

43 stroke survivors were recruited between February 2019 and February 2020 that had experience PSSP for ≥ 2 months. All participants had moderate to severe pain on movement (≥4 NRS) and had passive joint restriction that was suspected clinically to be frozen shoulder. All participants approached to participate consented to be involved in the study.

41 participants completed the Tampa Scale for Kinesiophobia scale and 2 participants dropped out without completing the questionnaire. Patient demographics are shown in Table 39 overpage. Questionnaire participants have been separated into Low and High TSK scores according to the cut-off value of 37. Post hoc analysis indicated that scores of all items were significantly different apart from item 8 *Just because something aggravates my pain does not make it dangerous* , U = 175 (p=0.48).

There was no statistical difference between low and high TSK groups () for:

1) Time post stroke or stroke type

2) Time with PSSP

3) Side of hemiplegia or number of participants who had hemiplegia in their dominant arm

4) Number of participants who were independently mobile.

Two additional questions were asked to establish the perceived impact of mood on pain and movement behaviours. There were significantly more participants in the High TSK group who agreed that low mood reduced their arm movement behaviours (p = 0.01).

25 Participants were classified as having a high kinesiophobia score of ≥37 and so qualified to be interviewed. 21 Interviews were completed and it was not possible to complete interviews with 4 participants. All 4 participants not available for interview gave ‘the burden of hospital appointments’ as the reason.

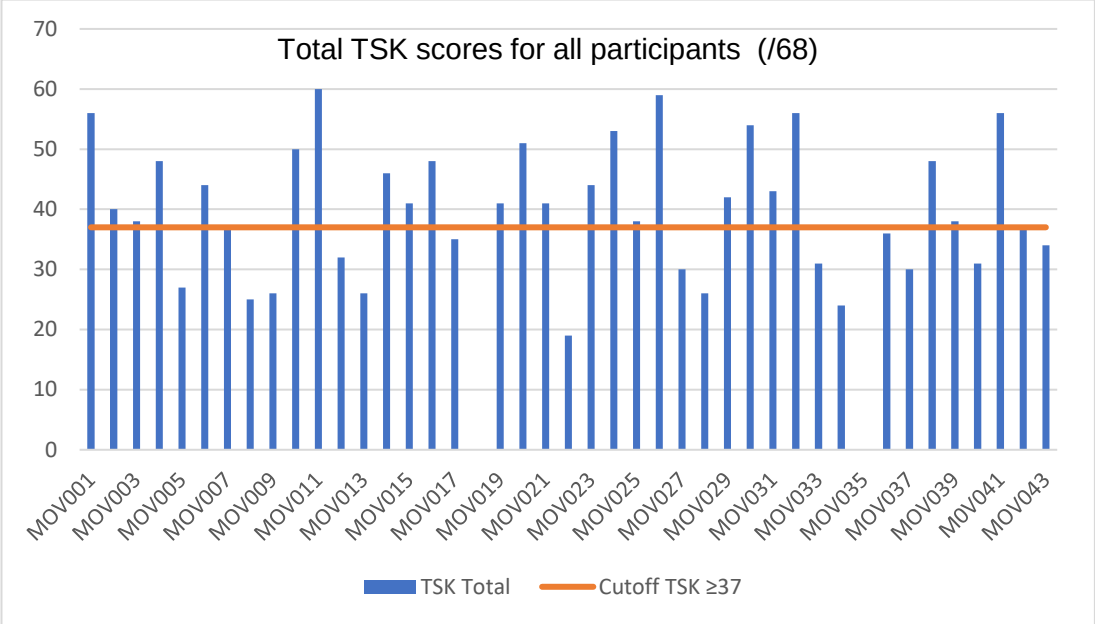
A graph of all participants Tampa Scale of Kinesiphobia (TSK) scores is presented over page graph 16.In addition, items relating to a more Somatic focus and Items relating to a more Activity Limitation focus were calculated for each participant. These results are presented in graph 17 and 18 as box plots to show interquartile ranges, mean and data ranges. There was a fairly even contribution of somatic and activity limitation sources for fear of movement for each participant.

The demographics and other clinical information of the Interviewees is set out in tables 40,41,42 overpage. Participants had experienced Post Stroke Shoulder Pain (PSSP) for a median of 10.33 months (range from 3 – 117 months). 19 interview participants were able to mobilise independently with or without an aid, the remaining two could only transfer independently. The interview cohort was from a diverse ethnic cohort representative of upper limb service patient caseload. 4 participants had previously been given a diagnosis of depression and two participants were currently completing some form of part time work.

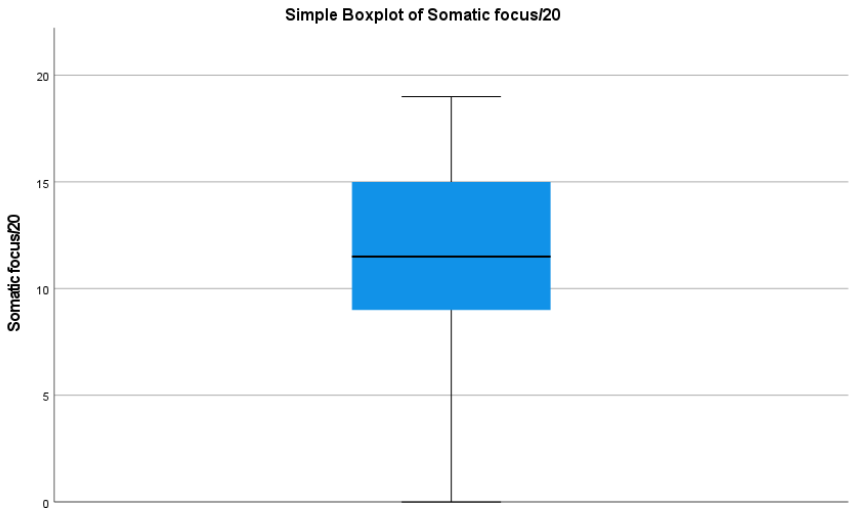
Table 41: Questionnaire Participant Summary Demographics (Study 4)

Variable	LOW TSK (n=16)	HIGH TSK (n = 25)	Test Statistic	P value for difference
Total TSK Score (median)	30.00	46.00	U =425.50	<0.001
Somatic Focus (mean)	8.41 (0.74)	13.8 (0.61)		
Activity Focus (median)	15.00	23.00		
Male/Female	14/4	16/9	X^2=0.94	0.50
Age (mean)	59.69 (SE 1.56)	60.88 (2.12)	T(41)= 0.15	0.88
Time Post Stroke - months (median)	13.23	12.08	U=161.00	0.31
Stroke Type Ischeamic/Haemorrhagic	13/3	21/4	Fishers Exact	1.00
Side of Hemiplegia (L/R)	11/5	18/6	X^2=0.93	0.50
Hemiparesis on Dominant Hand (Number of participants)	6	7	Fishers Exact	0.50
Time of PSSP -months (median)	12.2	8.7	U = 132.50	0.10
When I feel sad my shoulder pain is worse (Number of participants that agree or strongly agree)	1	7	Fishers exact	0.07
When I feel sad, I move my arm less (Number of participants that agree or strongly agree)	3	14	X^2=6.74	0.01
Independent walking (with or without aid)	14	22	Fishers Exact	1.00

Graph 16: Total TSK scores for each participant (cut-off set at scores of ≥ 37)



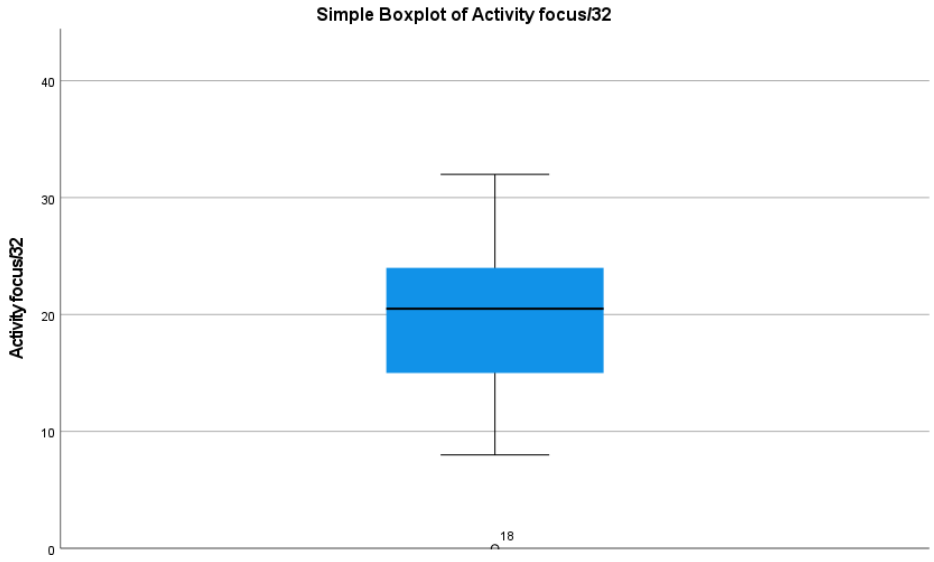
Graph 17: Scores of Somatic Focus (/20) Questionnaire items for each participant



(Box = Interquartile ranges, whiskers = total data range, black line = mean of total sample.

(Mean = 11.79 (SD 4.12), Range scores = 0 – 19)

Graph 18: Scores of Activity Focus (/32) Questionnaire items for each participant



(Box = Interquartile ranges, whiskers = total data range, black line = mean of total sample.

(Mean = 19.37 (SD 7.32), Range scores = 0 – 32)

Table 42: Interview Participants Demographics

n =	ID	Gender	Age	Ethnicity	History of Depression	Currently Working	Mobility
1	MOV001	M	62	Other	No	No	Independent with aid
2	MOV002	M	61	white Irish	No	No	Independent with aid
3	MOV003	F	52	white British	Yes	No	Independent with aid
4	MOV004	M	38	white British	No	No	Transfer but not walk
5	MOV006	F	44	white British	No	No	Independent with aid
6	MOV007	F	72	black British	No	No	Independent with aid
7	MOV010	F	58	Other	No	No	Independent without aid
8	MOV011	F	87	Mixed	No	No	Transfer but not walk
9	MOV014	M	52	white British	No	No	Independent without aid
10	MOV015	M	75	white British	No	Yes	Independent without aid
11	MOV016	M	65	black British	Yes	No	Independent without aid
12	MOV019	F	59	white British	Yes	No	Independent without aid
13	MOV020	M	57	black African	No	No	Independent without aid
14	MOV021	M	51	white British	No	No	Independent without aid
15	MOV023	M	68	white British	Yes	No	Independent with aid
16	MOV024	F	59	white British	Yes	Yes	Independent with aid
17	MOV025	M	68	Other	No	No	Independent with aid
18	MOV026	M	62	black African	No	No	Independent with aid
19	MOV030	F	61	white British	No	No	Independent with aid
20	MOV032	M	60	black British	No	No	Independent with aid
21	MOV038	F	63	white British	No	No	Independent with aid

Table 43: Interview Participant Stroke Type, Time with PSSP and Diabetes

n =	ID	Stroke Type	Stroke Territory	Hemiplegic Side	Time with PSSP (months)	Diabetes
1	MOV001	Ischemic	R MCA	Left	5.9	no
2	MOV002	Ischemic	L Thalamic	Right	3.6	no
3	MOV003	Ischemic	R MCA	Left	15.4	no
4	MOV004	Ischemic	R MCA	Left	4.0	no
5	MOV006	Haemorrhagic	R MCA	Left	28.6	no
6	MOV007	Ischemic	L Hemi Pontine	Right	13.2	yes (type 2)
7	MOV010	Ischemic	R ACA	Left	15.9	no
8	MOV011	Ischemic	RMCA	Left	12.0	no
9	MOV014	Ischemic	L Pontine	Right	4.7	no
10	MOV015	Ischemic	R MCA	Left	17.6	no
11	MOV016	Ischemic	R MCA	Left	10.3	yes (type 2)
12	MOV019	Haemorrhagic	R MCA	Left	3.3	no
13	MOV020	Ischemic	R MCA	Left	11.7	no
14	MOV021	Haemorrhagic	R MCA & Basal Ganglia	Left	1.9	no
15	MOV023	Haemorrhagic	L ICH	Right	117.1	no
16	MOV024	Ischemic	R MCA	Left	7.0	no
17	MOV025	Ischemic	R MCA	Left	3.0	no
18	MOV026	Ischemic	R MCA	Left	4.9	no
19	MOV030	Ischemic	RMCA	Left	4.9	no
20	MOV032	Ischemic	R MCA	Left	19.3	yes (type 2)
21	MOV038	Ischemic	RMCA	Left	10.9	no

Table 44: Interview Participants Questionnaire Results and Shoulder Treatments to date

n =	ID	TSK Total	Somatic Focus /20	Activity Focus /32	When I feel sad my shoulder pain is worse?	When I feel sad, I move my arm less?	Shoulder Treatments to date
1	MOV001	56	18	32	2	4	1 x steroid injection
2	MOV002	40	11	23	4	4	None
3	MOV003	38	8	22	4	4	2 x steroid injection and shoulder support
4	MOV004	48	17	23	1	3	1 x steroid injection and shoulder support
5	MOV006	44	14	22	3	3	None
6	MOV007	37	12	18	4	2	Botox injections
7	MOV010	50	15	24	1	1	None
8	MOV011	60	18	31	1	3	None
9	MOV014	46	15	23	3	4	Shoulder support Tramadol and Gabapentin
10	MOV015	41	13	18	1	1	Shoulder support and paracetamol
11	MOV016	48	14	24	1	4	Pregabalin 100mg
12	MOV019	41	15	19	1	3	None
13	MOV020	51	10	31	3	3	Shoulder support
14	MOV021	41	15	16	1	1	Physiotherapy (exercises)
15	MOV023	44	14	22	1	1	Sling, Scan, Physiotherapy (exercises and mobilisations)
16	MOV024	53	19	24	1	3	Physiotherapy (exercises)
17	MOV025	38	11	17	1	2	Shoulder support and paracetamol
18	MOV026	59	17	30	4	3	Shoulder support and Neurofen
19	MOV030	54	17	27	1	4	none
20	MOV032	56	16	29	1	1	None
21	MOV038	48	12	26	1	1	Codeine

Additional Questions are scored as per Likert scale score (1 = Strongly Disagree, 2 Disagree, 3 Agree, Strongly Agree)

Interview Results

21 out of 25 participants who had TSK scores above the cut-off value (≥37) were available for semi structured interview. The research question of interest for the interviews were:

1) *What influenced fear of hemiplegic arm movement?*

2) *What factors other than fear have influenced reduced hemiplegic arm movement*

Research Team and Reflexivity

The semi structured interviews were by conducted by a female neuroscience master's student and a male specialist neurological physiotherapist.

The student did not have any previous experience of treating or assessing patients with PSSP and was not a clinician so did not have any prior bias in regard to good or bad practice. The student also did not have any previous experience in interviewing patients

The specialist neurological physiotherapist (who was also the main investigator PhD student) had extensive experience of treating patients with PSSP and so may have had some unconscious bias when directing questioning. This physiotherapist also had previous experience of conducting semi-structured interviews as part of his master's degree.

8 participants were interviewed by the master's student and 13 participants were interviewed by the physiotherapist researcher. This ensured that there was a rich data set of both interviewer styles.

Relationship to Participant

The research team were not part of the participants treating team and it was clarified at several points that participants answers would have no impact on decisions for their ongoing treatment. In addition, if participants had accompanying partners or carers and wanted them to be present then this was facilitated to ensure the participants felt comfortable and help them to be as candid as possible about the topics under investigation. Participants were aware that data would be anonymised to protect their identity.

Coding

Coding was conducted by the 2 interviewers and an additional neurological physiotherapist who has experience in treating PSSP and has experience in conducting qualitative research. Initial coding was completed for 18 transcripts before the final 3 interviews were conducted by the physiotherapist researcher to establish if saturation was achieved. No additional topics were raised in these interviews and so it was established that saturation was achieved in the transcript data set in relation to the research question of interest (Francis et al., 2010).

A semantic and latent approach to coding was used. Semantic coding is where the surface meaning of a statement was coded. Latent coding are assumptions implied in conversation. These latent ideas were also drawn from interviewer notes during the interviews (Braun and Clarke, 2006). Selective coding was conducted by the three researchers independently and then meetings were held to review and agree on themes and subthemes.

Themes Analysis Results

2 Themes were established for Question A: What has influenced fear of arm movement and 3 Themes were collated for Question B: What factors other than fear have influenced reduced affected arm movement? See below (Table 43 and Table 44 overpage) for descriptions of each theme and Appendix G for all quotes used for each theme

Table 45: Themes for Question A What has influenced fear of arm movement ?

Question A: What has influenced fear of arm movement ?	
Primary Themes	Theme Description
1 A: Negative Interpretation of Symptoms	Pain was seen a cue to stop moving as otherwise they would damage their shoulder. Participants were a fearful of click and clunks when moving their arm and had unanswered questions about their symptoms
2A: Perceived poor pain management	Participants report a lack of specialist assessment and review once pain had developed. In addition, some participants found shoulder supports unhelpful and several viewed uncertainty about analgesia.

Table 46: Themes for Question B: What factors other than fear have influenced reduced affected arm movement?

Question B: What factors other than fear have influenced reduced affected arm movement?	
1B: Redundant Appendage	Participants expressed a lack of attention to their arm in rehab and a lack of observed recovery which possibly drove learnt non-use behaviours.
2B: Negative influences on self-management	Internal and external factors that participants perceive have negatively affected their ability to self-manage moving their hemiplegic arm.
3B: The demotivating transition from acute care to community living	Participants expressed the demotivating and upsetting effects of loss of independence in the community after leaving acute care, feeling abandoned by services and the challenges of hidden disability.

Question A: What has influenced fear of hemiplegic arm movement?

Each theme will now be discussed with composite subthemes. Example quotes are given for each subtheme. All data for each theme can be viewed in Appendix*

Theme 1A: Interpretation of Symptoms

Subtheme 1.1A Previous experience of moving arm painful

All participants had been experiencing pain for significant periods. Some participants expressed that previous experiences of moving the arm had been so painful that they were now fearful of moving it.

020 'Yeah, because of the pain, yes. And because of the pain sometimes I'm scared to do exercise, I'm telling you the truth.'

019 'The pain has got worse and since going to this gym…And that makes me feel I'm not sure about it'

Subtheme 1.2A Pain as cue to stop

Pain was expressed by some participants as a cue to discontinue movement and this cue was occasionally re-enforced by treating therapists.

021 because every time you hit the pain barrier you think, oh gosh, now it's time to stop now.

026 It's painful and I'm not trying to move it. To move it it's so painful, so I can't use it --

Cue to stop re-enforced by treating therapists:

021 'Well they said, if you're in pain stop, so that was definitely a message that came through.'

014 'They said don't, I've always been told when it gets painful stop.'

024 Well they say that you've obviously overdone it, you need to like rest, this is your body telling you, isn't it?

Subtheme 1.3A Pain equals Damage

The behaviour to limit movement was often driven by beliefs that the shoulder pain was the result of underlying damage and continuing to move would cause further damage:

024 Well I, what I'm thinking's going on, I feel like it's, it's going to sort of tear it, it goes into a spasm, so I feel it's going to, it's tearing something in my shoulder, and it makes me think, oh should I really be doing that?

019 I can feel, it gets to this point and it's like, and she said, do it, go some more, and I'm terrified because I don't want to break it. It just doesn't want to go any further.

038 I don't stretch it beyond a certain point as I'm concerned it will cause harm

This fear of damage had sometimes been driven by information given by health care workers

011 Well they told me you've got to be careful that your arm doesn't come out of the socket because I'll have to have an operation.

023 Because there's obviously something not right there and that's when they diagnosed a shoulder tear of the muscle. And that's when, we then obviously then do the procedure of the consultant, orthopaedic came, and then we do the operation or we don't.

Subtheme 1.4A Clicks, Clunks and swelling

Unusual sounds or sensations when moving the arm also seemed to reenforce for some participants that potential damage might be occurring during movement.

020 if I sit down for a while, I try to raise it up, I will get like a crack on my shoulder that, you know, something that is dislocated and it wants to go back, like, yeah. A big crack - -Yeah, then I stop because of how I just feel like, oh my God, it maybe is, it's breaking off.

019 So I know that when it's feeling clunky, feeling like it's stretched too far, stretches a bit and then it gives way, so then you have an idea that, oh well it's, I've either gone into a place where that feels better or is this a step too far

030 All, because sometimes when I lift the arm I can hear the joints, like it just, it go 'cuck',so like, you know, something just popped, it feel like….. yeah, sometimes worries me.it feel like it's about to be separated from the shoulder, you know?

