Proprioception and Unilateral Neglect after Stroke

by

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Doctor of Philosophy, Physiotherapy

under the supervision of

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This is to certify that the thesis entitled **"Proprioception in Unilateral Neglect after Stroke"** submitted by **Georgia Fisher** in fulfilment of the requirements for the degree of Doctor of Philosophy (Physiotherapy) is in a form ready for examination.

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I, Georgia Fisher declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, Physiotherapy, in the Graduate School of Health at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Abstract

Unilateral neglect and proprioceptive impairment are two common sequelae of stroke with negative impacts on functional recovery. Unilateral neglect and proprioception impairment are linked through their shared involvement in sensorimotor integration, particularly of the upper limb, which has received little attention previously resulting in significant gaps between evidence-based best practice and usual clinical practice (evidence-practice gap). These are exacerbated by similar, and separate evidence-practice gaps in clinical assessment of unilateral neglect and proprioception impairment. Hence, addressing the current issues with assessment of unilateral neglect and proprioception impairment is a critical first step in this area and is the overall aim of this thesis.

Although there are systematic reviews specific to assessment and treatment of unilateral neglect and proprioception impairment separately, previous to this thesis none had examined the link between the two. Thus, the first study (Chapter 3) of this thesis is a systematic review, which found that people with unilateral neglect after stroke have more frequent and severe proprioception impairment than those without. Furthermore, the studies included in the review used various outcome measures of both unilateral neglect and proprioception that were often not comprehensive. Previous research had indicated a large evidence-practice gap for the assessment of proprioception, however, proprioception assessment in clinical stroke rehabilitation had not been described in detail.

To address this, the second study (Chapter 4) was a survey of clinicians in stroke rehabilitation about their knowledge and practical application of proprioception impairment assessments. These results showed significant clinician knowledge gaps, and mixed ability to identify signs of proprioception impairment in clinical practice. The study also showed that most clinicians use an unstandardised position matching task to assess proprioception impairment, which was likely due to the limited functional relevance and poor ability to detect change of current clinical assessments. Given that clinical position matching assessment was unstandardised, proprioceptive impairment was not quantified and, subsequently, not correlated to

other upper limb impairments or to the presence of unilateral neglect. Therefore, the next study of this thesis (Chapter 5) was a cross-sectional investigation of proprioception and other upper limb impairments in people with stroke that aimed to quantify clinical position matching assessment and correlate it with upper limb function. Chapter 5 found no significant relationship between quantified clinical position-matching assessment and upper limb impairments in people with stroke, along with a high inter-person and intra-person variability in position matching ability after stroke.

In line with the findings about unilateral neglect assessment in Chapter 3, there were previously reported inconsistencies in the type and comprehensiveness of unilateral neglect assessment used in clinical stroke rehabilitation. However, the reasons for this were unknown. Therefore, the aim of the final study of this thesis (Chapter 6) was to identify determinants of clinician's selection and use of unilateral neglect assessment, and to explore the reasons for the current evidence-practice gap. Chapter 6 had a mixed-methods design including clinician focus groups and clinical notes audit, and found different barriers and facilitators to the use of clinical assessments of neglect between the hospital and community settings. Additionally, implementation of unilateral neglect assessment was influenced by specific behavioural determinants, including clinician knowledge, healthcare system role delineation, and implementation setting.

Collectively, the findings of this thesis provided preliminary evidence on the relationship between unilateral neglect and proprioceptive impairment, and the importance of its consideration in clinical assessment. Furthermore, this thesis' findings provided insights on the factors that explain the evidence-practice gap separate to the clinical assessment of unilateral neglect and proprioceptive impairment. These included a lack of clinician knowledge of both impairments, multiple barriers to implementation of unilateral neglect assessment in clinical practice, and a poor clinical utility of current proprioception assessment tools in practice. Each of these are important areas for further research to facilitate the translation of evidence-based clinical assessment of unilateral neglect and proprioception impairment into practice. Once research of this nature is completed, clinical assessment of the relationship of unilateral neglect and proprioception impairment can commence, which would further improve the rehabilitation outcomes of people with these impairments after stroke.