Others felt that movement resulted in increased swelling around their arm

024 I feel it's like inflamed, sort of angry, you know when you've got something that's like a swollen ankle? I feel my shoulder's like that really, and it's, that's how I feel about it.

026 Yeah, there's swelling. When I move it too much the hand will be swollen. My hand will be swollen like this. It will be swollen here when I move it too much

Theme 2 A: Perceived poor management of shoulder pain

Subtheme 2.1A Lack of specific advice for the shoulder when pain developed

Many participants expressed a lack of specific expert assessment, treatment and advice when their pain developed:

016 No, I've had, I've been, I've spent three months in the (name removed). 12 weeks, or 11 weeks, of physio in the local community and that was two, three, four times a week for 12 to 11 weeks. So that was good, but they didn't understand what was wrong with me. They didn't understand the shoulder thing.

006 They could have been trying to do something instead of just leaving it, if that makes any sense.

015 But then when it came to it the physiotherapist who I saw at that time said that I should just wait for it to get better of its own accord. So I think maybe more could have been done at that stage

020 The only, he said to me, try to do exercise sometimes with the arm. Just doing exercise, wiggling it around or try to raise it up and down, something like that.

One participant expressed that their therapist had disowned responsibility for treating the shoulder pain problem

024 But regarding the shoulder, it as sort of disregarded, it was oh, it's a frozen shoulder, it's nothing to do with what we're treating. And the longer it went on, I think the longer it seized up, and the more it seized

Subtheme 2.2A: Poor Handling and Incorrect Advice

One participant reported poor acute handling of the shoulder which they perceived had caused damage.

023 Because of careless nursing care, I was, my mechanical handling was, where the muscle was torn, I tend to protect it and guard against anything happening towards it.

Two participants reported being given therapy advice that currently would not be considered best practice:

015 The physiotherapist did say, did give me exercises to do. and I've still got a, I'm trying to think of the correct word for it, a think that fits over the top of the door so it was -- A pulley, that's the word, a pulley. And I have used the pulley and I do still use that.

032 Yeah, they, yeah, subluxation, they were very concerned I might get that, so they were quite keen to make me wear this sling the whole time, which I did do

Subtheme 2.3 A Lack of perceived efficacy of shoulder supports

Two participants did not perceive the benefit of shoulder supports and found that they actually increased symptoms:

015 Because it didn't really seem to have any overall beneficial effect and it was quite restrictive…When I was out walking for example it got quite painful around my neck just with the weight of my arm hanging around my neck.

008 To be honest the support didn't actually help, no, because I found it rather bulky, the shoulder support thing I had. So it didn't actually do much for me. So hence it just actually got worse for me when I wore it

Subtheme 2.3A Uncertainty about analgesia

Some participants weren't sure if prescribed analgesia was helping their pain

015 Actually an alternative that was offered was the ibuprofen gel, which I was rubbing onto my shoulder. But again it didn't really seem to make any difference.

016 I started taking painkillers. Nothing too serious, paracetamol and nothing much stronger than that, Neurofen and things like that, but they didn't really help that much to be honest.

014 I was on tramadol, they stopped that and I started gabapentin. So I probably had pain when I had the tramadol but I didn't probably notice it. But now with the gabapentin I'm taking probably a little bit less and I don't know if it's enough. Because mum's taking two tablets, I'm taking one tablet each time. So is that enough?

One participant had concerns about taking pain medication regularly

030 I'm not a person who is a fan of pain medication because I know it constipate you and I don't like pain medication so if I have, if I have pain I would rather to go to bed and lie down and sleep, try to sleep off the pain.

Another had experienced side effects and so had discontinued some analgesia

024 No, he gave me the Co-codamol and I, I just thought, I was tired, so I don't want this, well it's knocking me out. And then I, I was too tired to do any sort of exercising, like trying to walk, just to make my legs stronger, etc. So, and then I just thought oh, I'll take paracetamols.

Question B : What factors other than fear have influenced reduced affected arm movement?

Theme 1B Redundant Appendage

Subtheme 1.1B: Arm ignored in rehab

Several participants expressed that there was a lack of attention on their arm during rehab, which appeared to be due to a service focus on mobility and discharge:

032 The amount of attention that was spent on my arm was not much. It was only my leg that they, walking that was their interesting initially. Getting out of bed, walking, that was what it is. Because they actually gave me some walking stick to walk and that stopped that you roll, that was the interest initially.

014 *Yeah, because the (hospital name removed) never really worked on the arm as much. They were always leg working orientation. So, get you out of hospital… So they done, I think it was three hours a week on lower limb and an hour and a half on upper limb a week, which is nothing really is it*?

One participant expressed that a therapist and doctor had told them that there was no point in treating the upper limb

006 my physiotherapist turned round and told me that, oh, there's nothing that we can do about your arm because it hasn't made any improvement. We would have expected it to make improvements by now. And that really discouraged me….. I've had a doctor turn round and say to me, oh, there's nothing we can do for your arm. You will never get movement back in your arm, and I burst into tears, to be honest.

Some participant admitted that the focus of rehabilitation on mobility was also driven by them early on

030 I would say that it was 75% more on the walking because I was, I couldn't walk at all. I couldn't bear the thought of somebody, to have to tell somebody that I need to use the toilet. I couldn't, I couldn't cope with that one (<u>inaudible</u>) so when I went in they asked what would I like to be done and I'm specific telling that I would like to walk again.

023 But also I think it's the fact that, and I may have played the role as well, is that the shoulder has always been considered a second problem, a second position problem. The walking was the main thing, because obviously the walking is relevant for going to the toilet, going out or walking, going to the gym. So the walking was the primary aim, we need to get him to walk, we need to get him to walk. And the shoulder has been left on the side

Subtheme 1.2B: No observed recovery

Many expressed that they had not observed any recovery in their upper limbs. This included disembodiment metaphors such as 'outside of my body was dead.. none of it they could move, none at all'. This indicated some participants almost viewed their arm as no longer being part of them:

011 I just cannot move it at the moment. I can't move it at all, I have to use this arm to lift it up.

030 I couldn't move it, the hand, none at all, when I leave the hospital. I couldn't lift the arm and put the hand to my mouth, I can put it at my forehead, I can put it on top of my head…outside of my body was dead and I couldn't, my foot, my left foot and my hand, none of it they could move, none at all.

020 well obviously I cannot move it, so the disadvantage is that I cannot use it for anything. I can't do anything with it, with my arm obviously

This was also express in the arm being 'redundant' in function:

016 Yeah, because when I'm eating at the table, my left arm will just be hanging down by the side of the chair and when she comes to the table she (inaudible) says, come on raise your arm. So, my arm just sits redundant on the side of the plate

032 Yeah, I do try but I just realised that I was trying to serve the food and when I actually picked up food in my left hand, which is very weak, it just came straight on the floor.

011 The worst thing is when I get on my, what's it called, remover? What's it called Brian? The red thing (inaudible) the turner. I manage to hold on now but as I let go and sit down the worst thing is when my hand just flops. And that is horrible when it flops and I've no control over it.

Subtheme 1.3B: Learned Non use

Learnt non-use behaviours were expressed by some participants

024 You will always try and always use your stronger arm. You don't even think to use that arm.

This was possibly driven by embarrassment in one case who didn't like the way they looked when attempting to use their arm

021 I know it's probably an aspiration, a goal, try and lift the cup to my mouth, but if you end up looking like a demented, like I say, a ten year old, you're not going to put yourself in that position

Theme 2.0B Negative Influences on self management

Subthemes 2.1B Possible External Locus of health control

Some participants expressed views that could be interpreted as indicating a external health locus of control, where access to health practitioners is the only solution to moving the arm more:

038 I can't physically move my arm, so I don't think about moving my arm because I can't, I'm limited by how much support I'm getting to get it moving

001 I don't know how I can get it to move. It's got to be some kind of treatment. This injection I'm having now in my shoulder too, yeah. I hope, I'm waiting for it. I think that would help me to move my arm as well, that injection, yeah…. Because the doctor, he promised me. He said within three week you will be fine. I hope so, yeah

014 I've felt that I haven't had the help to move it.

Subthemes 2.2B Lack of self management strategies

Three participants expressed that they had not had enough information to self-manage moving their arm

026 Once in a week it doesn't even work to me. It doesn't work unless if somebody's coming and they say, OK, this is what you have to be doing for the rest of the week. It doesn't work like that

021 But they didn't, I don't know if they gave me advice apart from when I was actually with the OT person. There wasn't much advice, what to do outside of the session.

032 Yeah, when I first had my stroke early on, there was not a lot of advice given how I should move my arm. Even after today I have not been told how I should move my arm

Subtheme 2.3B Exercises perceived as boring or ineffective

Two participants expressed that they found exercises or treatments boring

021 I know they're trying to get the pathways to reignite, or etc, etc, but when you spend an hour trying to do it and you think, God, this is going nowhere, what is the point of this? And I'm sure there is a point, but it's, it didn't feel very productive to be honest…..I used to dread occupational therapy just because it was, I knew it was good for me, I knew they were trying to do the right thing, but I got to a mental block after a while, it was like, oh my God, another hour of … cones.

024 They are boring, these exercises, yeah

Another participant did not perceive a benefit of exercises

015 I think the negative aspect of it is that these exercises don't really seem to have any positive effect.

Subtheme 2.4B Social persuasion factors

One participant expressed a perception of social isolation which was limiting motivation

014 But I live on my own most of the time so I've probably got a bit unmotivated, which, my mum comes up say every month or so for ten days.

In addition, this participant expressed that their GP had advised rest for his blood pressure which had also reduced his activity levels

014 My blood pressure was still a bit high and he was worried about that so…. And the first words that the doctor said was, you've got to rest. So, what do you do? My doctor told me to rest so I'm going to rest.

Others reported experiencing social persuasion as 'nagging'

023 I'm nagged, being nagged is the story of my life

016 when the family get around, my wife, my kids and they say, did you do the exercise today? No. And then, come on dad, you've got to do it, you've got to do it. Then it turns into a bit of a nag.

Subtheme 2.5B: Arm movement behaviour vulnerable to low mood or environmental change

As shown 13/21 participant agreed or strongly agreed that they move their arm less when they feel sad. This proportion was significantly more than the low TSK group (p=0.01). The negative effect of mood on arm movement behaviours was also expressed in the interviews by participants and a partner of participant:

016 There's lots of bad days, so you neglect or decide not to do the exercises you planned to do the night before… I've not been doing a great deal, to be perfectly honest. Probably about 10% or 15% of what they would normally expect me to do.

024 I think when I had this it just sort of was like gosh, I can't do anything, so the, I think it was a bit of depression as well, maybe, so

Partner of 007: Yeah, I do feel like her self-doubt gets in the way a lot. She thinks, oh, I can't do this, she gets really frustrated

002 Like, I don't know, say there's an orange and I want to peel an orange. One day I'll peel, I'll think, yeah, I'll do that, but another day I'll think, I can't just do it, I just can't do it. And you just leave it there. So it's just, it just depends on your, the way your mind's going at the time

Another participant found that factors such as the weather affected their movement behaviours

002 in the winter I haven't moved it enough, anywhere near enough. Because it's cold and you just want to wrap up warm and go to sleep, basically

Theme 3B: The demotivating transition from acute care to community living

Subtheme 3.1B: Awareness of new disability post stroke when at home

One participant expressed a real resonance with one of items questions in the Tampa Scale of Kinesiophobia 'My body is at risk since my stroke'

026 yes because I, I'm disabled. I'm not really mobile and able to do what I normally do. So yes, I strongly agree that it, my body is at risk. Yes, I can't wash plates. I can't do anything in the sink. I can't bath on my own.

Another participant expressed feeling their life was 'completely finished off' when adapting to living at home

032 When you are still in the hospital you are fine, your brain doesn't go spinning around as well but when you go home is when you, then you're in the real world. You need to do certain things but if your hand doesn't, you've got, sort adapt it, you'll, doesn't allow you to even lift something. Take something from the fridge, put it outside or make a cup of tea. That is when your life is completely finished off. There's certain thing that you always, you feel like you would, when you go home you feel like you're going back to your normal life as it used to be, but that is not the case.

Subtheme 3.2B: Feeling Abandoned by community services

Several participants expressed feeling abandoned when discharged from acute services which they found demotivating and upsetting

015 There was a gap actually. If I remember rightly it took quite a long time till the community therapist actually made contact didn't it? Yeah. Yeah. Well we thought it was going to happen as soon as you came out of hospital, but it was about three or four weeks before they came

032 Everything that I was told was going to happen when I leave the hospital, nothing happened….Everything that I was told was going to happen, never happened.

038 When I first came home, I came out with so much enthusiasm and I felt like I was abandoned. I didn't hear from anyone for 17 weeks before I received any care in the community.// I did get down and tearful. They had spent all that money on my recovery and then it all stopped. I got lost in the system

This feeling of abandonment was also accompanied by a sense that community services were overloaded and ineffective by some participants:

026 But the work at this moment they can't do it anyway because they are, maybe they are treating now about ten people in a day so they can't spend the whole time with me. Yeah, they come for the assessment one day, second day that's all. They just come briefly. They don't, they are too overloaded, that's what I think

023 the further you get away from the critical care, the further you go into community care, the more ineffective you get, you find that generally what people are doing is just basically polishing their pensions, they're not particularly effective… , there is no long term care for these patients, and that's what is lacking. And this is where the shoulder has got lost.

Subtheme 3.3B: Hidden Impairments after stroke

Two participants found they had difficulty retaining advice about the upper limb

024 one thing that's been noticeably changed since the stroke is the, the attention span to be doing something, you get bored more quickly, don't you?

021 I think probably someone did try to explain it, but again my ability to retain information at that time was a bit suspect.

Another participant found that fatigue was a barrier to their daily function

024 I went into a phased return to work. And they said oh, start on three and then do four the next week. And at the end of the first week I just burst into tears, and I'm like yes, I'm so tired.

(8.5) Discussion and Conclusions

This study successfully recruited a convenience sample of 41 stroke survivors who have experienced long term pain and stiffness in their hemiplegic shoulder. The sample represented an ethnically diverse cohort of community dwelling stroke survivors who were predominantly independently (88%) mobile with or without an aid. All had passive shoulder joint restriction characteristics of frozen shoulder.

This cohort study discovered that 61% (25/41) had developed maladaptive levels of fear of movement of their affected arm, as measure on the Tampa Scale of Kinesiophobia (TSK).

It is significant that the cohort in study had a large proportion of people with maladaptive fear of movement as this could be one explanation as to the high proportion of frozen shoulder in people post stroke. As discussed in these cases the fear avoidance has potentially extended the period where frozen shoulder pathological processes are active, which may be one factor in why they have developed long lasting pain and stiffness (Jump et al.,2021; Lubis and Lubis, 2013).

Significantly more people in the high TSK group felt that they moved their arm less when they felt sad, compared to the low TSK group ($p = 0.01$). Although, this question has not been validated formally, this is a possible indicator that people with high TSK scores are more vulnerable to mood fluctuations impacting on their arm movement behaviours. These results align with a study in non-neurologically impaired subjects where high kinesiophobia scores were associated with low mood (Lundberg et al. 2006)

Previous studies in the general population have also shown an association between age, gender and kinesiophobia (Branstrom et al. 2008). However, this study did not find a statistical difference between age or gender between low TSK and high TSK groups (Wasiuk-Zowada et al., 2021)

21/25 of the high TSK group were interviewed by two researchers and inductive thematic analysis was conducted on the interview transcripts.

Two themes were established to answer question **What influenced fear of arm movement?':**

1) Interpretation of symptoms

2) Perceived poor shoulder management

Three themes were established to answer the question: **What factors other than fear have influenced reduced affected arm movement?**

1) Redundant Appendage

2) Negative influences on self-management

3) The demotivating transition from acute care to community living

These themes and subthemes will be used to structure the following discussion including clinical implications for each topic area.

A: What influenced fear of arm movement?':

1A Interpretation of Symptoms

This theme indicated that previous experiences of pain were feeding into some participants fear of movement. Perceived pain severity and intensity have been found to be associated with levels of kinesiophobia in the general population (Lundberg et al. 2006). This is fairly unsurprising, however the reasons behind high perceived severity of pain may be explained by one of the subthemes where several participants were concerned that moving into pain would cause damage.

Fear of damage appeared to be particularly enhanced when participants experienced unfamiliar clicks or sounds when moving the arm. These beliefs potentially fall into 'catastrophising' beliefs, where a persons' internal conclusions about pain is that it is the result of significant damage (Vlaeyen et al. 2000). Kinesiophobia and catastrophising beliefs have been shown to be closely associated in previous studies (Feleus et al. 2007). These catastrophising beliefs have been shown to predict perceived pain severity in non-stroke subjects when a muscle injury was induced in experimental conditions (Parr et al. 2012).

Pain catastrophising has been broken down into 3 component factors

1) rumination: continuous thoughts about pain and anticipation of pain during an encounter

2) magnification: where perceived threats are heightened

3) helplessness: where a person has reduced self-efficacy to impact on the pain

(Petrini and Arendt-Nielsen, 2020)

Helplessness or levels of pain self-efficacy have been shown to influence shoulder disability outcomes at 6 months in a large cohort of non-stroke subjects (Chester et al 2019).

The clinical implication of this is that people with high levels of fear avoidance and catastrophizing beliefs are likely to perceive greater levels of pain and disability (Kromer et al., 2014). Studies have shown that people with these beliefs also limit their range of movement (Vernon et al. 2013).

In a recent study examining factors that positive factors that influence outcome in relation to PSSP showed pain education and diagnosis information were significant contributor to outcome (Zhu et al 2013). Therefore, it is possible this education helped to reduce 'Danger in Me' feelings for the stroke survivors (Moseley and Butler 2017). Another potential useful treatment approach is graded exposure to stimuli with education and emotional support using a joint physiotherapist and psychologist intervention. The have shown to be helpful in studies of people with high levels of fear avoidance (Boersma et al. 2004). Therefore, this study indicates a greater need for a specialist approach to people who rate highly on kinesiophobia scales.

A single case study of patient with Complex regional pain in their hemiplegic arm found 1 hour of daily Cognitive Behavioural Therapy (CBT), impacted on pain perception and levels of kinesiophobia over 6 weeks (Sethy et al. 2017). The CBT involved cognitive reconditioning techniques such as deep breathing and relaxation and behavioural modification techniques such a pacing and grade exposure (Sethy et al. 2017). Therefore, even though this was with a single case and involved a different pain condition it is possible these techniques could also be useful for patients with sustained pain and restriction.

In addition to CBT style interventions it is also important to consider the broader social environment. Personal resilience of participants may influence how they adapt to pain (Sturgeon et al., 2010). Resilience and Self efficacy are inter-related with both being influenced by social connection and experiences that promote positive emotional states (Sturgeon et al. 2010). Goal directed Resilience Training 'GRIT' could have a place in future pain treatments in cases of PSSP (Kent et al., 2015).

2A Perceived poor shoulder management

Participants expressed frustration at a lack of attention to their pain and being told to 'just wait' or that the shoulder pain 'was nothing to do with what we're doing' by health professionals. A perception that clinicians needed to be more attentive to a pain problems has been found in a cohort of stroke and spinal injury survivors (n =32) to result in higher perceived pain interference with function (Adams, 2016).

Participants also expressed that the lack of explanation for their pain was disconcerting and some felt their therapists didn't know what was wrong with their shoulder 'they didn't understand what was wrong with me. They didn't understand the shoulder thing'. This may have reduced stroke survivors' perception of control over their pain symptoms. Stronger perceptions of control over pain have been shown to reduce how much pain interferes with function in a cohort of 40 patients post spinal cord injury (Hanley et al., 2008).

It is possible therefore that in this cohort, participants have developed higher levels of fear of movement because no one has clearly explained their problem and how best to manage it. This has fed into to potentially more catastrophic thinking about potential damage and have led to further disuse of the arm (Vlaeyen and Linton, 2012). Providing specific information relies on clinician skill in identify the best treatments. A recent survey identified that the top two perceived barriers by clinicians in providing effective shoulder treatments to stroke survivors was a perceived lack of time and perceived lack of training in this area (Kumar et al., 2020). Therefore, this indicates there is a training need to ensure therapist treating patients with hemiplegic shoulder pain have sufficient assessment and treatment skills (Kumar et al.,2020).

Three themes were identified when exploring perceived barriers by clinicians to giving good shoulder treatments in the general population (Maxell and Robinson 2021):

(1) Lack of consensus: “we all have different approaches.”

(2) Challenges to Changing Practice: It’s “really hard to change and switch to a different approach,”

(3) Getting “Buy in” to Treatment: “…so you have to really sell it early”.