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List of Abbreviations

AHPRA: Australian Health Practitioners Regulation Agency

AXIS: Appraisal Tool for Cross-Sectional Studies

CBS: Catherine Bergego Scale

CT: Computed Tomography

DENA: Dublin Extrapersonal Neglect Assessment

EmNSA: Erasmus modifications to the Nottingham Sensory Assessment

IMU: Inertial Measurement Unit

GCS: Glasgow Coma Scale

HREC: Human Research Ethics Committee

JPR: Joint Position Reproduction

KF-NAP: Kessler Foundation Neglect Assessment Process

MED: Movement Extent Determination

MoCA: Montreal Cognitive Assessment

MRI: Magnetic Resonance Imaging

NIHSS: National Institute of Health Stroke Scale

RASP: Rivermead Assessment of Somatosensory Performance

SSA: Site Specific Assessment

TDF: Theoretical Domains Framework

TIA: Transient Ischaemic Attack

TPD: Threshold of passive motion detection

UL-PPA: Upper Limb Physiological Profile Assessment

VAS: Visual Analogue Scale

Publications

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Statement of contribution of authors

In addition to Ms Fisher and her supervisory team, the chapters below were also contributed to by the following individuals:

Chapter 3

Professor Arianne Verhagen (data analysis, manuscript review)

Chapter 4

Professor Annie Rochette (protocol development, manuscript review)

Chapter 5

Mr Sam Gilbert (data analysis, manuscript composition)

Ms Muneeba Chaudry (data collection)

Ms Katja Valente (data collection)

Chapter 6

Associate Professor Emma Power (protocol development, manuscript review)

Ms Annaleise Getley (protocol development, data collection)

Appendix 1

Ms Victoria Keogh (data collection, data analysis)

Thesis Limitations

The final year of this thesis was conducted in the era of the SARS-COV19 pandemic. For approximately ten of these months, Australia was in varying degrees of lockdown and restrictions, which impacted significantly on the data collection of the studies herein reported, with the targeted sample sizes for studies in Chapters 4, 5, and 6 not achieved. First, recruitment for Chapter 5 was completely ceased due to policies preventing external professionals from conducting research in the public healthcare system. At the time of writing, this policy was still in place and thus data collection for this study was halted in March 2020 and unable to continue. Therefore, the planned sample size of 45 participants was not achieved, and was reduced to 10 participants. Second, healthcare clinicians in both inpatient and community settings faced enormous disruption to their practice in the form of continually changing restrictions and the necessity of moving as much of their work as possible to the telehealth medium. Disruptions related to SARS-COV19 significantly limited ancillary time in clinical loads, including time to participate in research studies, which may justify the high level of survey attrition, and small sample sizes for the survey-based study described in Chapter 4.

Finally, the priority of SARS-COV19 trials in the human research ethics application system meant that approvals for new or amendments to non-COVID related projects were significantly delayed. Chapter 6 was in the development phase in the beginning of 2020, and thus its timeline was extended by six months from completion in August 2020 to January 2021. Additionally, approval for the planned third study site in another state could not be obtained on time because of higher regulations and requirements from that state. Everything possible was done to overcome these barriers, including modifying studies to be delivered remotely, incentivising the survey, and attempting to find another in-state site for Chapter 6. However, the magnitude of the pandemic effects on society and healthcare systems had a significant and unavoidable impact on the sample sizes presented in the following chapters.

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This thesis is the result of the unequal opportunity, access, and privilege that the colour of my skin and heritage made possible. I acknowledge that this work was written on the stolen lands of the Gadigal people, and that Sovereignty has never been ceded. I acknowledge the Traditional Owners and Custodians of the land, and pay my respect to Indigenous Elders past, present and emerging.

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Chapter 1: Background to thesis

1.1 Introduction

Stroke is the leading cause of disability in Australia, and in 2012 the total burden of disease cost was $49.3 billion (Deloitte Economics 2013). Stroke was defined by the World Health Organisation in the 1970's as the *'rapidly developing clinical signs of focal disturbance of cerebral function, lasting more than 24 hours or leading to death with no apparent cause other than that of vascular origin'* (Capildeo, Haberman et al. 1978). An established and common sequela of stroke is impairment in multiple brain functions that result in subsequent activity limitations and participation restrictions (Stroke Foundation Australia 2018). Separate brain regions typically have specialised functions, and so these impairments are often linked to the location and size of the lesion, and can span a wide variety of clinical presentations (Carr 2010).

In this context, management of stroke relies on a multidisciplinary team, inclusive of medical and allied health professionals (Stroke Foundation Australia 2017). Initial treatment is largely the domain of medical practitioners, who have the goal of stabilising the person with stroke and minimising the impact of the cerebral lesion (Stroke Foundation Stroke Foundation Australia 2019). Once this occurs, the multidisciplinary rehabilitation process can commence, in which a variety of medical and allied health professionals manage impairments within their scope of practice (Stroke Foundation Australia 2018).

Perhaps the most variable group of post-stroke impairments that require a trans-disciplinary approach are those related to parietal lobe dysfunction. The parietal lobe developed with the movement of Homo sapiens' ancestors from a terrestrial to an arboreal lifestyle, which required the forelimbs to shift from simple locomotive function to adequate skill and dexterity to navigate life amongst the trees. With that there was need for precise knowledge of the location of the limbs in space in order to accurately plan and execute movements, and locate and obtain food. There are two fundamental components of limb position knowledge, the position and nature of the limb itself, and the space in which the limb is moving, which are subsequently disrupted in parietal lobe damage.