(Maxell and Robinson 2021)

This indicates that gaining consensus amongst expert clinicians about early approaches to PSSP followed by training in key areas such as hyper acute and acute stroke units will help clinicians to improve the clarity of message for stroke survivors

Another, important consideration is that previous studies have shown a large number of potential interventions used by clinicians (Pomeroy et al., 2001). This level of choice is potential unhelpful and overwhelming to clinicians. In addition, the mixed level of clinical evidence even for commonly used adjuncts such as shoulder support is confusing for clinicians (Saikaley et al. 2020). Some participants in this study felt shoulder supports were ineffective or at worst exacerbated their pain. This finding in confirmed by a previous study that found certain supports increased pain compared to no supports (Van Blandel et al., 2017). Therefore, there has to be clear understanding about why an adjunct is being used with regular review to ensure it is achieved the desired effect. Clearer care plans are required that are specific to different presentations rather than grouping all pain together (Holmes et al., 2020)

A further point to consider is that people who are susceptible to more catastrophic beliefs can be susceptible to maladaptive thinking around their treatment where they overly focus on negative aspects of their treatment (Petrini and Arendt-Nielsen, 2020). Therefore, it is possible participants who are susceptible to developed fear avoidance are also more likely to give negative accounts of their treatment to date. This indicates the need for joint psychological and physiotherapy input in these cases to fully understand drivers of pain and behaviours.

B: What factors other than fear have influenced reduced affected arm movement?

1B Redundant Appendage

In this theme participants expressed a general lack of attention to their arm that was driven by a focus on regaining mobility. This lack of attention and a lack of perceived recovery in their arm seemed to generate feelings of their arm being 'useless'. One participant used a disembodiment metaphor of his arm being separate and 'dead'

Fear avoidance models explain that people often weigh up if an activity is worth them doing in context of the threat of pain (Vlaeyen and Linton, 2012). The perception that the arm is not recovering and that movement so far has not been successful potentially feeds into lowering motivation and self-efficacy, as the person does not experience mastery (Chester et al., 2019). Therefore, this lack of perceived mastery of their arm recovery is combining with fear avoidance to enhance disuse behaviours.

Disuse of the arm is not only important in allowing frozen shoulder pathological processes to continue. In addition, learnt non-use has been shown to result in potentially detrimental but reversible cortical reorganisation (Taub 2003). Therefore, this disuse behaviour could be impacting on their ongoing recovery.

This indicates that people with significant weakness need to be educated on the benefits of passive movement for joint health even if active movements are not presently possible. These arms have been called profoundly affected arms in the literature (Allison et al., 2018). Difficulty caring for profoundly affected arms appears to be influence by age, levels of hypertonicity and additional stroke impairments (Allison et al.,2018). Therefore, support structures to help patients with arm movements need to consider these potential limiting factors. In addition, adjuncts such as electrical stimulation, which help support movement regardless of level of recovery, should regularly be considered in people with profoundly affected arms.

2B) Negative influence on self-efficacy

The participants that expressed some beliefs that could indicate an external locus of health control may be important in understanding why they are more susceptible to disuse arm behaviours. Individuals with an external locus of health control tend to engage less in self-management activities as they do not perceive they have as much control over outcomes. Reduced internal locus of control has been proven to associate with increased discharge anxiety when transitioning from acute to community services (Genis et al., 2016). The clinical implication is that people who express more external locus of health control beliefs may require a different approach. Internal locus of control has been shown to be negatively affect by feeling stressed and positively affected by a good relationship with the health care worker and being given education related to their condition (Sorlie and Sexton, 2004). Therefore, ensuring good rapport with patients and carers whilst providing clear personalised information that is specific to the patients' shoulder problem seem critical.

Some participants found treatments or exercises boring which is important as this indicates a need for clinicians to keep checking in with patients about their feelings toward rehabilitation approaches. This could include the use of

rehabilitation groups to help provide vicarious experience and social persuasion (Clarke et al., 2016). Alternatively, adjuncts such as music or gaming could be used to provide motivation for arm movement repetition (Thaut and LaGlasse, 2012). A recent meta-ethnography and systematic review of stroke survivors and carer givers perspectives on community found although stroke survivors were given exercises for their stroke they wanted more individualised contact with a physiotherapist (Pindus et al., 2018). This could also indicate that clinicians ensure their treatments are individually tailored to the stroke survivors' goals, so it prevents disengagement,

One participant indicated reduced social motivation due to isolation and others experienced some social persuasion negatively as nagging. This aligns with discussions around fear avoidance that being told to do something is far less convincing to person than them actually trialling an approach and perceiving success (Vlaeyen et al.2000). This highlights that in the context of people who are experiencing limited success in achieving arm recovery, social persuasion can be seen as upsetting. Another factor is that these participants are experiencing pain and people in pain have been shown to have reduced social engagement (Duenas et al. 2016). This feeling of wanting to withdraw from social engagement due to the pain could be enhancing some stroke survivor's perception of being 'nagged'.

Other subthemes indicated that people felt they had not been given self-management strategies and also noticed the impact of mood on reducing their motivation. As discussed in the redundant appendage theme, it appears that there is a perceived lack of focus on the upper limb in acute care driven by a focus on mobility. In light of current understanding of frozen shoulder pathological processes, it is now important that treating clinicians understand the benefit of giving advice on arm movement regardless of recovery status. In addition, mood monitoring is part of standard acute stroke care and so it important that interventions are given in timely manner once consistent low mood has been identified.

3B The demotivating transition from acute care to community living

This theme showed that participants felt abandoned when they transitioned to community living. This has been found by several other studies looking at transitions between services (Pindus et al. 2018). A potential explanation for this phenomenon is lack of preparation information given to patients in the acute setting (Wiles et al. 2002). A study examining patient's expectations of recovery after stroke found that participants interviewed prior to discharge had higher expectations of recovery compared to when they were reinterviewed in the community (Wiles et al. 2002). This was speculated to be potentially as a result of the perceived disparity between rapid early change followed by of perceived slowing of recovery later at home (Wiles et al. 2002). A recent review highlighted the need for clinicians to receive more training on delivering information about recovery in a timely way that maintains hope without setting up false expectations (Burton et al., 2021). It is recommended that this information should be given via a multidisciplinary team approach so messages were seen to be clear and consistent (Burton et al.,2021).

Some of the comments in interviews about a sense of abandonment by stroke survivors when they are discharged home has

Another factor to consider is that previous studies in the general public have shown people with musculoskeletal pain are more likely to report a lack of social support (Nicholson et al. 2020). Therefore, it is possible that the shoulder pain is enhancing these feelings of abandonment. In addition, as discussed earlier people who are more susceptible to catastrophic health beliefs may also be susceptible to negative appraisals of their support (Casio 2020). As personality traits such as optimism and high self-efficacy have been shown to impact positively on perceived disability and motivation, it may be beneficial for clinicians to regularly measure these traits during rehabilitation to understand how to modify

approaches (Chester et al. 2019). A personality measure previously used in stroke survivors is the NEO five factor inventory (Aben et al. 2002).

Poor levels of perceived life control have also been found to be associated with high kinesiophobia in non-stroke subjects (Lundberg et al. 2006). 64% (16/25) of participants in the high tsk group agreed or strongly agreed with item 6 '*My stroke has put my body at risk for the rest of my life' ,*indicating they perceive less life control as a result of their stroke. In this study, even though the majority of participants in this study were able to mobilise independently with or without an aid, some participants expressed the shock of new limitations post stroke when discharged from acute services. This in combination with several participants feeling abandoned by services may have contributed to participants not being as motivated to problem solve different ways of managing their pain. Another factor expressed by some participants is that hidden impairments such as cognitive impairments or fatigue were a barrier in them engaging more in rehabilitation. It is important that clinical measures of cognition and fatigue feed into approaches to the patient's shoulder pain.

Chapter 8 Conclusions

This study has identified a high proportion of stroke survivors with suspected frozen shoulder in their hemiplegic arm have developed maladaptive levels of fear of movement. Interviews of these subjects indicates that fear is driven by a negative interpretation of symptoms as well as perceived poor management of their pain. Specifically, participants perceived a lack of specific advice and attention to shoulder pain when it developed. In addition to fear, stroke survivors identified that there was a lack of attention to their arm in acute services which potentially fed into learnt non-use behaviours. Also, subjects identified the

challenges of transitioning to community living and adjusting to new stroke disability as potentially demotivating to arm movement behaviours.

The prevalence of frozen shoulder in stroke survivors with PSSP and the emerging evidence about pathological mechanisms highlights the need for patients to move their affected arms regularly regardless of motor recovery. Although the interview data is not directly generalisable the mixed methodology of this study has highlighted that psychosocial factors are a potentially significant factor in arm movement behaviours. Future research is required to examine joint physiotherapy and psychology approaches for people who have developed, or who are at risk of developing PSSP. These approaches have proved effective for people with chronic musculoskeletal conditions in the general public but other than a single case study, these approaches are yet to be trialled in the stroke survivor population with PSSP.

Chapter 8 Study Limitations

Although the Tampa scale of Kinesiophobia has been shown to have stable psychometric properties when examining people with shoulder pain, it has not yet been extensively used in the stroke survivor population. In addition, other studies have found factors such as somatising and worrying have been better predictors of outcome compared to kinesiophobia (Feleus et al. 2007). Therefore, future work needs to be conducted to validate the TSK scale for stroke survivors in combination with other personality trait and psychological outcomes, to gain a better understanding of psychosocial predictors of outcome in this cohort.

The only item that was not significantly different between the Low TSK and High TSK group was item 8*:Just because something aggravates my pain does not mean it is dangerous,* which was a reverse worded item. Interestingly only 7/25 of the high TSK participants disagreed or strongly disagreed with this item compared to 2/16 in the low TSK group. This finding was contradicted by the high TSK interview answers indicating a potential problem with this item. It is well known that reverse items can be problematic in confusing patients (De Vellis 2012). In fact the internal consistency of the TSK has been found to be improved by removing the reversed items (Swinkels-Meewisse et al. 2003). Therefore, it is possible that future research should use a shortened form of the TSK where these reverse items are removed (Swinkels-Meewisse et al. 2003).

As discussed, the main researcher in this study has had extensive experience in treating patients with PSSP. Therefore, although efforts were made to improve the analysis rigour, unconscious bias may have influenced the selective coding approach. Further research is required to confirm findings in this study.

This worked focused specifically on participants with high ‘maladaptive’ levels of kinesiophobia. In future it would also be beneficial to examine the lived experience of participants with low kinesiophobia scores to examine how the lived experience of these people differs from those with high kinesiophobia scores.

Chapter 9 Thesis Conclusion

Biopsychosocial factors in the onset and longevity of Post Stroke Pain

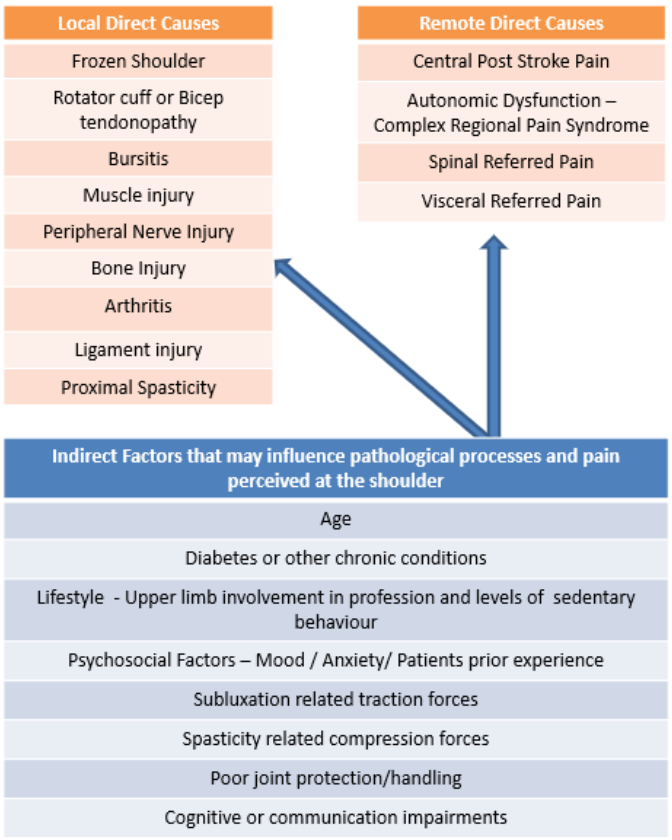
To conclude this Thesis this chapter presents a model based on the findings of the studies combined with the current evidence base.

Pain perceived at the shoulder can essentially be separated into 2 sources

i) local to the shoulder joint and
ii) remote to the shoulder joint.

As shown in Figure 40, there are direct sources of pain that are influenced by indirect factors such as Age, Lifestyle factors (such as exercise behaviour) and Psychosocial factors. Further interactions between these factors is explored in Fig 41

Fig. 41: Possible local and remote sources of pain perceived at the shoulder after stroke



(9.1) Insights into local shoulder pathological processes

This thesis has mainly focused on indirect and direct influences on local shoulder joint pain and restriction. The findings of study 1 are in alignment with other studies that show that passive shoulder external rotation and abduction restriction starts early within the first two weeks in very weak hemiparetic shoulders (Ada et al., 2020; Allison et al.,2018). Early (within 2 weeks) passive restriction of these two movements, as well as reduced shoulder proprioception appear to predict developing moderate to significant pain by 8 weeks (Rajaratnam et al. 2007). This indicates pathological processes that cause restriction start early and lead to moderate to severe pain later.

Indirect factors such as age and pre-existing muscle bulk (possibly due to premorbid exercise behaviours) appear to influence how quickly a stroke survivor develops pain and restriction in their hemiparetic shoulder. These factors as well as diabetes are likely to influence tendon health and the presence of age related tendonosis (Holmes et al., 2020; Jonsson et al. 2006). Tendons with tendonosis changes are potentially more susceptible to injury and inflammation (Bass et al.,2012). Traction forces as a result of subluxation and poor handling may further exacerbate this problem through trauma of soft tissues (Bass et al., 2012; Paci et al., 2007; Idowu et al.,2017; Wanklyn et al., 1996). These indirect factors appear to accelerate processes that result in restriction and pain as they all impact on soft tissue health and a susceptibility to a pro-inflammatory joint environment (see Figure 41).

Pro-inflammatory joint environments appear to disrupt joint homeostasis resulting in a continuous laying down of collagen fibrils around the joint capsule, resulting in Frozen Shoulder (Jump et al., 2021) (see Figure 41). Once inflammation is established neovascularisation processes can be triggered near nerve endings which is possibly why early frozen shoulder is reported as being so severely painful in the early stages (Lewis et al., 2015).

In this thesis a small pilot indicated stroke survivors who have pain and restriction tended to use scapula retraction as an initiation strategy. It is possible that this was a compensation strategy as a result of passive glenohumeral joint restriction and weakness. It could also be due to weakness of shoulder internal rotators resulting in scapula retractors being unopposed during movement initiation (Lum et al., 2003). Thoracic flexion postures appear to increase scapula external rotation in the general population (Yabata and Fukui et al., 2022).It is possible that stroke survivors with reduced core strength may be adopting increase thoracic flexion which may be contributing to increased Scapular retraction during movement initiation. It is likely that observed compensation strategies are a combination of reduced descending motor control and local mechanical weakness and restriction. Future research examining movements pre and post range changes (as the result of treatments) will help to unpick whether descending motor control or local restriction is the dominant factor in the observed strategies.

As scapula movement adaptations and variations don't always signal pathology, it is difficult to fully understand the significance of scapula movement changes (McQuade et al., 2016). A potentially more useful finding is that clinical measurements of active glenohumeral external rotation range showed a clear relationship with dynamic rotational scapular range and active shoulder flexion range. During forward flexion scapula rotation adjustments appear to allow efficient humeral elevation movement (Stokdijk et al.,2003). Possibly this is due to maintaining optimal muscle length tension relationships and rotational torque forces (Beer at al., 2007). External rotation power appears to aid these adjustments. In study 1 of this thesis, it was found that external rotation muscle recovery by three weeks reduced a stroke survivors' risk of developing pain by 8 weeks. The relationship of external rotation power and scapula rotation dynamic range may explain why external rotation has a potentially protective role against pain and restriction. It is possible that more efficient scapula movement is protective of soft tissues and injury. Although, it is important to acknowledge that these inferences are based on small sample data sets and further research is required.

In regard to shoulder treatments when clinical signs of frozen shoulder are established, the effectiveness of hydrodilatation injections (steroid plus saline) were analysed. It was found that these were effective at reducing pain and improving passive joint range. Improvements in external rotation and abduction were most associated with pain reduction, further confirming the relationship of these movements with frozen shoulder pathology. Age was shown to impact on range changes as a result of injection treatments. This is likely because of pre-morbid joint, bone and tendon changes.

It is likely that timely use of steroid rather than additional saline are the main factor in range and pain improvements post hydrodilatation injection (Wu et al., 2017). In the evaluation in this thesis, there was no difference in outcome between subjects who had less (<30ml) or more (>30ml) additional saline. However, a recent meta-analysis of hydrodilatation versus steroid alone in the general population indicates that hydrodilatation may be more effective in reducing early pain, despite long term outcomes being similar (Challoumas et al., 2020). This early pain reduction may be important in some clinical situations.

Significant upper limb weakness after stroke is also closely associated with developing spasticity in the shoulder internal rotators and adductors (Ada et al. 2020; Allison et al., 2018). Spasticity can restrict passive movement and is exacerbated by early pain and inflammation (Thibaut et al., 2013). This highlights the likely close interrelationship between proximal spasticity and frozen shoulder.

A pilot study indicated that although Pectoralis Major was the most consistent contributor to internal rotation/adductor tone, although there was lots of individual variation in muscle contribution. This casts doubt on previous assumptions that certain muscles such as Subscapularis always contributed to internal rotator/adductor spasticity. Identifying target muscles for botulinum toxin injection therefore requires specialist assessment of each individual case; likely with the use of needle EMG assessment.

Sustained restriction due to either frozen shoulder or shoulder spasticity can result in permanent contracture of muscle and soft tissue (Allison et al. 2018). This means there is a growing case for trialling the use of botulinum toxin or steroid injection as soon as restriction and discomfort starts to prevent severe pain and restriction (Lindsay et al., 2021). However, as both spasticity of shoulder internal rotators/adductors and frozen shoulders present in similar ways they are often difficult to differentiate clinically from each other. An algorithm has been developed using diagnostic Lateral Pectoralis nerve blocks to address this problem (Fitterer et al., 2021).If Pectoralis Major spasticity is the primary cause of restriction this can result in instant improvements of range (Fitterer et al., 2021). In contrast if range is unaffected this algorithm assumes that frozen shoulder or in more chronic cases joint contracture are the predominant cause of restriction (Fitterer et al., 2021). However, as shown in this thesis although Pectoralis Major is a common contributor to internal rotator and adductor spasticity; there is often individual variability. This highlights the risk of false positives and negatives using this algorithm approach.

Further research is required to improve diagnostic methods to aid the differentiation between proximal shoulder spasticity and Frozen Shoulder. Trials should include the use of Suprascapular nerve block (SNB) as a possible diagnostic technique. Although the Suprascapular nerve does not innervate any motor components of the internal rotators or the adductors; it is known to account for upto 70% of the sensory supply of the proximal shoulder (Vorster et al. 2008). Proximal spasticity is modulated by sensation, so this means SNB could be useful to reduce proximal tone, aiding differentiation. It would be useful for a future trial to establish which nerve block techniques in isolation or as combinations are most useful in differentiating pain problems.

Nerve block techniques as well as having diagnostic value, often reduce pain and muscle guarding and can be effective treatment techniques. Understanding the characteristics of stroke survivors who only require a simple nerve block to allow them to move their arm more regularly versus those who require more extensive steroid or botulinum toxin injections, is also an important research question that needs answering in future.

Literature reviews as part of this research indicate that neither botulinum toxin or steroid injection have been used with the early 3 month period post stroke. Trialling these treatments within this period will be an important future research objective.

In addition to injection treatments, there is growing evidence that regular passive or active shoulder movements are important for treating and preventing shoulder pain the hemiparetic arm (Serrezuela et al. 2020; Van Bladel et al. 2022). They can help improve shoulder joint range and can halt frozen shoulder fibrosis processes (Lubis and Lubis, 2013; Van Bladel et al., 2022;). This clarifies why weakness appears to be a key driver of shoulder pain and restriction (Saikaley et al. 2020). It is also likely that lower limb and trunk power influence the shoulder complex via the kinetic chain, influencing pain as an outcome (Richardson et al., 2020). Preventive and treatment protocols should all involve regular shoulder movements and global strengthening where possible. However, further research is required to understand optimal strengthening and ranging protocols in the early post stroke period.

In regard to psychosocial factors influencing further longevity of restriction and pain; study 5 indicates that fear of movement is common in the painful hemiparetic shoulder. As discussed in the introductory chapters, protective pain reduction behaviour is a normal adaptive response to allow heeling. However, this can become maladaptive when ongoing fear avoidance of movement continues. Passive or active joint movements that are required to maintain joint health and halt pain processes are avoided resulting in further restriction and pain (Lubis and Lubis, 2013). Study 5 found possible individual factors that may influence a stroke survivor developing these more maladaptive behaviours.