Possibly due to their shared anatomy, the understanding of both processes developed almost concurrently. There were indications in the late nineteenth century that a sixth 'muscle sense' existed, which detected position and movement of the body (Bell 1833). However, it was not until 1907 that Sherrington first used the term by which it is now known – proprioception (Sherrington 1907). Traditionally, proprioception has been conceptualised as a set of sensorimotor processes that lead to the ability to detect movement and positions at different joints, judge forces exerted by muscles, and time muscular contractions (Proske and Gandevia 2012). These processes depend on information about the size and shape of body parts (Ingram, Butler et al. 2019), which is informed by a second, more complex aspect of proprioception, termed the body representation (Shenton, Schwoebel et al. 2004, Longo, Azanon et al. 2010, Ingram, Butler et al. 2019).

It was also at the end of the nineteenth century that the first cases of disturbed awareness of space were documented, when Hughlings Jackson reported a case of '*imperception,*' and proposed this defect as unique to other symptoms of cortical lesions (Hughlings Jackson 1897). Following, in 1898 the Austrian neurologist Gabriel Anton suggested in his introduction to an examination of focal diseases of the brain not perceived by the patient '*that the side of the body from which no signal and no stimulus reaches the center, consequently becomes indifferent, and it is ignored by the patient himself'* (Anton 1898). However, the collection of symptoms associated with deficits in perception of one side of space was not formally referred to as "unilateral neglect" until the late1950's (Welch and

Stuteville 1958). Unilateral neglect is now understood as the reduced ability to perceive, orientate, or respond to stimuli on the contralateral side of a cerebral lesion, most commonly after a stroke (Wee and Hopman 2008).

Proprioceptive impairment and unilateral neglect are linked by their shared disruption of the perception of the body and the space that surrounds it. Such disruption severely limits functional capacity, which is the primary domain of two professions in the rehabilitation team – physiotherapists and occupational therapists. However, despite decades of investigation of unilateral neglect and proprioception impairment in clinical rehabilitation, there continues to be significant barriers to assessing and treating both (Menon and Korner-Bitensky 2004, Hillier, Immink et al. 2015). Importantly, unilateral neglect and proprioception impairment are not often considered as clinically related impairments. Given their shared anatomy and contribution to successful limb function, it is likely that improving understanding of one will subsequently impact the other, and vice versa. Thus, this thesis considers proprioception impairment and unilateral neglect in tandem.

The introductory chapter begins with a description of the current understanding of the anatomy and physiology underlying proprioception and unilateral neglect. Then, the impact of unilateral neglect and proprioception impairment on functional recovery after stroke is presented. Finally, the methods and current clinical practice of assessing severity of unilateral neglect and proprioception impairment in humans, and their limitations are outlined. Hence, this chapter will lay the foundation for the subsequent studies that further our understanding of the optimal clinical assessment of unilateral neglect and proprioception impairment

1.2 Unilateral neglect and proprioception

1.2.1 Unilateral neglect

Unilateral neglect is a condition in which a person does not orientate or respond to stimuli presenting on the contralesional side of a brain injury, most commonly occurring after a right-sided stroke (Wee and Hopman 2008).
The understanding of unilateral neglect that was formulated late in the 19th century (described above) was propelled forward rapidly in the early 20th, following the influx of patients to hospitals and medical centres suffering brain damage from shrapnel wounds in the first and second world wars. In 1919, Holmes reported the case of a patient with lesions localised to the posterior and upper parts of both parietal lobes that displayed *'gross disorders in spatial orientation that would run into objects which they saw clearly and have great difficulty in finding their way about and in learning the topography of the room*' (Holmes and Horrax 1919). Brain's (1941) extended the descriptions of Holmes and Horrax in a report of three cases of unilateral parietal lobe injury that demonstrated its relationship with disturbed visual orientation and awareness of the body (Brain 1941).

Brain first described the multifactorial nature of unilateral neglect and linked the condition to a disturbance of the whole '*body scheme on one side of the body*.' Indeed, a disorder of body 'scheme' is how unilateral neglect was specifically conceptualised in Critchley's comprehensive overview of parietal lobe symptomology in 1953 (Critchley 1953). Interestingly, the lack of perception of one half of the external space was presented as a separate but related impairment to unilateral neglect, with visual and spatial 'imperception' being considered as separate again. Critchley's work highlights the variety of 'imperception' subtypes that are possible in parietal lobe damage, including a neglect of visual, tactile, auditory, and proprioceptive information, and of internal representations of the body and space.