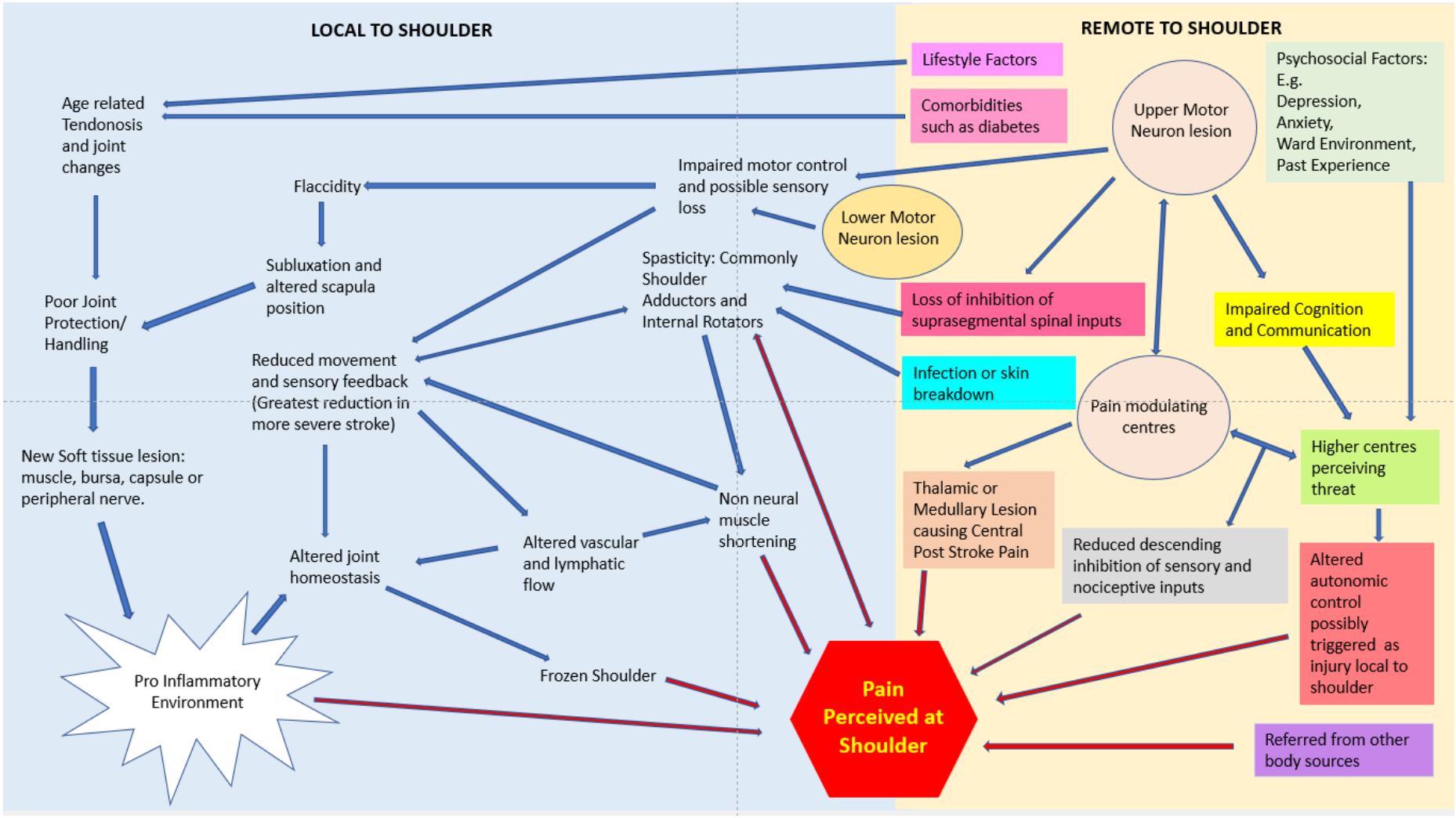
Negatively interpreting symptoms as a threat to further injury was a common theme, leading to stroke survivors feeling that movement avoidance was the safest behaviour. This is likely why pain education has been shown to be associated with better pain outcomes and reduced longevity of pain (Zhu et al., 2014). Another common theme influencing maladaptive pain behaviours was a perception of poor management of their shoulder. It is an established phenomenon that a patient's trust in their healthcare team impacts on perceived symptom severity and quality of life (Birkhauer et al., 2017). It is important for treating teams to spend time to explain management and intervention plans. This will help gain trust and reduce a stroke survivors perceived threat when they are experiencing pain symptoms.

As discussed earlier resilience training could be helpful to prevent or treat maladaptive behaviours related to the hemiparetic upper limb. In order to identify people that could be at higher risk of maladaptive behaviours and catastrophising, measures 'intolerance of uncertainty' could be beneficial in combination with measures of self-efficacy (Buhr and Dugas,2002). Intolerance of uncertainty has been shown to influence catastrophising, anxiety and perceived pain but is so far underexplored in PSSP (Lopez-Martinez et al. 2022).

Perceived abandonment when transitioning to community living, a lack of perceived upper limb functional recovery and negative influences on self-efficacy were also themes that appeared to impact on reducing beneficial arm movement behaviours in individual stroke survivors. It is well known that stroke survivors are at high risk of low mood and depression, particularly when they have lasting physical impairments (Wade et al., 1987; Kutlubaev et al., 2014). Low mood learned helplessness and a lack of engagement in rehabilitation are all inter-related (Ezema et al., 2019; Lyvia et al., 2006). Implementing improved psychological care to aid difficult transitions and boost self-efficacy will require improved awareness, and training amongst stroke professions (Gilliam et al. 2012). A key message being that time spent with stroke survivors to explore and support the impact of stroke on their lives should be seen as a valid use of clinical time (Gilham et al., 2012).

Psychotherapeutic interventions such as motivational interviewing or Cognitive Behavioural Therapy may be beneficial to help stroke therapist adjust and can help lower pain perception (Patel et al, 2018; Zanini et al. 2018). These may help to reduce movement avoidance and perceived threat if shoulder pain develops. It will also be beneficial for services to identify stroke survivors who at higher risk of developing low mood or who have lower self-efficacy (Lyvia et al., 2006). Individualised goals particularly when a subject has minimal recovery in the upper limb are likely to be beneficial in maintaining a stroke survivors' engagement in their rehabilitation (Forgea et al., 2021). In profoundly affected limbs; this could involve highlighting the importance of passive movements to preserve joint health and to prevent pain and contraction complications

Fig. 42 : Direct and Indirect Local and Remote factors influencing pain perceived in the shoulder in hemiparetic arms after stroke (Blue lines are indirect factors and red lines are indirect factors)



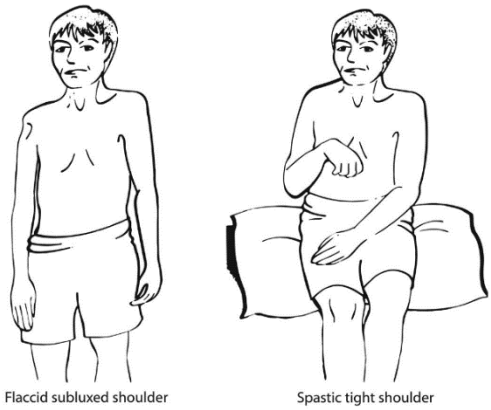
(9.2) Future Research

Improving diagnostic accuracy: In regard to further understanding the natural history mechanistic principles behind different pathologies within the PSSP bracket it would also be beneficial for future observations studies to attempt to repeat findings of previous studies examining serum levels of MMP/TIMP levels in subjects with frozen shoulder via a blood test (Lubis and Lubis, 2013). It may also be possible to combine these tests with modern inflammatory biomarker panels. As a pro-inflammatory environment is key to triggering progressive fibrosis this could help to establish biomarkers of the early stages of frozen shoulder. These blood tests should be combined with contrast enhanced MRI scans, xrays and clinical tests so findings can be triangulated (Pompa et al. 2011).

Wider implementation of best practice:

Shoulder pain pathways are being developed in an attempt to drive better management of shoulder pain. Simple approaches such as stratifying according to presentation such as below (see Fig 3) has shown to improve pain in 65% of cases and completely resolve pain in 21 -41% (Walsh et al. 2021) (see Figure). This is an improvement on previously reported resolution rates of 14 – 27% (Walsh et al. 2021). A further pathway has been developed at UCLH in parallel with this work, which classifies shoulder pain into 4 commonly seen categories: Hypotonic, Proximal spasticity/high tone, Subacromial pain and Frozen shoulder (Lakra et al. 2023). This pathway now requires further validation and testing

Fig 43: Hypotonic versus hypertonic presentation.



(Take from Fig 1, page 2 Walsh et al., 2021)

Evidence for earlier intervention:

Although the pathways are implemented in rehabilitation settings, several months after pain onset. The data of this thesis in combination with other studies have strengthened the case for earlier intervention within 2-3 months of stroke. It is important to note that variation in stroke services across the country may impact where stroke survivors at high risk of shoulder pain reside during their early recovery..

The role of resilience and behaviour change interventions

There is also a need to understand the possible role of resilience training in this population as it has proved beneficial in people with chronic pain (Kent et al., 2015). This may require further work to identify who would most benefit from these programs using scales such as the kinesiophobia scale used in this thesis as well as other scales such as the intolerance of uncertainty scale. This work may require further scale validation work in stroke survivors.

Implementing best practise

As the future work starts to galvanize best practise protocols, further work will need to be conducted to understand how best practice can be implemented across different settings further work needs to conduct on a population level to establish service restrictions and current practice in different settings. This could be conducted via a survey.

Training programs and clinical pathways could be trialled and examined against longitudinal outcomes which could then be used to inform national guidelines. As discussed

Potential Thesis Limitations

Setting and Population: The studies in this thesis relied on convenience samples from a specialist tertiary service or three London stroke units. In addition, several studies focused on participants who had significant upper limb hemiparesis as these are most at risk at developing PSSP. However, it is important to note that these clinical setting and this population may not be representative of caseloads and facilities across the country.

Potential Bias: There could have been unconscious bias by the investigator. All outcomes in the observation studies were conducted by the PhD student. This means that the assessor was unblinded to the purpose of the study. Although significant effort was made to standardise assessment protocols as well as ensuring measurements were repeated for consistency, unconscious bias cannot be ruled out from the findings.

Sample size: All of the studies included in this study had relatively small samples. Appropriate interpretive statistical analyses were used as well as inclusion criteria to improve homogeneity of the population. However, due to the complex nature of stroke and PSSP as demonstrated in figure 41 further work needs to be conducted to prove the generalisability of these findings.

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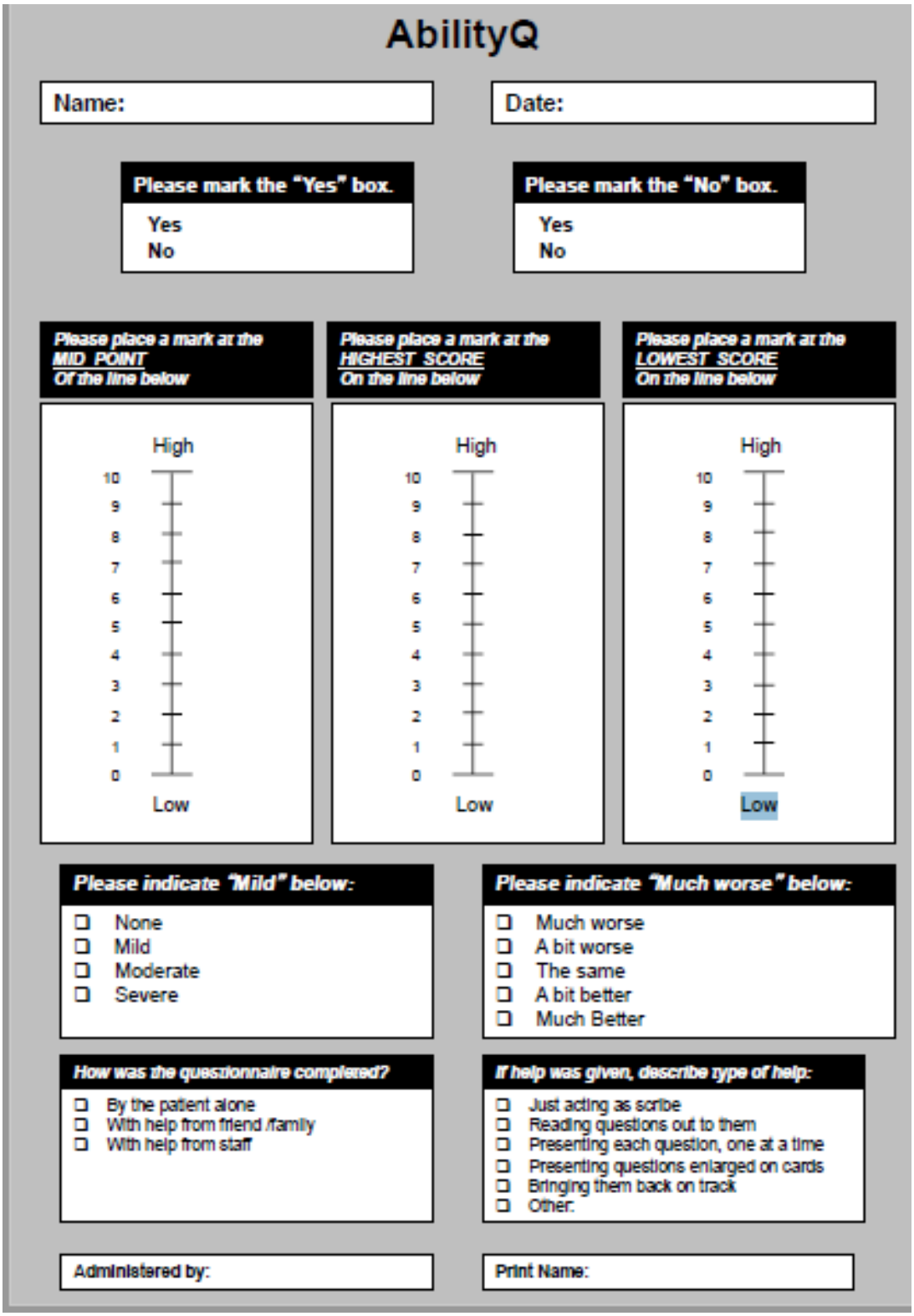
(12.0) Appendices

Appendix A: Ability Q Assessment Sheet



AbilityQ

Name:

Date:

Please mark the "Yes" box.

Yes
No

Please mark the "No" box.

Yes
No

Please place a mark at the MID POINT Of the line below

High
10 9 8 7 6 5 4 3 2 1 0
Low

Please place a mark at the HIGHEST SCORE On the line below

High
10 9 8 7 6 5 4 3 2 1 0
Low

Please place a mark at the LOWEST SCORE On the line below

High
10 9 8 7 6 5 4 3 2 1 0
Low

Please indicate "Mild" below:

- ❑ None
- ❑ Mild
- ❑ Moderate
- ❑ Severe

Please indicate "Much worse" below:

- ❑ Much worse
- ❑ A bit worse
- ❑ The same
- ❑ A bit better
- ❑ Much Better

How was the questionnaire completed?

- ❑ By the patient alone
- ❑ With help from friend /family
- ❑ With help from staff

If help was given, describe type of help:

- ❑ Just acting as scribe
- ❑ Reading questions out to them
- ❑ Presenting each question, one at a time
- ❑ Presenting questions enlarged on cards
- ❑ Bringing them back on track
- ❑ Other:

Administered by:

Print Name:

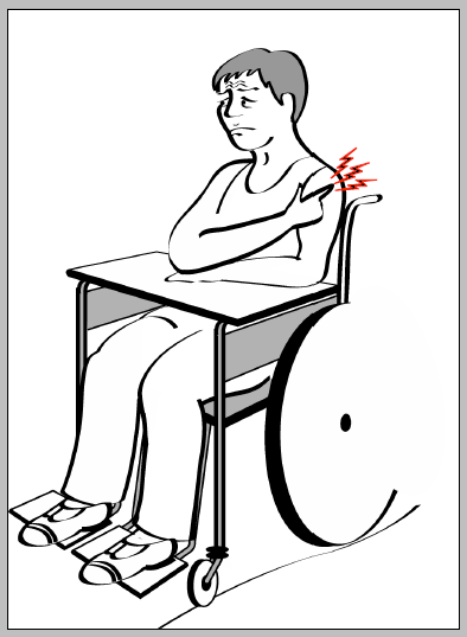
(Turner- Strokes and Rusconi, 2003)

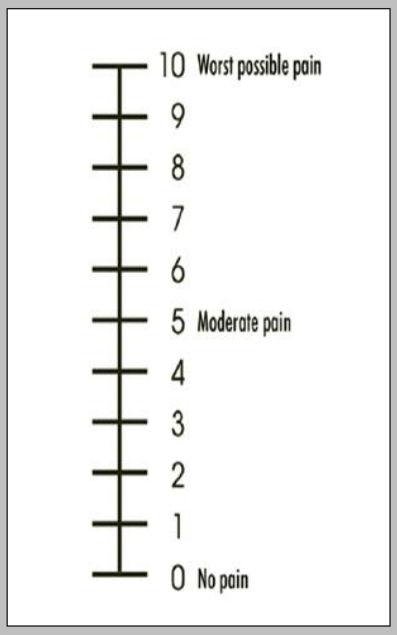
Appendix B: Shoulder Q Assessment Sheet

Do **you** have **pain** in your **shoulder?**

☐ Yes ☐ No

How **bad** is the **pain** when sitting still?

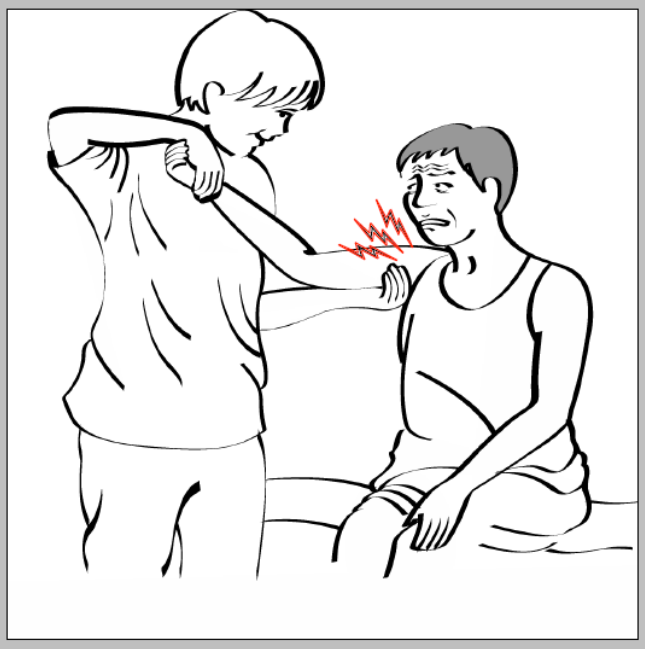


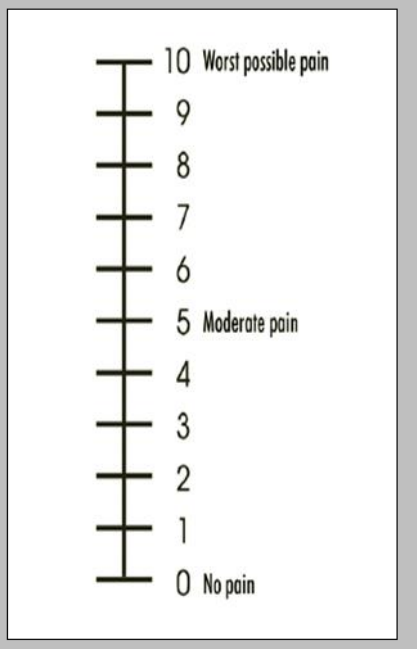


(Turner- Strokes and Rusconi, 2003)

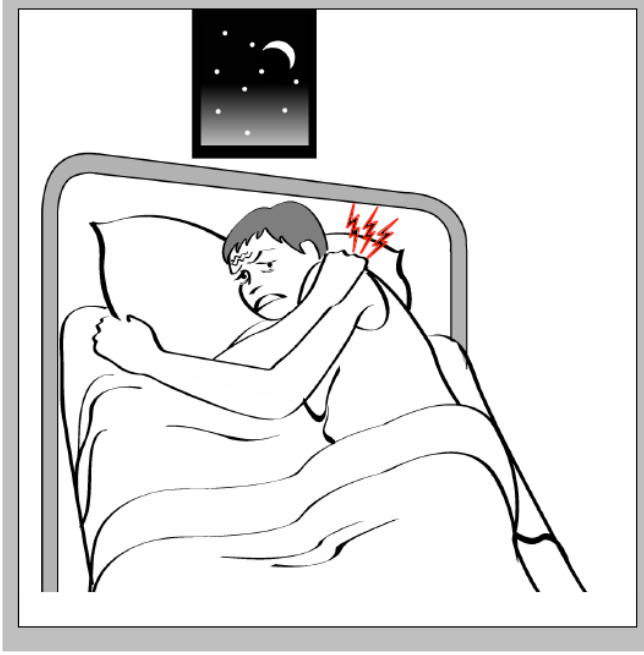
Appendix B: Shoulder Q Assessment Sheet

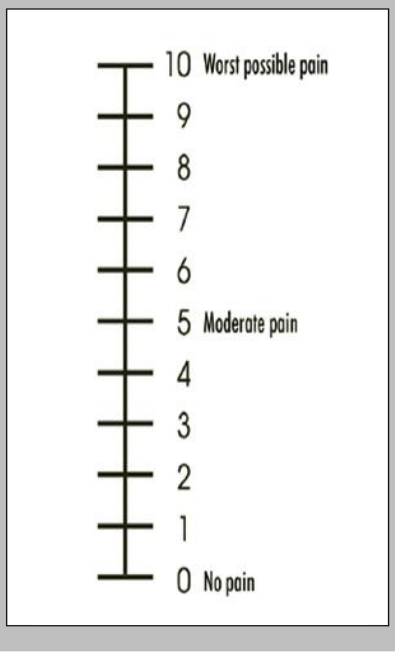
How **bad** is the **pain**
when your arm is **moved?**





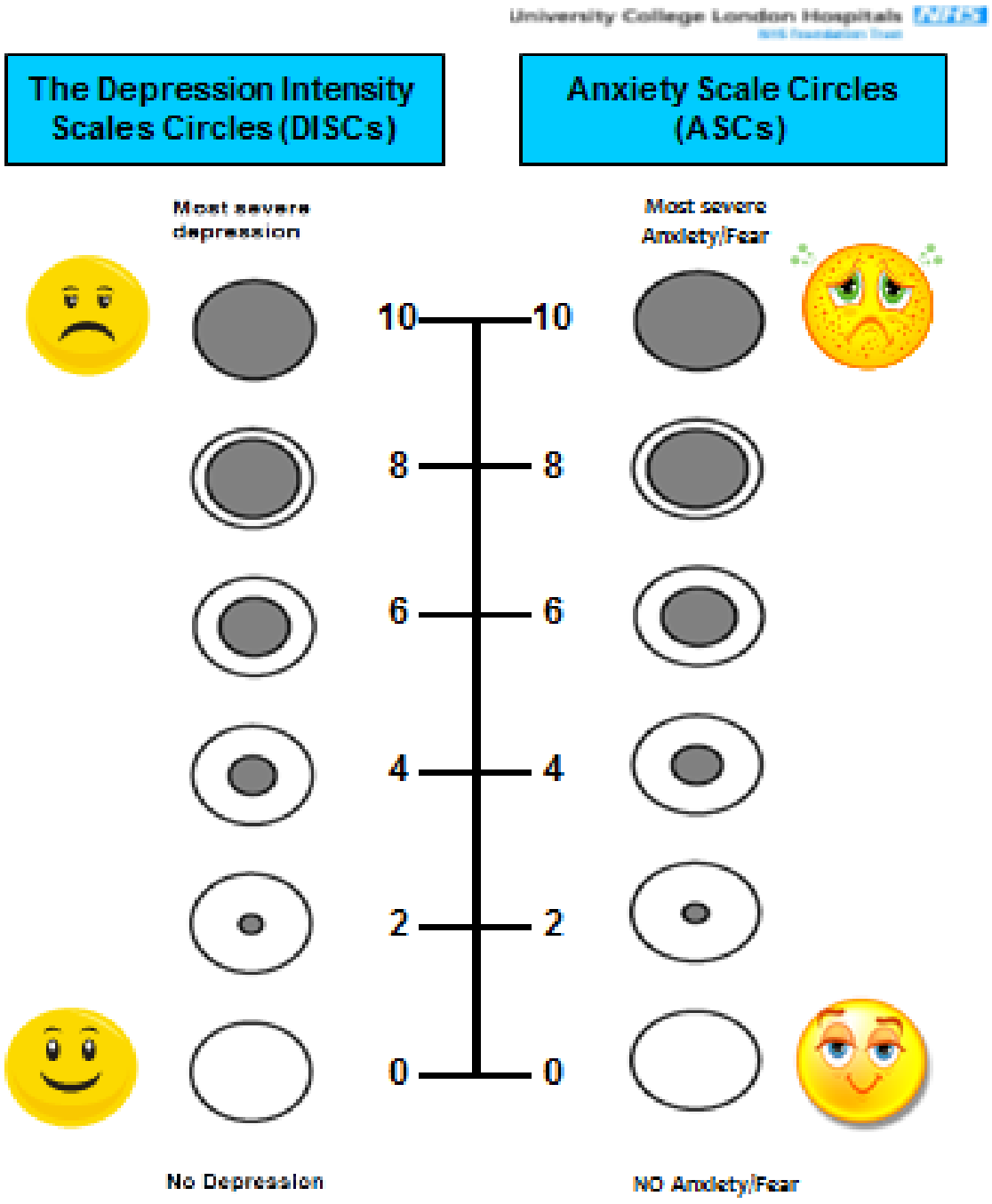
How **bad** is the **pain** at **night?**





(Turner- Strokes and Rusconi, 2003)

Appendix C: Depression and Anxiety assessment sheet



COMMENT/OBSERVATION:

APPENDIX D: 5 x Active Shoulder flexion and lowering cycles in the scapular plane for each case (Chapter 7)

Plots show DEGREES OF MOVEMENT (Y axis) against TIME (millisec)

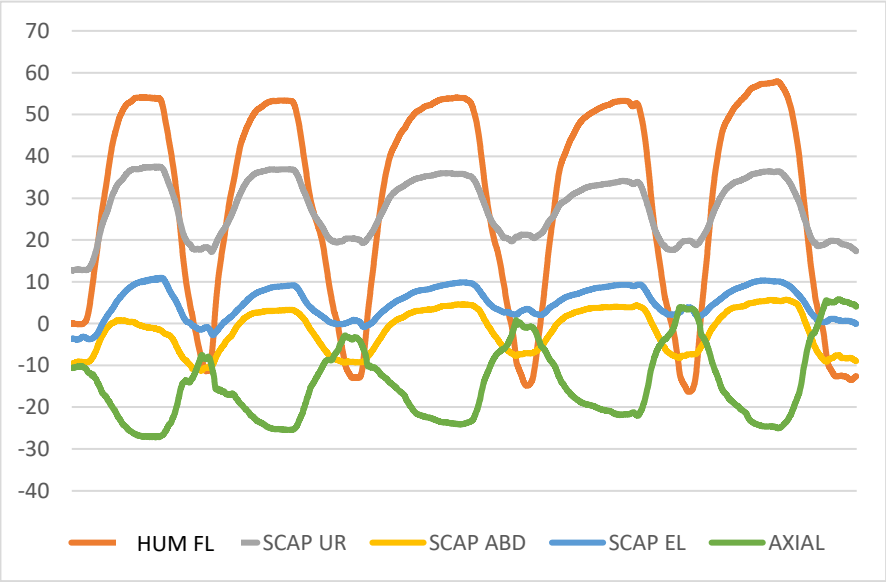
Plot Key:

HUM FL = Glenohumeral Flexion SCAP UR = Scapula Upward Rotation SCAP EL = Scapula Elevation

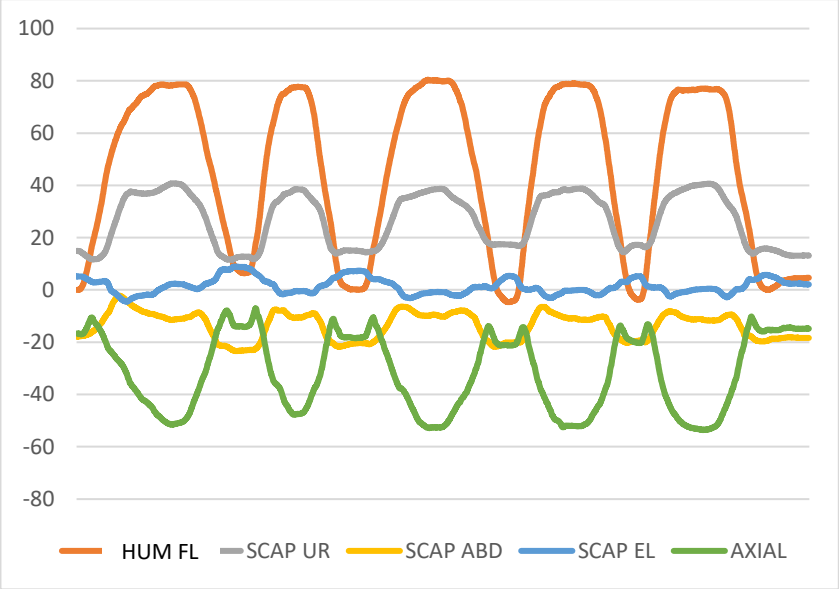
SCAP ABD = Scapula Abduction = positive gradient, Adduction = negative gradient)

AXIAL = Axial rotation (External rotation = negative gradient, Internal rotation = positive gradient)

KIN01 LEFT (HEMIPARETIC ARM) (x axis: 50.00 seconds)



KIN01 RIGHT (NON HEMIPARETIC ARM)(x axis: 39.16 seconds)



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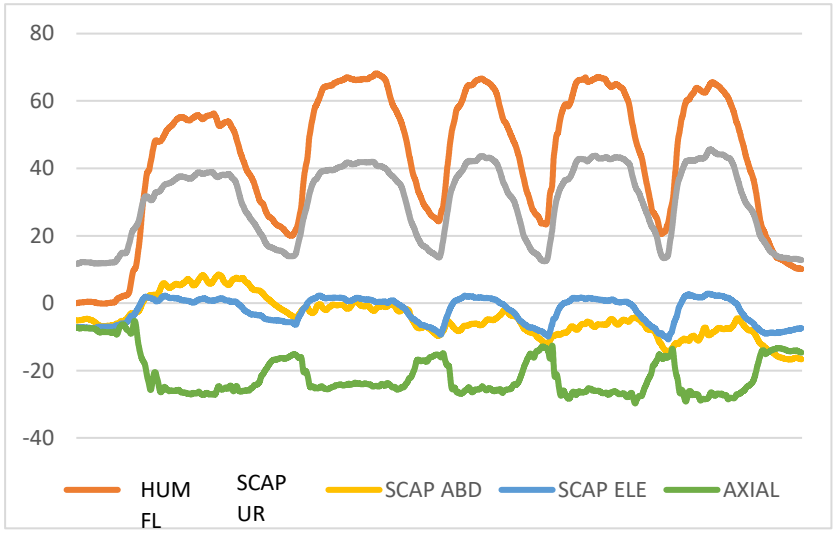
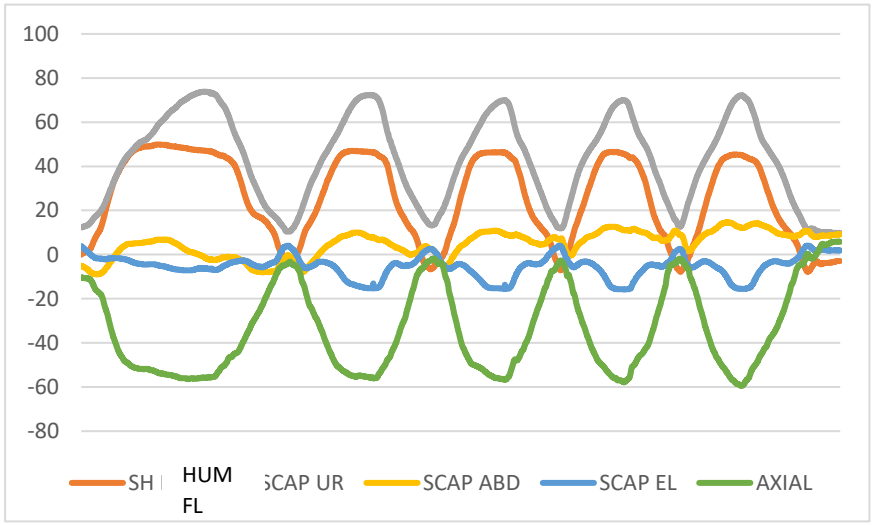
SCAP ABD = Scapula Abduction = positive gradient, Adduction = negative gradient)

AXIAL = Axial rotation (External rotation = negative gradient, Internal rotation = positive gradient)

KIN 03 LEFT (HEMIPARETIC ARM) (x axis: 41.05 seconds)



KIN03 RIGHT (NON – HEMIPARETIC ARM)(x axis: 37.20 seconds)



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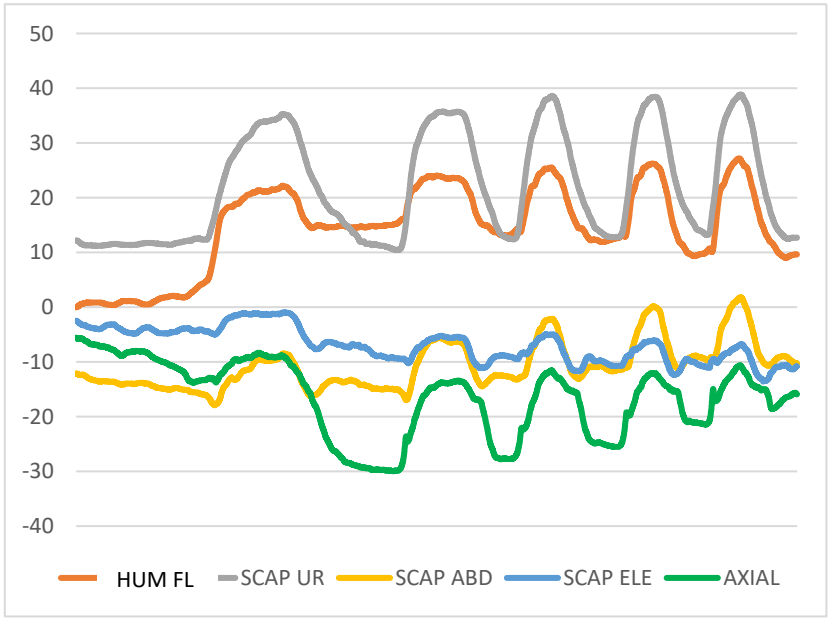
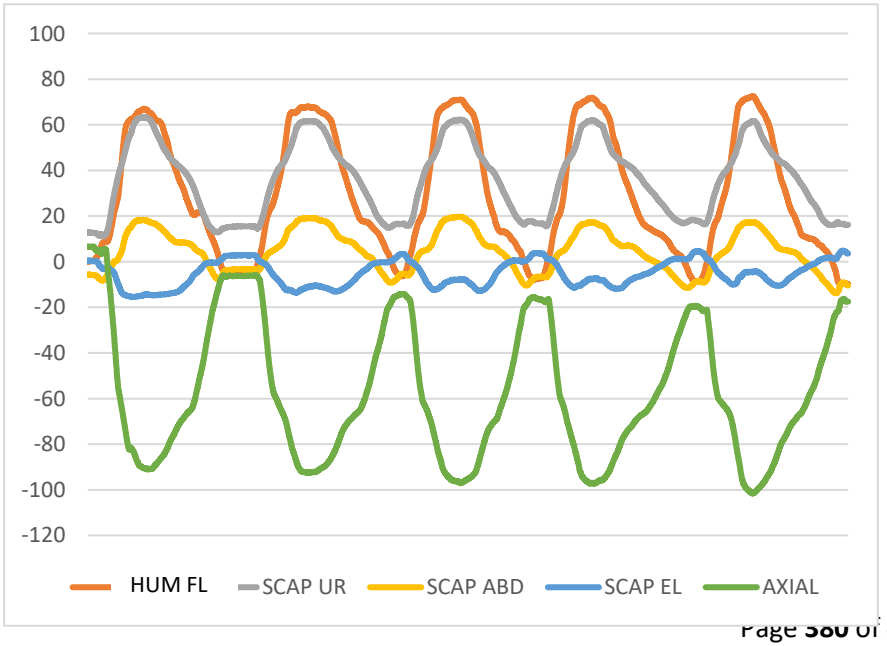
SCAP ABD = Scapula Abduction = positive gradient, Adduction = negative gradient)

AXIAL = Axial rotation (External rotation = negative gradient, Internal rotation = positive gradient)

KIN04 RIGHT (HEMIPARETIC ARM) (x axis 59.21 seconds)



KIN 04 LEFT (NON – HEMIPARETIC ARM) (x axis: 62.11 seconds)



APPENDIX D: 5 x Active Shoulder flexion and lowering cycles in the scapular plane for each case (Chapter 7)

Plots show DEGREES OF MOVEMENT (Y axis) against TIME (millisec)

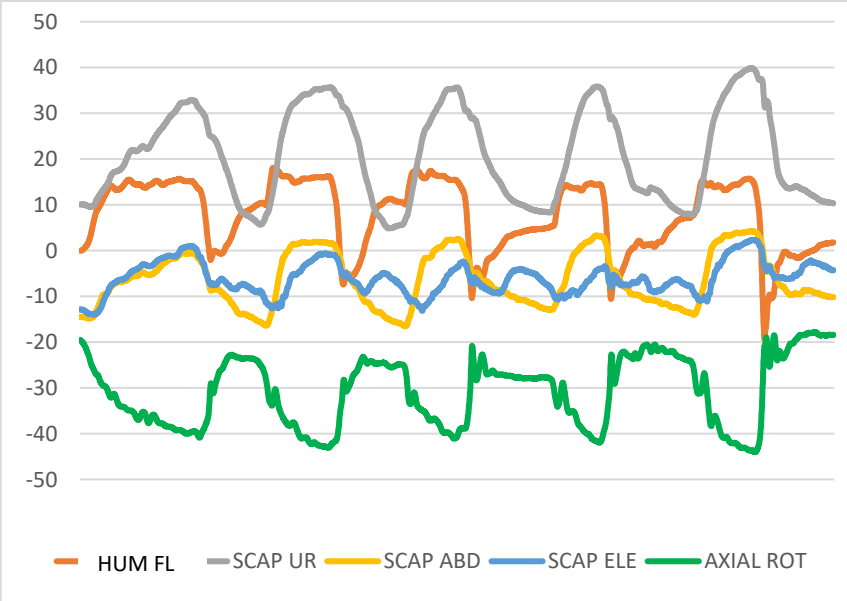
Plot Key:

HUM FL = Glenohumeral Flexion SCAP UR = Scapula Upward Rotation SCAP EL = Scapula Elevation

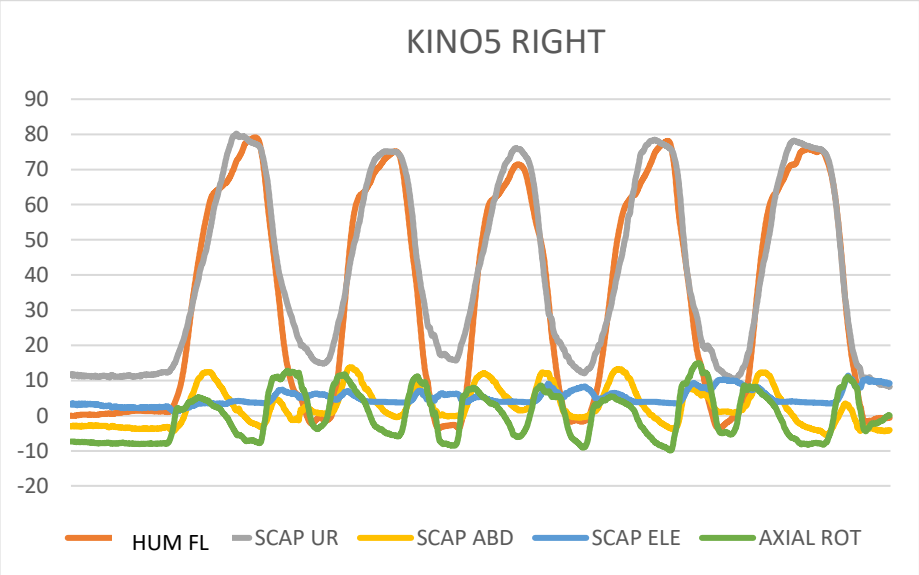
SCAP ABD = Scapula Abduction = positive gradient, Adduction = negative gradient)

AXIAL = Axial rotation (External rotation = negative gradient, Internal rotation = positive gradient)

KIN05 LEFT (HEMIPARETIC ARM) (x axis 37.81 seconds)



KIN05 RIGHT (NON- HEMIPARETIC AMR) (x axis 34.81 seconds)



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Plots show DEGREES OF MOVEMENT (Y axis) against TIME (millisec)

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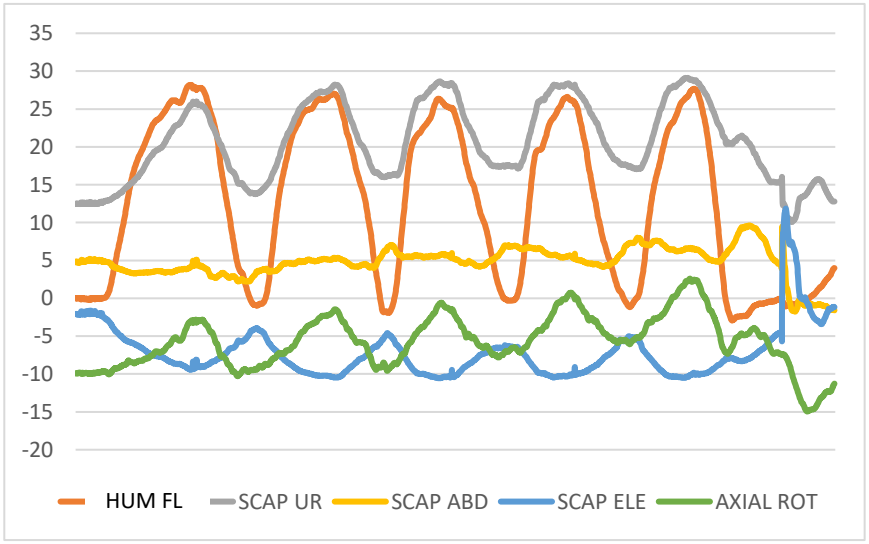
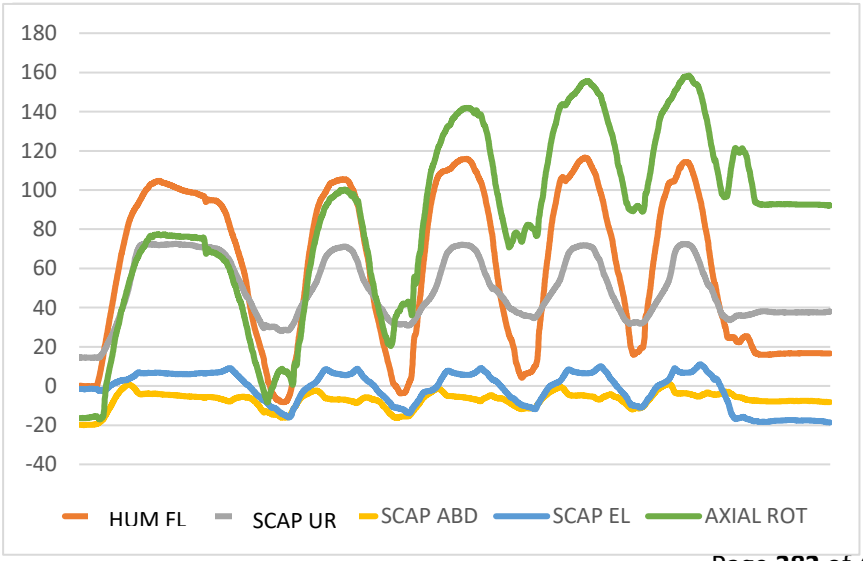
SCAP ABD = Scapula Abduction = positive gradient, Adduction = negative gradient)

AXIAL = Axial rotation (External rotation = negative gradient, Internal rotation = positive gradient)

KIN 06 RIGHT (HEMIPARETIC ARM) (x axis 27.13 seconds)



KIN 06 LEFT (NON – HEMIPARETIC ARM) (x axis 39.00 seconds)



APPENDIX D: 5 x Active Shoulder flexion and lowering cycles in the scapular plane for each case (Chapter 7)

Plots show DEGREES OF MOVEMENT (Y axis) against TIME (millisec)

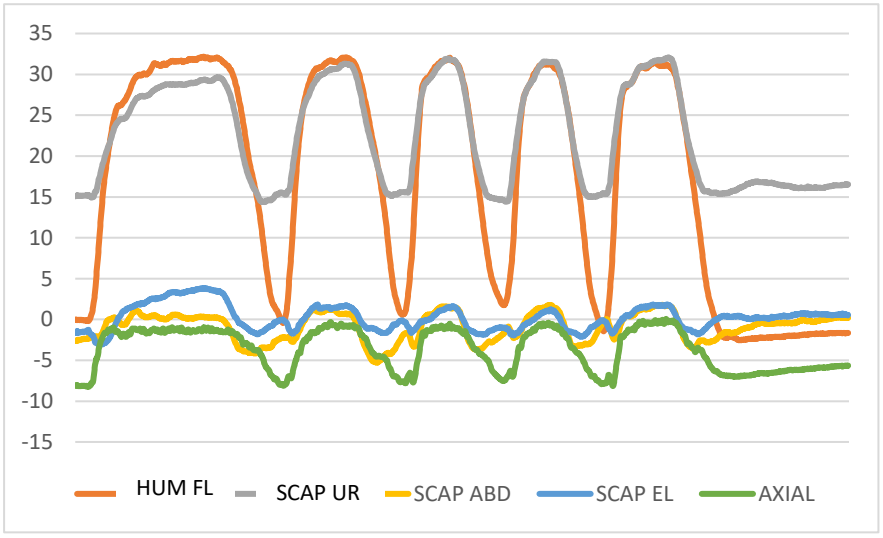
Plot Key:

HUM FL = Glenohumeral Flexion SCAP UR = Scapula Upward Rotation SCAP EL = Scapula Elevation

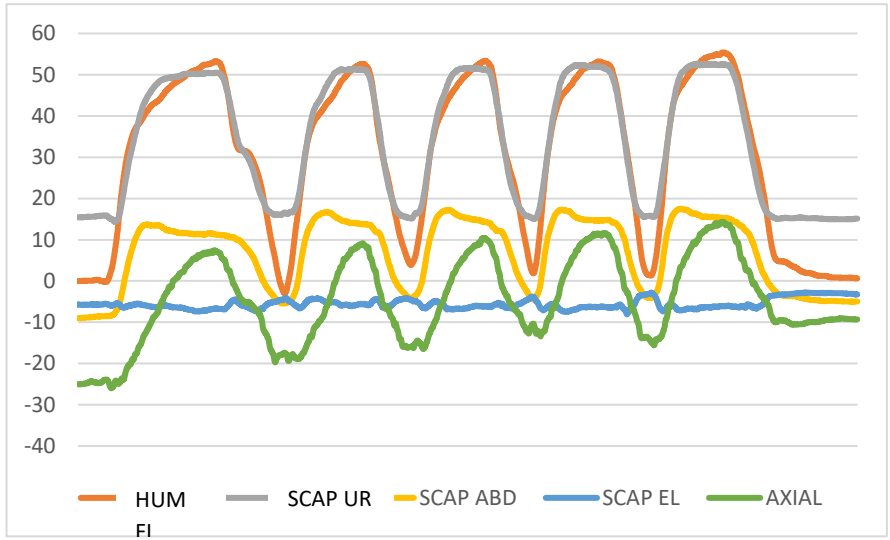
SCAP ABD = Scapula Abduction = positive gradient, Adduction = negative gradient)

AXIAL = Axial rotation (External rotation = negative gradient, Internal rotation = positive gradient)

KIN07 RIGHT (HEMIPARETIC ARM) (x axis: 23.99seconds)



KIN 07 RIGHT (NON – HEMIPARETIC ARM)(x axis: 32.5seconds)



APPENDIX D: 5 x Active Shoulder flexion and lowering cycles in the scapular plane for each case (Chapter 7)

Plots show DEGREES OF MOVEMENT (Y axis) against TIME (millisec)

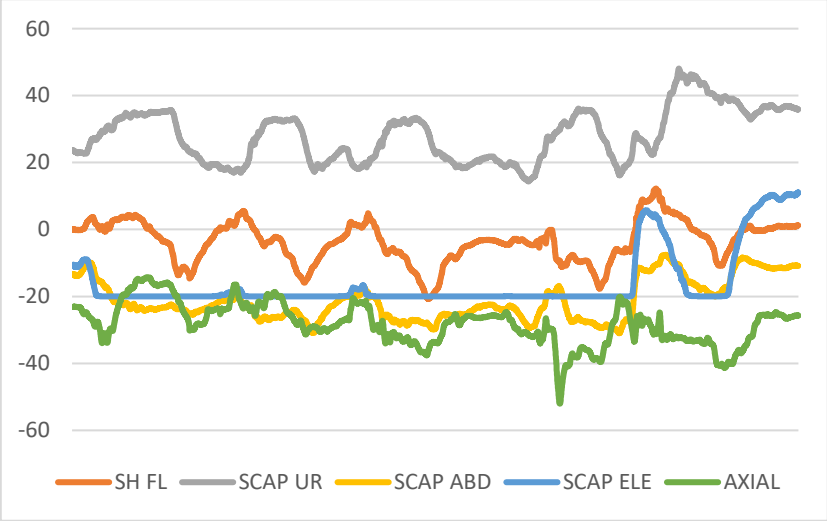
Plot Key:

HUM FL = Glenohumeral Flexion SCAP UR = Scapula Upward Rotation SCAP EL = Scapula Elevation

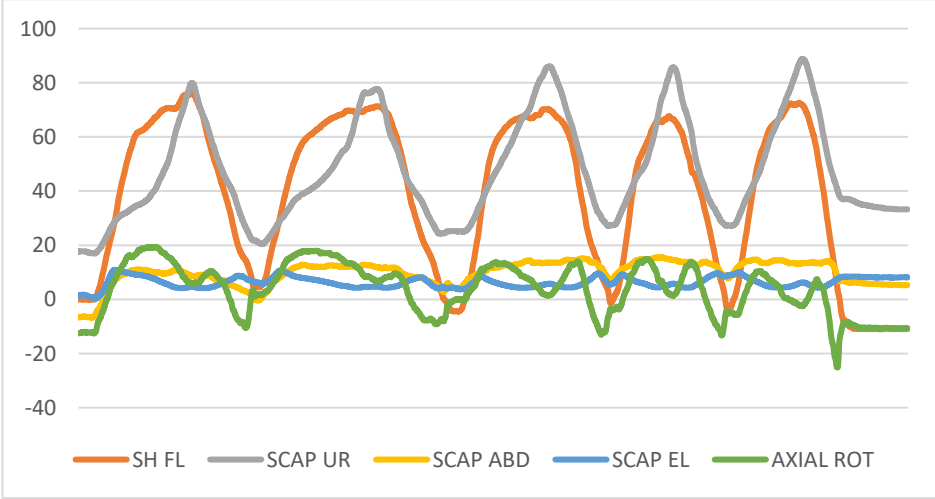
SCAP ABD = Scapula Abduction = positive gradient, Adduction = negative gradient)

AXIAL = Axial rotation (External rotation = negative gradient, Internal rotation = positive gradient)

KIN 08 RIGHT (HEMIPARETIC ARM) (x axis: 51.75 seconds)



KIN 08 LEFT (NON – HEMIPARETIC ARM) (x axis: 46.42 seconds)



APPENDIX D: 5 x Active Shoulder flexion and lowering cycles in the scapular plane for each case (Chapter 7)

Plots show DEGREES OF MOVEMENT (Y axis) against TIME (millisec)

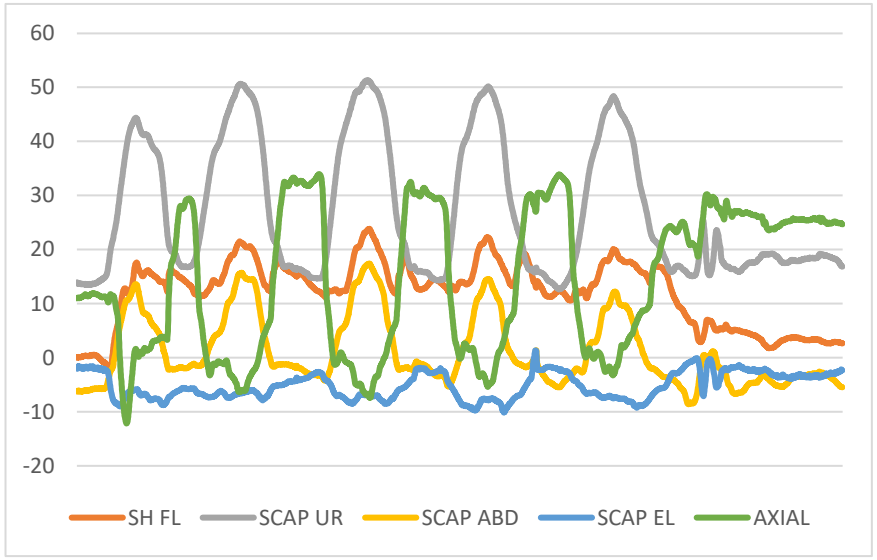
Plot Key:

HUM FL = Glenohumeral Flexion SCAP UR = Scapula Upward Rotation SCAP EL = Scapula Elevation

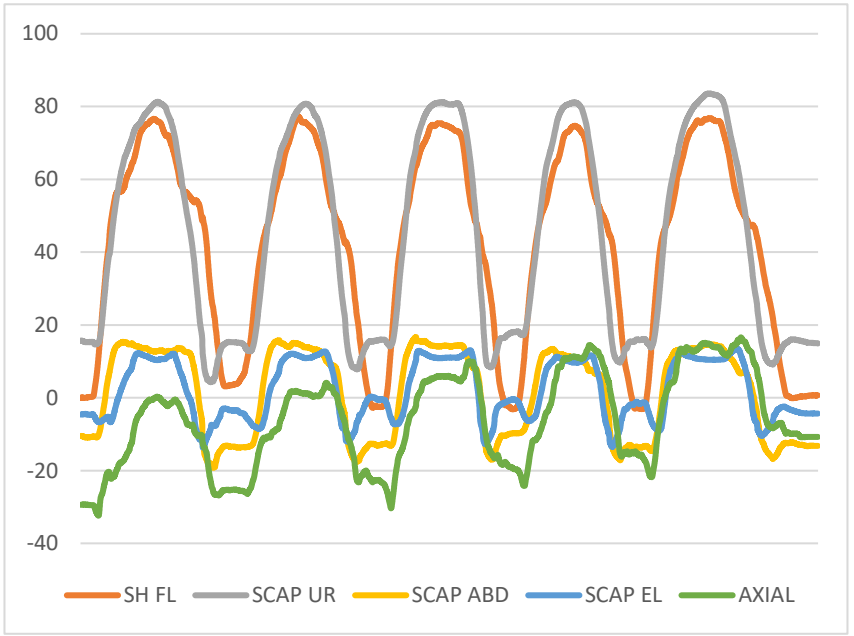
SCAP ABD = Scapula Abduction = positive gradient, Adduction = negative gradient)

AXIAL = Axial rotation (External rotation = negative gradient, Internal rotation = positive gradient)

KIN 09 RIGHT (HEMIPARETIC ARM) (x axis: 33.60 seconds)



KIN 09 (NON – HEMIPARETIC ARM) (x axis: 45.24 seconds)



APPENDIX D: 5 x Active Shoulder flexion and lowering cycles in the scapular plane for each case (Chapter 7)

Plots show DEGREES OF MOVEMENT (Y axis) against TIME (millisec)

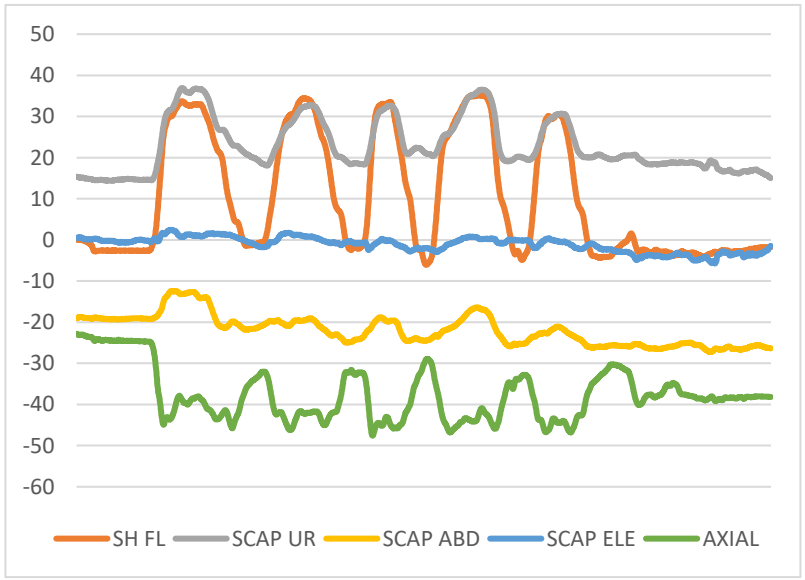
Plot Key:

HUM FL = Glenohumeral Flexion SCAP UR = Scapula Upward Rotation SCAP EL = Scapula Elevation

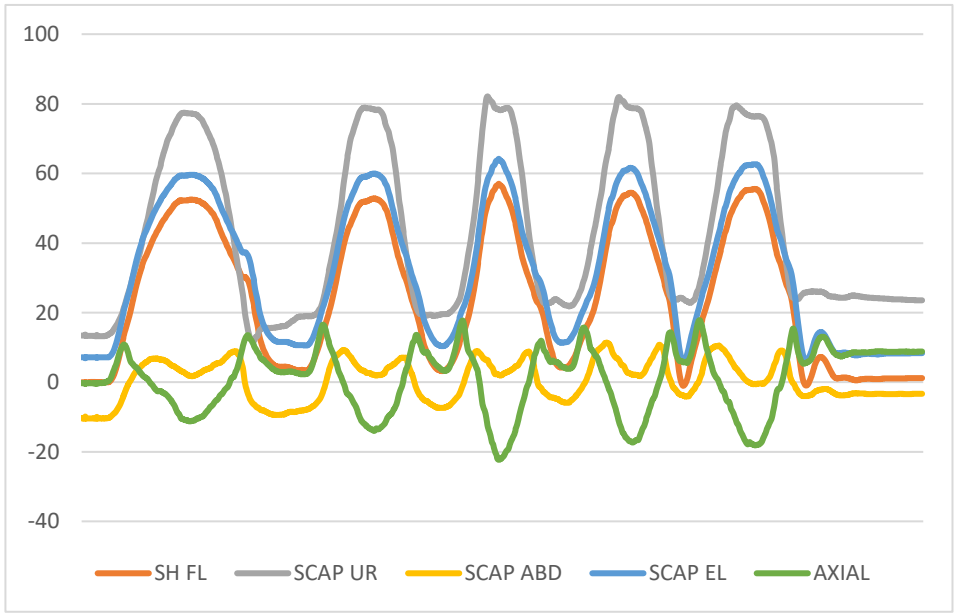
SCAP ABD = Scapula Abduction = positive gradient, Adduction = negative gradient)

AXIAL = Axial rotation (External rotation = negative gradient, Internal rotation = positive gradient)

KIN010 LEFT HEMIPARETIC ARM (x axis: 23.20 seconds)



KIN010 RIGHT (NON-HEMIPARETIC ARM) (x axis: 23.37 seconds)



APPENDIX D: 5 x Active Shoulder flexion and lowering cycles in the scapular plane for each case (Chapter 7)

Plots show DEGREES OF MOVEMENT (Y axis) against TIME (millisec)

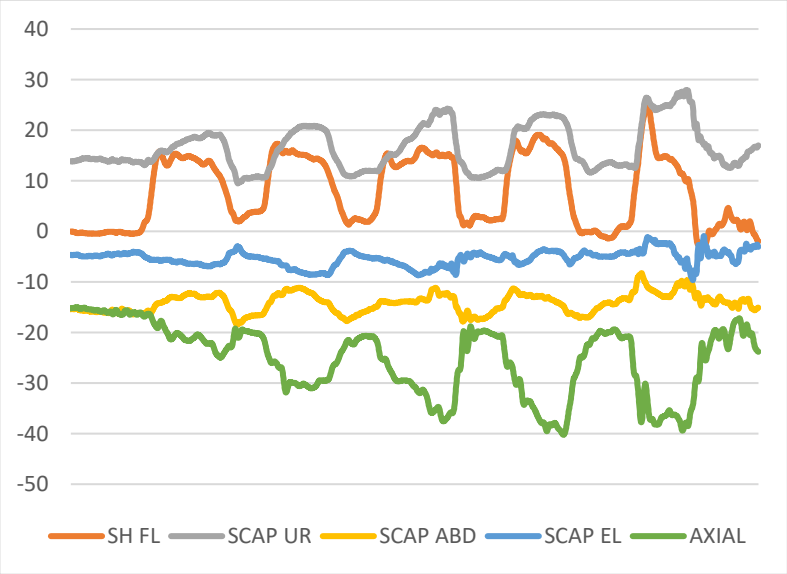
Plot Key:

HUM FL = Glenohumeral Flexion SCAP UR = Scapula Upward Rotation SCAP EL = Scapula Elevation

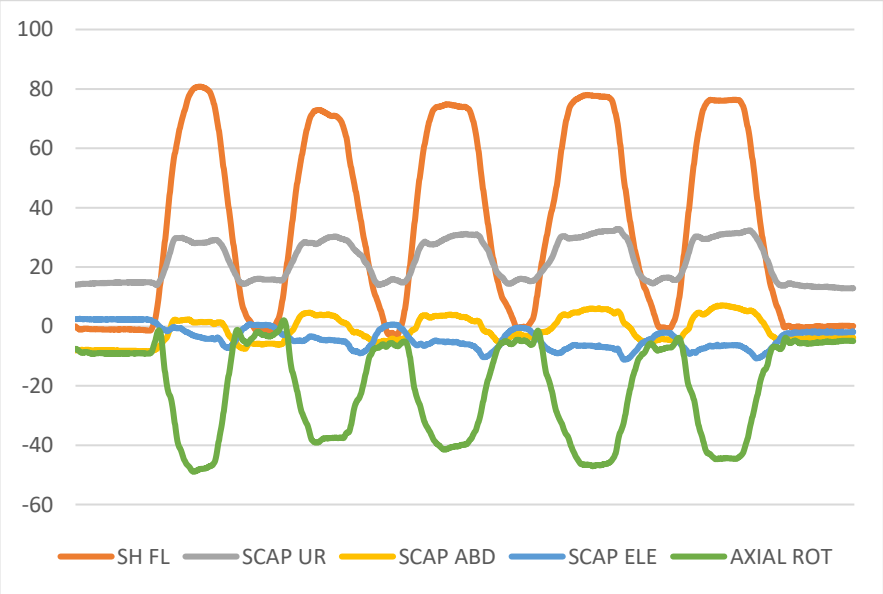
SCAP ABD = Scapula Abduction = positive gradient, Adduction = negative gradient)

AXIAL = Axial rotation (External rotation = negative gradient, Internal rotation = positive gradient)

KIN011 LEFT (HEMIPARETIC ARM) (x axis: 26.79seconds)



KIN011 RIGHT (NON -HEMIPARETIC ARM) (x axis: 21.26seconds)



APPENDIX D: 5 x Active Shoulder flexion and lowering cycles in the scapular plane for each case (Chapter 7)

Plots show DEGREES OF MOVEMENT (Y axis) against TIME (millisec)

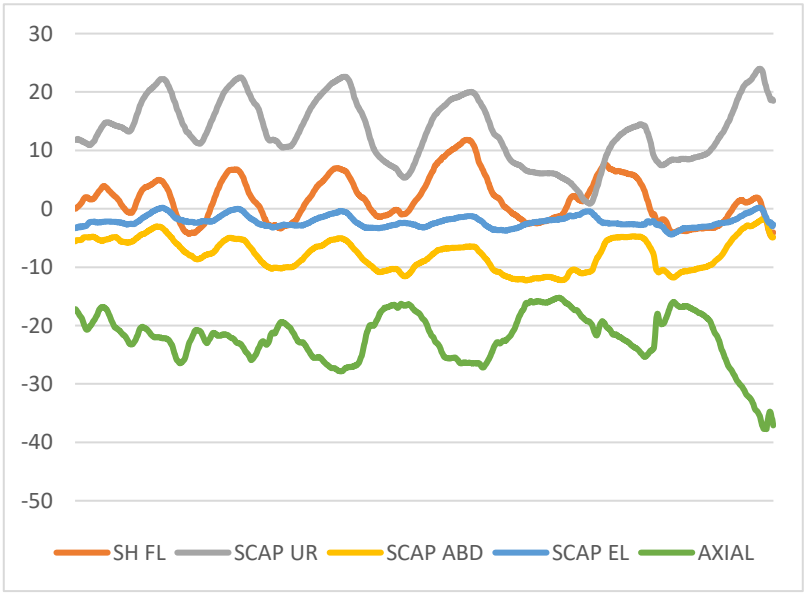
Plot Key:

HUM FL = Glenohumeral Flexion SCAP UR = Scapula Upward Rotation SCAP EL = Scapula Elevation

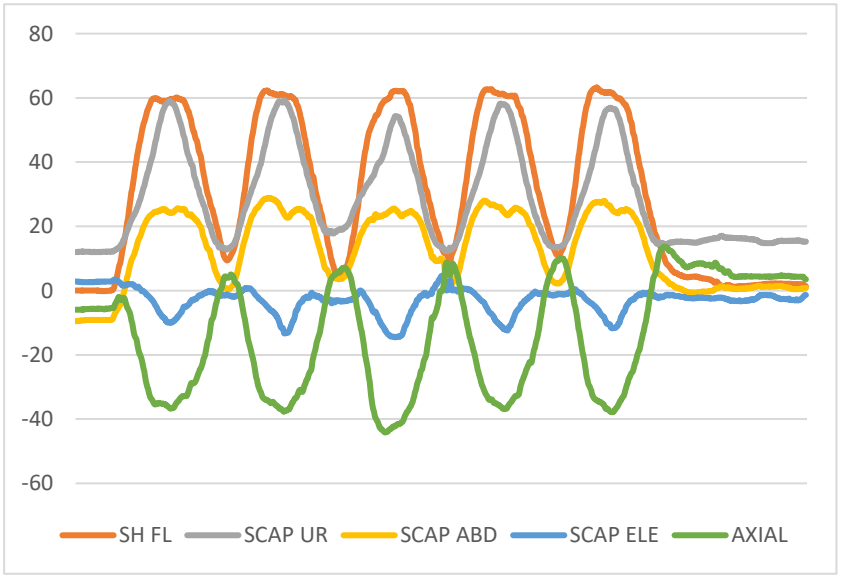
SCAP ABD = Scapula Abduction = positive gradient, Adduction = negative gradient)

AXIAL = Axial rotation (External rotation = negative gradient, Internal rotation = positive gradient)

KIN012 LEFT (HEMIPARETIC ARM) (x axis: 17.21 seconds)



KIN012 RIGHT (NON -HEMIPARETIC ARM) (x axis:17.01 seconds)



APPENDIX E:

Kinetikos System Sensor Performances (Chapter 7):

1) 3-axis accelerometer (scale:± 160 m/s2, noise: 0.002 m/s2/√Hz),

2) 3-axis gyroscope (±2000 deg/s, 0.01 deg/s/√Hz),

3) 3-axis magnetometer (±1.9Gauss, 0.2m Gauss/√Hz) a

4) Barometer (300-1100 mBar10, 0.85 √Pa/ Hz)

Appendix F: Systematic Review search terms (Chapter 5)

The searches were limited to “Human” and “English Language”.

PubMED

("hemiplegic shoulder pain"[MeSH Terms] OR "post-stroke shoulder pain" [All Fields] OR "post-stroke upper limb pain" OR "hemiparetic shoulder pain" AND "botulinum toxin"[All Fields] AND "spasticity"[All Fields]) OR "subluxation"[All Fields] OR (""[All Fields]

AND "early intervention"[All Fields] AND "treatment"[All Fields]) OR "early treatment"[All

Fields]) OR ("early dosage"[MeSH Terms] OR ("importance of early dosage"[All Fields]

AND ""[All Fields] AND " stroke"[All Fields]) OR "cerebrovascular disease "[All Fields]) AND ("upper extremity"[MeSH Terms] OR "arm"[All Fields]) AND "upper limb"[MeSH Terms] OR ("upper limb rehabilitation"[All Fields] OR "botulinum toxin rehabilitation"[All Fields] OR "upper limb spasticity"[All Fields] OR "post-stroke shoulder spasticity"[MeSH Terms]) OR "intractable pain"[MeSH Terms] OR "intramuscular injections"[All Fields] OR "hemiplegia"[All Fields]) AND "botulinum toxin A" [All Fields]) OR "rehabilitation"[MeSH Terms] OR "chronic vs sub-acute intervention"[All Fields] OR "chronic spasticity vs sub-acute spasticity"[All Fields]) AND botulinum toxin[All Fields]) OR (Botox intervention[All Fields] AND stroke duration [All Fields]) OR ("time post stroke importance" [MeSH Terms] OR "botulinum toxin therapy"[All Fields]) OR ("intramuscular injections of BoNT-A"[MeSH Terms] OR "interval between stroke and Botox injection" [All Fields] AND "non-remitting post-stroke shoulder pain" AND "time after stroke"[MeSH Terms] OR "time post-stroke"[All Fields]) OR (Botox treatment[All Fields] AND shoulder spasticity[All Fields]) OR ("botulinum toxin timing"[MeSH Terms] OR "botulinum toxin type A timing"[All Fields]) OR "flaccid hemiplegic shoulder" [All Fields] OR (("flaccid phase of recovery" [MeSH Terms] OR "post-stroke shoulder complication"[All Fields]) AND processing[All Fields]) OR ("early prevention" [MeSH Terms] OR "stroke hemiplegia" [All Fields])) AND "intractable hemiplegic shoulder pain" [All Fields])) AND ("humans"[MeSH Terms] AND English [Lang]).

Appendix F: Systematic Review search terms (Chapter 5)

Science Direct

hemiplegic shoulder pain, *post-stroke shoulder pain*, *hemiplegia*, *shoulder pain*, spasticity*, upper extremity*, *upper limb*, *upper limb spasticity*, *upper limb shoulder pain*, *arm*, *shoulder spasticity*, *stroke*, *cerebrovascular disease*, *chronic hemiplegic shoulder pain*, sub-acute hemiplegic shoulder pain*, *botulinum toxin*, *cerebrovascular disease*, *stroke*, *spasticity*, *botulinum toxin type A*, *Botox*, *early intervention*, *early treatment*, *hemiparetic*, *Botox intervention*, *pain*, *early Botox intervention*, *stroke duration*, *pathophysiology*, *importance of early intervention*, *stroke hemiplegia*, *post-stroke shoulder complications*, *early prevention*, *Complex regional pain syndrome*, *botulinum toxin therapy*, *range of motion*, *chronic stroke patients*, *acute stroke patients*, *Botox injections*, *intramuscular injections*.

Ovid Medline

hemiplegic shoulder pain, *post-stroke shoulder pain*, *hemiplegia*, *shoulder pain*, spasticity*, upper extremity*, *upper limb*, *upper limb spasticity*, *arm*, *shoulder spasticity*, *stroke*, *cerebrovascular disease*, *chronic hemiplegic shoulder pain*, sub-acute hemiplegic shoulder pain*, *botulinum toxin*, *cerebrovascular disease*, *stroke*, *spasticity*, *botulinum toxin type A*, *Botox*, *botox injections*, *early intervention*, *early treatment*, *hemiparetic*, *Botox intervention*, *pain*, *early Botox intervention* and *stroke duration*, *pathophysiology*, *importance of early intervention*, and 3months post-stroke* or 3months*, *complex regional pain syndrome*, *botulinum toxin therapy*, *range of motion*, *chronic stroke patients*, *acute stroke patients*, *intramuscular injections*, *type A botulinum toxins*, *intractable pain*, *refractory shoulder pain*, *spastic hemiplegia*.

Jobseeker

hemiplegic shoulder pain, *post-stroke shoulder pain*, *hemiplegia*, *shoulder pain*, spasticity*, upper extremity*, *upper limb*, *upper limb spasticity*, *arm*, *shoulder spasticity*, *spastic hemiplegia*, *stroke*, *cerebrovascular disease*, *chronic hemiplegic shoulder pain*, sub-acute hemiplegic shoulder pain*, *botulinum toxin*, *cerebrovascular disease*, *stroke*, *spasticity*, *botulinum toxin type A*, *Botox*, *early intervention*, *early treatment*, *hemiparetic*, *Botox intervention*, *pain*, *early Botox intervention*, *stroke duration*, *pathophysiology*, *importance of early intervention*, and 3months post-stroke* or 3months*, *stroke hemiplegia*, *painful shoulder*, *intractable pain*, *refractory shoulder pain*, *recovery*, *rehabilitation*, *post-stroke pain*, *non-remitting post-stroke shoulder pain*, passive range of motion*.

Appendix F: Systematic Review search terms (Chapter 5)

CINAHL

hemiplegic shoulder pain, *post-stroke shoulder pain*, *hemiplegia*, *shoulder pain*, spasticity*, upper extremity*, *intractable pain*, *upper limb*, *upper limb spasticity*, *arm*, *shoulder spasticity*, *stroke*, *cerebrovascular disease*, *chronic hemiplegic shoulder pain*, *spastic hemiplegia*, sub-acute hemiplegic shoulder pain*, *botulinum toxin*, *cerebrovascular disease*, *stroke*, *spasticity*, *botulinum toxin type A*, *Botox*, *early intervention*, *early treatment*, *hemiparetic*, *Botox intervention*, *pain*, *early Botox intervention*, *stroke duration*, *pathophysiology*, *importance of early intervention*, and 3months post-stroke* or 3months*, botulinum toxin injection*, *intractable pain*, *intramuscular injections*, *recovery*, *rehabilitation*, *non-remitting post-stroke shoulder pain*, *range of motion*, *refractory shoulder pain*, *interval between stroke and Botox injection*, *intractable hemiplegic shoulder pain*.

PEDro

hemiplegic shoulder pain, *post-stroke shoulder pain*, *hemiplegia*, *shoulder pain*, *shoulder pain-stroke*, spasticity*, upper extremity*, *upper limb*, *upper limb spasticity*, *arm*, *spastic hemiplegia*, *shoulder spasticity*, *stroke*, *cerebrovascular disease*, *chronic hemiplegic shoulder pain*, sub-acute hemiplegic shoulder pain*, *botulinum toxin*, *cerebrovascular disease*, *stroke*, *post-stroke spasticity*, *botulinum toxin type A*, *Botox*, *early intervention*, *early treatment*, *hemiparetic*, *Botox intervention*, *pain*, *early Botox intervention*, *stroke duration*, *pathophysiology*, *importance of early intervention*, and 3months post-stroke* or 3months*, *botulinum toxin use* and *hemiplegic shoulder pain*, or Botox injections* and *post-stroke shoulder pain*, *intractable hemiplegic shoulder pain*, botulinum toxin injection*, *interval between stroke and Botox injection*.

Appendix G: Tampa Scale of Kinesiophobia (Chapter 8)

QUESTIONS	Strongly disagree	Somewhat disagree	Somewhat agree	Strongly agree
1. I'm afraid I might injure myself if I move my arm (exercise)	1	2	3	4
2. My (shoulder) pain would increase if I try to overcome it with movement	1	2	3	4
3. My body is telling there is something dangerously wrong (when I have pain in my shoulder)	1	2	3	4
4. My pain would probably be relieved if I were to exercise (move my arm)	4	3	2	1
5. My (shoulder) pain isn't taken seriously enough by other people	1	2	3	4
6.My *stroke* (accident) has put my body at risk for rest of life	1	2	3	4
7. Pain always means I have injured my body	1	2	3	4
8. Just because something aggravates my pain does not mean it is dangerous	4	3	2	1
9. I am afraid that I might injure myself accidentally	1	2	3	4
10. The safest thing I can do to prevent my pain from worsening is being careful not to make any unnecessary movements	1	2	3	4
11. I wouldn't have this much pain if there weren't something potentially dangerous going on in body	1	2	3	4
12. Although my condition is painful, I would be better off if I were physically active	4	3	2	1
13. Pain lets me know when to stop moving my arm (exercising) so I don't injure myself	1	2	3	4
14. It's really not safe for a person with a condition like mine to be physically active	1	2	3	4
15. I can't do things normal people do because it is too easy for me to get injured	1	2	3	4
16. Even though something is causing me a lot of pain. I don't think it's actually dangerous	4	3	2	1
17. When in pain, no one should have to move their arm (exercise)	1	2	3	4
Additional questions:				
18. When I feel sad my shoulder pain is worse	1	2	3	4
19. When I feel sad I move my arm less	1	2	3	4

As shown scoring for items 4,8, 12, 16 are reverses. The wording 'accident' has been replaced by stroke in item 6. The wording 'Exercise' has been replaced by move my arm

Appendix H: Interview Participant Preparation and Topic Guide (Chapter 8)

INTERVIEW PREPERATION

- Thanks for talking to me today and offering to take part in this study.
- My name is ****** , title ****** at the University College London, University of London.
- My aim within this interview is to ask you questions relating to the shoulder pain you experienced after your stroke. I am interested in your own views of how you see these things.
- The interview is likely to take about 30 minutes. Please feel free to ask questions at any stage during the interview and there will be opportunity to ask questions at the end of the interview.
- During the interview I will refer to movements of the arm affected by your stroke, which can mean any movement either by yourself or someone assisting
- If there are any questions you do not want to answer or you would like to stop the interview at any time please just let me know. This will not impact your care or future treatment in any way.
- If you have any questions relating to your care, I will liaise with your GP or relevant clinicians to get these answered for you.
- I would like to quickly review the information sheet and consent form that you read and signed prior to agreeing to this interview. Just to remind you that this interview will be audio-recorded. The interview will then be typed out and analysed as part of a PhD project. All participants will be anonymised during the transcription and in the write up of the project and no identifiable information will be used.
- If you would like, I can send you a summary of the research findings on completion of the study if you are happy to provide your address or email address for me to send this to you.
- I have a list of topics that I want to talk about but please remember there are no correct answers and I am just interested in your views and opinions.
- Do you have any questions before we start the interview?
- Are you still happy to take part in the interview?

Appendix I: INTERVIEW GUIDE: Based on The Theory of Planned Behaviour (Azjen, 2013*): Defined Behaviour: Moving the painful arm regularly either via exercise, functional activity or passive movement by a carer/therapist* (Chapter 8)

Consequences of behaviour (behavioural beliefs)

1) What do you think are the disadvantages of moving your painful shoulder?(Prompt) How do you think movement will affect your shoulder or your pain? (Prompt) What makes you think this?

2)What do you see as the advantages of moving your painful arm? (Prompt) What makes you think this?

3) What else comes to mind when you think about moving your painful shoulder?

Beliefs about the normative expectations of others (normative beliefs) – perceived social pressures

4) Was there any specific advice, information or treatments you received from health care professionals that affected how much you moved your painful arm?(Prompt)Were you prescribed any shoulder supports or adjuncts? Did this affect how much you moved your arm?

5) Have the opinions of family or friends influenced how much you move your painful shoulder and how you manage the pain? (Prompt) Can you give me examples?

6) Who or what has influenced you the most in how much you move your shoulder and manage the pain?

Beliefs about the presence of factors that may facilitate or impede performance of the behaviours (control beliefs)

7) Can you describe what would help you to move your painful shoulder more?

8) What do feel has got in the way of you moving your painful shoulder regularly? (Prompt) How well supported were you with pain relief and advice?

9) How could services be improved to help you manage your shoulder pain better and move your affected arm more?

Self-discrepancy (Effects of what you feel you should be doing compared to what you are doing)

10) Do you think that you are moving your affected arm an ideal amount to help it recover? (Prompt) Can you explain why you feel this?

Appendix J: Full Theme and Subtheme content (Chapter 8)

Question A: What has influenced fear of hemiplegic arm movement?

Theme 1A INTERPRETATION OF SYMPTOMS

Sub theme	Participant Quote
1.1A Previous experiences of moving arm unpleasant	MoV020 Yeah, because of the pain, yes. And because of the pain sometimes I'm scared to do exercise, I'm telling you the truth. MoV003 Well because it's painful, you think if you move it in a certain way it will hurt you. MoV030 when I do move it, it makes it more pain. I feel more pain when I move it. MoV026 It's painful and I'm not trying to move it. To move it it's so painful, so I can't use it -- Mov019 The pain has got worse and since going to this gym….And that makes me feel I'm not sure about it. MoV001 Actually it's not comfortable. If I need to move my arm, it's uncomfortable, painful. MoV015 It's a severe disincentive to exercise when it is so painful. MoV024 But it was the pain that stopped me, it was the, the initial pain, the pain was just horrible, it was that, and then once you stop using something, it's like anything, isn't it? You just ignore it and you think well I can get away with it, so, yeah.
1.2A Pain as cue to stop moving arm	MoV021 because every time you hit the pain barrier you think, oh gosh, now it's time to stop now. And some participants felt this message was reinforced by therapists MoV021Well they said, if you're in pain stop, so that was definitely a message that came through. MoV014 They said don't, I've always been told when it gets painful stop. MoV024 Well they say that you've obviously overdone it, you need to like rest, this is your body telling you, isn't it?
1.3A Pain equals Damage	MoV032 I'm just, because it's painful, so you're worried about moving it in the first place…..because you never know what is in there that would, you might strain a muscle or something. Yeah, because it's very weak and very painful….Well I think, probably, maybe the muscle down there is damaged or something.

	MoV021 Well it worries me a little bit, sometimes if it's painful that I'm not going to do more harm than good if I carry on doing exercise. MoV019 I can feel, it gets to this point and it's like, and she said, do it, go some more, and I'm terrified because I don't want to break it. It just doesn't want to go any further. MoV038 I don't stretch it beyond a certain point as I'm concerned it will cause harm MoV030 when we're out walking or I'm moving against anything it, it come in my thoughts like supposing I hurt my arm because I'm on a blood thinner, it always come in my thought that, if I hurt my arm it will be very serious so (inaudible) it's really, it come in my thoughts that if I hurt my arm it will be serious. MoV026. When I move it, it's causing a lot of damage to it because it's so painful MoV014 There's probably a little bit of muscle damage isn't there? MoV024 Well I, what I'm thinking's going on, I feel like it's, it's going to sort of tear it, it goes into a spasm, so I feel it's going to, it's tearing something in my shoulder, and it makes me think, oh should I really be doing that? …Yes, yeah, you're yeah, you're frightened you're damaging it, but because you don't know enough about it. This fear of damage had sometimes been driven by information given by health care workers Mov011 Well they told me you've got to be careful that your arm doesn't come out of the socket because I'll have to have an operation. Mov023 Because there's obviously something not right there and that's when they diagnosed a shoulder tear of the muscle. And that's when, we then obviously then do the procedure of the consultant, orthopaedic came, and then we do the operation or we don't.
1.4A Clicks ,Clunks and swelling	MoV020 if I sit down for a while, I try to raise it up, I will get like a crack on my shoulder that, you know, something that is dislocated and it wants to go back, like, yeah. A big crack --Yeah, then I stop because of how I just feel like, oh my God, it maybe is, it's breaking off.., My elbow is like pushed in and my shoulder is, there's a bit of, it's always cracking (imitates noise) I don't know if it's, it's not dislocated but there is something that is, there is a place that is open. MoV019 So I know that when it's feeling clunky, feeling like it's stretched too far, stretches a bit and then it gives way, so then you

	have an idea that, oh well it's, I've either gone into a place where that feels better or is this a step too far This is also accompanied by some participants of a feeling of instability in the shoulder MoV030 All, because sometimes when I lift the arm I can hear the joints, like it just, it go 'cuck',so like, you know, something just popped, it feel like….. yeah, sometimes worries me.it feel like it's about to be separated from the shoulder, you know? MoV019 As difficult as it was and I sometimes had to use my right hand to support my left arm, *to raise it up*, and that wasn't painful going up, it's only when it comes down and there's a click and it hurts MoV038 I feels like it's clicking out of place, It does click in and out… It does worry me that it will move too far and then I won't get it back, it does click it in and out Others expressed feelings of swelling and tightness Mov024 I feel it's like inflamed, sort of angry, you know when you've got something that's like a swollen ankle? I feel my shoulders like that really, and it's, that's how I feel about it. Mov026 Yeah, there's swelling. When I move it too much the hand will be swollen. My hand will be swollen *like* this. It will be swollen here when I move it too much
1.5 An Unanswered questions and fragments of terminology	MoV010 Some days just think only why? Why I still have *that* pain? Mov015 What I'm thinking about is why is it that that movement causes pain. I'm not an expert on how the body works. It makes me wonder, but I don't have an answer to that.. It does make me wonder why a stroke which is I guess a mental thing, it's affecting the brain, why should that manifest itself in pain in my shoulder? MoV023 We don't know if it's because, is it the scapula which is not working and not pulling the muscle at the back, or is it because the contraction of the front, to the pectoralis is keeping the thing in position. We've got no idea because I can't believe that supraspinatus is the cause of this, there's something else going on in the whole economy. So, we don't know what the neurological component, what the tendon component or the capsule of the shoulder, what the scapula plays. We've got no idea, nobody has ever, and we always concentrated on the walking because we think that's what we need MoV016 Well, I thought it was somewhat dislocated but I've been in front of physiotherapists, they talk about sublux and things like that, and when I've asked what that means they say, well it's sort of semi

	dislocated and they explain that the muscle surrounding the ball joint has sort of let go of the ball joint and now it's going to have to get back in. MoV024 Again I think, knowing the severity of the shoulder, I for one would have liked to have thought they was, they'd conducted a scan, to have a look at it, to see what was causing the, what's the root cause of this?

Appendix J: Full Theme and Subtheme content (Chapter 8)

Question A: What has influenced fear of hemiplegic arm movement?

Theme 2A PECEIVED POOR SHOULDER MANAGEMENT

Subtheme	Participant Quote
2.1A Lack of Specific advice about the shoulder when pain developed	Mov024 But regarding the shoulder, it was sort of disregarded, it was oh, it's a frozen shoulder, it's nothing to do with what we're treating. And the longer it went on, I think the longer it seized up, and the more it seized Mov021 but it hasn't a specific, they wouldn't have any specific advice about when it hurts do you stop, what do you do? I don't think they would get into that level of detail really. Mov021I guess not knowing which exercises to focus on is probably the biggest one. And I've got a tonne of exercises that I've done that we've written down, but I'm not, I wouldn't 100% know which ones to focus on now. Exactly, so it's like if someone could just tell me, look, here's five exercises, do these four times a day, and this should help, and if not we'll review it in a week, we'll try something else or move it on. Mov032 Yeah, when I first had my stroke early on, there was not a lot of advice given how I should move my arm. Even after today I have not been told how I should move my arm Mov020 The only thing , he said to me, try to do exercise sometimes with the arm. Just doing exercise, wiggling it around or try to raise it up and down, something like that. Mov016 No, I've had, I've been, I've spent three months in the (name removed). 12 weeks, or 11 weeks, of physio in the local community and that was two, three, four times a week for 12 to 11 weeks. So that was good, but they didn't understand what was wrong with me. They didn't understand the shoulder thing. Mov019 But, and I, because I, you say you're worried about your shoulder, more recently you're worried about your shoulder and you will actually verbalise that and say, I'm really worried about this. And yet the physio side of things is still getting you doing press ups and rowing machines and all sorts of other stuff, so from that point of view, you're left as a family and a support and for Pam, you're thinking, well hold on, somebody slow this up and look at this in a little bit more detail. Mov005. But if your arm is painful your physio sessions are not, what you call, are not well managed Mov006 They could have been trying to do something instead of just leaving it, if that makes any sense.

	Mov015 But then when it came to it the physiotherapist who I saw at that time said that I should just wait for it to get better of its own accord. So I think maybe more could have been done at that stage. Mov004 I would have liked, probably more advice on how to manage shoulder pain, yeah. Lack of prognostic and diagnostic clarity Mov016 but everybody's a bit vague about the return for the amount of effort and pain that you endure, how long do you have to endure it for? Is it just a week? Is it two weeks? Two months? Mov023 Torn, but not detached completely therefore he said, we could intervene and repair it but that would mean then your shoulder is going to be blocked for three months, or something like that, which is going to hinder and delay your recovery. At that stage it was not really much to recover to be able to talk about. But so, and also he said, because it's not completely detached, let's see and wait. But there was no follow up on that, in terms of let's do another scan see how bad it is
2.2A Poor Handling and incorrect advice	Mov023 Because of careless nursing care, I was, my mechanical handling was, where the muscle was torn, I tend to protect it and guard against anything happening towards it. Mov015 The physiotherapist did say, did give me exercises to do. And and I'v trying to think of the correct word for it, a think that fits over the top of the door A pulley, that's the word, a pulley. And I have used the pulley and I do still use Mov032 Yeah, they, yeah, subluxation, they were very concerned I might get that, so they were quite keen to make me wear this sling the whole time, which I did do
2.3A Perceived ineffectiveness of shoulder supports	Mov015 Because it didn't really seem to have any overall beneficial effect a restrictive. When I was out walking for example it got quite painful around my neck just wi my arm hanging around my neck. Mov008 To be honest the support didn't actually help, no, because I found it rather bulky, the shoulder support thing I had. So it didn't actually do much for me. So hence it just actually got worse for me when I wore it
2.4A Uncertainty about analgesia	Mov015 Actually an alternative that was offered was the ibuprofen gel, which I was rubbing onto my shoulder. But again it didn't really seem to make any difference. Mov016 I started taking painkillers. Nothing too serious, paracetamol and nothing much stronger than that, *Neurofen* and things like that, but they didn't really help that much to be honest.

	Mov006 I have codeine and if it gets really bad then I'll take the codeine, but apart from that I try to brave it out. Mov014 I was on tramadol, they stopped that and I started gabapentin. So I probably had pain when I had the tramadol but I didn't probably notice it. But now with the gabapentin I'm taking probably a little bit less and I don't know if it's enough. Because mum's taking two tablets, I'm taking one tablet each time. So is that enough? Mov024 No, he gave me the Co-codamol and I, I just thought, I was tired, so I *don't want this*, well it's knocking me out. And then I, I was too tired to do any sort of exercising, like trying to walk, just to make my legs stronger, etc. So, and then I just thought oh, I'll take paracetamols. Mov030 I'm not a person who is a fan of pain medication because I know it constipate you and I don't like pain medication so if I have, if I have pain I would rather to go to bed and lie down and sleep, try to sleep off the pain. Mov032 Yeah, I've been given paracetamol but I'm not sure if it was for my arm. I think it was for the general pain that I was getting in my body.

Themes for Question B: What factors other than fear have influenced reduced affected arm movement? (Chapter 8)

Theme 1B REDUNDANT APPENDAGE

Subtheme	Quotes in each subtheme
Subtheme 1.1B Arm Ignored in rehab	Driven by service: MoV030 Not a lot of effort had been put on my arm anyway apart from somebody checking it. No, no, I don't get no treatment for the shoulder. MoV014 Yeah, because the (hospital name removed) never really worked on the arm as much. They were always leg working orientation. So, get you out of hospital… So they done, I think it was three hours a week on lower limb and an hour and a half on upper limb a week, which is nothing really is it? MoV020 The main focus is always, just to get you up and going, that's it MoV024 Like my personal feelings are there wasn't enough done at the star (for the arm), it was a neglected part MoV025 My national health six week care did not concentrate on the arm, they concentrated on the leg… Well it's more leg because they say you will get better and leg takes priority over arm, but I don't think that that's the case. I didn't have this pain before the stroke, I didn't have the pain following the stroke for three months, it started afterwards. So it could be the joint wasn't moved, the arm wasn't moved and that caused it MoV008 OK, first of all I think what they should have done, when someone has a stroke first of all, is not leave you there for ages without movement. Well that's what happens. You sit there for weeks on end without any kind of movement because it hurts from the beginning, well mine did. And I think, had I been encouraged to move from day, second day even, it might have been a bit better. MoV032 The amount of attention that was spent on my arm was not much. It was only my leg that they, walking that was their interesting initially. Getting out of bed, walking, that was what it is. Because they actually gave me some walking stick to walk and that stopped that you roll, that was the interest initially. MoV006 my physiotherapist turned round and told me that, oh, there's nothing that we can do about your arm because it hasn't made any improvement. We would have expected it to make improvements by now. And that really discouraged me MOV006 I've had a doctor turn round and say to me, oh, there's nothing we can do for your arm. You will never get movement back in your arm, and I burst into tears, to be honest. And stroke survivors MoV030 I would say that it was 75% more on the walking because I was, I couldn't walk at all. I couldn't bear the thought of somebody, to have to tell somebody that I need to use the toilet. I couldn't, I couldn't cope with that one (inaudible) so when

	I went in they asked what would I like to be done and I'm specific telling that I would like to walk again. MoV023 But also I think it's the fact that, and I may have played the role as well, is that the shoulder has always been considered a second problem, a second position problem. The walking was the main thing, because obviously the walking is relevant for going to the toilet, going out or walking, going to the gym. So the walking was the primary aim, we need to get him to walk, we need to get him to walk. And the shoulder has been left on the side
Subtheme 1.2B: No observed recovery	MoV011 I just cannot move it at the moment. I can't move it at all, I have to use this arm to lift it up. MoV014 I know it's just not working. There's no muscle there for it work properly, so need to build the muscle back up somehow. MoV030 I couldn't move it, the hand, none at all, when I leave the hospital. I couldn't lift the arm and put the hand to my mouth, I can put it at my forehead, I can put it on top of my head…outside of my body was dead and I couldn't, my foot, my left foot and my hand, none of it they could move, none at all. MoV020 well obviously I cannot move it, so the disadvantage is that I cannot use it for anything. I can't do anything with it, with my arm obviously Mov023 No, I mean I still, I still couldn't punch my way out of a wet paper bag, so ... Lack ability to use in function Mov016 Yeah, because when I'm eating at the table, my left arm will just be hanging down by the side of the chair and when she comes to the table she (inaudible) *says, come on* raise your arm. So, my arm just sits redundant on the side of the plate Mov032Yeah, I do try but I just realised that I was trying to serve the food and when I actually picked up food in my left hand, which is very weak, it just came straight on the floor. Mov023 But I think there is also another component here which is at the moment Nick is not really independent at all and that's because he needs the left arm to carry the stick. The right arm, it's useless because it cannot carry a cup of coffee, even if it is a can which is – Mov011 The worst thing is when I get on my, what's it called, remover? What's it called Brian? The red thing (inaudible) the turner. I manage to hold on now but as I let go and sit down the worst thing is when my hand just flops. And that is horrible when it flops and I've no control over it.

Subtheme 1.3B: Learnt Non Use	Mov024 You will always try and always use your stronger arm.You don't even think to use that arm. Mov021 I know it's probably an aspiration, a goal, try and lift the cup to my mouth, but if you end up looking like a demented, like I say, a ten year old, you're not going to put yourself in that position

Theme 2B NEGATIVE INFLUENCES ON SELF EFFICACY TO MOVE THE ARM

Subtheme	Quotes in each Subtheme
2.1B Possible External Locus of Health Control	MoV001 I don't know how I can get it to move. It's got to be some kind of treatment. This injection I'm having now in my shoulder too, yeah. I hope, I'm waiting for it. I think that would help me to move my arm as well, that injection, yeah…. Because the doctor, he promised me. He said within three week you will be fine. I hope so, yeah. MoV014 I've felt that I haven't had the help to move it... it painful at the moment. Mov038 I can't physically move my arm, so I don't think about moving my arm because I can't, I'm limited by how much support I'm getting to get it moving
2.2B Lack of Self management strategies	Mov026 Once in a week it doesn't even work to me. It doesn't work unless if somebody's coming and they say, OK, this is what you have to be doing for the rest of the week. It doesn't work like that Mov021 But they didn't, I don't know if they gave me advice apart from when I was actually with the OT person. There wasn't much advice, what to do outside of the session. Mov032 Yeah, when I first had my stroke early on, there was not a lot of advice given how I should move my arm. Even after today I have not been told how should I move my arm
2.3B Exercise perceived as boring or ineffective	Mov021 I know they're trying to get the pathways to reignite, or etc, etc, but when you spend an hour trying to do it and you think, God, this is going nowhere, what is the point of this? And I'm sure there is a point, but it's, it didn't feel very productive to be honest…..I used to dread occupational therapy just because it was, I knew it was good for me, I knew they were trying to do the right thing, but I got to a mental block after a while, it was like, oh my God, another hour of … cones. Mov024 They are boring, these exercises, yeah,

	Mov015 I think the negative aspect of it is that these exercises don't really seem to have any positive effect.
2.4B Social Persuasion factors	Mov014 But I live on my own most of the time so I've probably got a bit unmotivated, which, my mum comes up say every month or so for ten days. Mov014 My blood pressure was still a bit high and he was worried about that so…. And the first words that the doctor said was, you've got to rest. So what do you do?My doctor told me to rest so I'm going to rest. Mov023 I'm nagged, being nagged is the story of my life Mov016 when the family get around, my wife, my kids and they say, did you do the exercise today? No. And then, come on dad, you've got to do it, you've got to do it. Then it turns into a bit of a nag.
2.5B Arm movement behaviour vulnerable to low mood or environmental change	Mov016 There's lots of bad days, so you neglect or decide not to do the exercises you planned to do the night before… I''ve not been doing a great deal, to be perfectly honest. Probably about 10% or 15% of what they would normally expect me to do. Mov024I think when I had this it just sort of was like gosh, I can't do anything, so the, I think it was a bit of depression as well, maybe, so Mov002 in the winter I haven't moved it enough, anywhere near enough. Because it's cold and you just want to wrap up warm and go to sleep, basically MoV002 Yeah, yeah, yeah. I tend, you tend not, I tend to do things that I think I can do. Oh, if there's something there that I think, well, I'm not going to be doing, I won't try it. When sometimes you possibly should. But you think, oh, I just can't, I won't try it. Like, I don't know, say there's an orange and I want to peel an orange. One day I'll peel, I'll think, yeah, I'll do that, but another day I'll think, I can't just do it, I just can't do it. And you just leave it there. So it's just, it just depends on your, the way your mind's going at the time MoV007 Carer Yeah, I do feel like her self doubt gets in the way a lot. She thinks, oh, I can't do this, she gets really frustrated

Theme 3B The demotivating transition from acute care to community living (Chapter 8)

Subtheme	Quotes in each Subtheme
3.1B New Disability Identity and adjusting to new life at home	Mov026 yes because I, I'm disabled. I'm not really mobile and able to do what I normally do. So yes, I strongly agree that it, my body is at risk. Yes, I can't wash plates. I can't do anything in the sink. I can't bath on my own. Mov032 When you are still in the hospital you are fine, your brain doesn't go spinning around as well but when you go home is when you, then you're in the real world. You need to do certain things but if your hand doesn't, you've got, sort adapt it, you'll, doesn't allow you to even lift something. Take something from the fridge, put it outside or make a cup of tea. That is when your life is completely finished off. There's certain thing that you always, you feel like you would, when you go home you feel like you're going back to your normal life as it used to be, but that is not the case MoV016 . So, we did, we went to places, went on holidays with very little notice and I owned a house, well I still own it technically. It's in the process of being sold, but we have a house in France. We go to the house in France and spend time and now it's all just changed completely, in a heartbeat, virtually. My life has been turned upside down. Yes, I've been considering suicide on more than one occasion. I'm joking, but not joking here. There was a fear at one point that if you put your hand up and say I'm feeling, that you could end up being sectioned, because that happens MoV038 My role as a grandmother; I've always been able to pacify my grandchild babies; by putting them on my shoulder; that's what really upset me. If I could use my arm properly I could have helped her. I could sing to her but I couldn't pat her back MoV023 what you need to understand is with stroke patients with certain, certainly from my experience the first concept of a stroke is total bewilderment. You know what you were before your stroke, you know what you were doing right up to the moment of your stroke, but beyond the stroke, once I, I can remember being taken out on the stretcher and throwing up in the back of the ambulance and that's it.

Subtheme 3.2B Feeling Abandoned by community services	Mov015 There was a gap actually. If I remember rightly it took quite a long time till the community therapist actually made contact didn't it? Carer: Yeah. Yeah. Well we thought it was going to happen as soon as you came out of hospital, but it was about three or four weeks before they came MoV038 When I first came home, I came out with so much enthusiasm and I felt like I was abandoned. I didn't hear from anyone for 17 weeks before I received any care in the community.// I did get down and tearful. They had spent all that money on my recovery and then it all stopped. I got lost in the system Mov025 since I went to the hospital, I did not speak to a professional about a stroke. The physiotherapist came to me, the occupational health came, but they didn't tell me or they didn't show me how I was improving. The only thing I had a six month interview, six month assessment. And in those six months, the lady who was supposed to come and check me out, did not come and check me out. And I did not get, there was no advice from anyone Mov032 Everything that I was told was going to happen when I leave the hospital, nothing happened….Everything that I was told was going to happen, never happened. Mov026. Yeah, they come for the assessment one day, second day that's all. They just come briefly. They don't, they are too overloaded, that's what I think Mov023 the further you get away from the critical care, the further you go into community care, the more ineffective you get, you find that generally what people are doing is just basically polishing their pensions, they're not particularly effective… , there is no long term care for these patients, and that's what is lacking. And this is where the shoulder has got lost. Mov014 it was a waste of time for what they've been doing,Electrical stimulation. They literally come in in the morning, put two bags on, 20 minutes they work out, they look at the (inaudible) clock -- And they're gone….And then my arm's on the chair then literally after that they make me bend my wrist back up. But then we only try to do that ten times and they're gone.
3.3B: Hidden Impairments in Stroke impacting	MoV024 one thing that's been noticeably changed since the stroke is the, the attention span to be doing something, you get bored more quickly, don't you?

on retaining information and fatigue	Mov021 I think probably someone did try to explain it, but again my ability to retain information at that time was a bit suspect. MoV024 I went into a phased return to work. And they said oh, start on three and then do four the next week. And at the end of the first week I just burst into tears, and I'm like yes, I'm so tired.