However, advances in medical imaging techniques in recent years have identified that unilateral neglect is not limited to lesions of the parietal lobe. Instead, lesions to the temporal, frontal, and occipital lobes along with the basal ganglia and thalamus are all present (Ringman, Saver et al. 2004, Ten Brink, Biesbroek et al. 2019). Given the multiple brain regions involved and the heterogeneity of possible clinical presentations, unilateral neglect is now understood as a result of dysfunction of the extensive neural networks connecting cortical visual and sensorimotor processing areas (Smith, Clithero et al. 2013, Takamura, Fujii et al. 2021) and is associated with larger lesion volumes (Ringman, Saver et al. 2004).

1.2.2 Proprioception

The term proprioception was coined by Sherrington in 1907 and combines the Latin *proprius*, meaning "one's own", with the concept of perception, and thus refers to "perceiving one's own self" (Hillier, Immink et al. 2015). Sherrington considered proprioception as *"… the perception of joint and body movement as well as position of the body, or body segments, in space",* and the *"perceptions of the relative flexions and extensions of our limbs."* Early understanding of proprioception was ideologically divided between a basic sense of joint angles that originated from peripheral afferent muscle receptors (Bastian 1869), and an integrated sense of body position in space that was contingent on cortical efferent signals (Bain 1855).

The view of proprioception as arising from the periphery dominated much of the 20th century, firmly supported by the work of Sherrington in his 1900 textbook chapter 'The Muscular Sense' (Sherrington 1900). Sherrington rejected notions of a centrally arising sense based on the preserved ability to determine body position of passive movements free from volitional input. It was argued that what would become known as 'proprioceptors' were active principally in the muscles, with secondary inputs from the joints and skin (Sherrington 1907). Currently there is no clear consensus regarding the exact magnitude of the contribution of muscle, cutaneous, and joint receptors to proprioception, although the muscle spindle and cutaneous receptors are widely viewed to provide the majority of proprioceptive feedback (Proske and Gandevia 2012, Proske and Gandevia 2018, Macefield 2021).

However, proprioception does not only rely on peripheral input (Proske and Gandevia 2018). The perception of movement occurs in the phantoms of amputated limbs, but only after conscious effort (Jones 1988). Over time, this perception diminishes and the phantom can undergo ‘telescoping’, where the perceived position of the phantom retracts to be inside the residual limb (Jones 1988). These findings suggest that the efferent motor command is involved in the sense of position; however, the ‘telescoping’ effect suggests that input from the muscle (or in this case, the absence of muscle) has an equally large influence. In experiments inducing a phantom limb using circulatory occlusion, the perceived hand position changes are dependent on its prior position despite no actual movement having taken place (Inui, Walsh et al. 2011). Similarly, other experiments inducing a phantom with the same method have shown that the magnitude of perceived limb movement is dependent on the motor command’s strength, again despite no actual limb movement occurring (Walsh, Gandevia et al. 2010). These findings demonstrate that the cognitive representation of the limb and the motor command itself are important contributors to the sense of movement.

Contrary to Sherrington’s original definition, proprioception is not solely a ‘muscular sense’. To sense the position and movement of “one’s own self” is impossible without first understanding what that ‘self’ is. Proprioception also includes the cognitive perception of the body, which is formally termed the body representation (Shenton, Schwoebel et al. 2004, Longo, Azanon et al. 2010, Ingram, Butler et al. 2019). Thus, the current understanding of proprioception conceptually integrates the two originally opposing views regarding the sense. Anatomically, the integration of centrally arising signals with feedback entering from the periphery occurs chiefly in the somatosensory area in the parietal lobes (Webb 2017), and thus damage to these lobes results in proprioception impairment.

1.3 Impact of unilateral neglect and proprioception impairment

Unilateral neglect is associated with poor motor recovery after stroke (Barrett and Muzaffar 2014), particularly of the upper limb (Ogourtsova, Archambault et al. 2015, Doron and Rand 2019). Subsequently, the presence of unilateral neglect results in poorer functional outcomes, greater length of hospital stay, higher incidence of falls, and a reduced likelihood of home as a discharge location (Cherney, Halper et al. 2001, Jehkonen, Laihosalo et al. 2006, Chen, Chen et al. 2015). The significant impact of unilateral neglect is likely due to its highly varied clinical presentation, as unilateral neglect can affect any combination of spatial domains, including the personal, peri-personal, and extra-personal (Vallar 1998). In addition, unilateral neglect can impact a variety of sensory modalities including visual, auditory, and somatosensory (Rode, Pagliari et al. 2017). People with unilateral neglect can present with a neglect of motor behaviours, in which there is failure to spontaneously use their contralesional limb that is independent of primary motor deficits (Punt and Riddoch 2006). There can also be a neglect of imagined space, termed representational neglect, where a person cannot mentally reconstruct contralesional portions of images of known physical spaces (Bisiach and Luzzatti 1978, Guariglia, Palermo et al. 2013). Mobility tasks and activities of daily living integrate all of the above functions, performance of which is subsequently significantly impaired in unilateral neglect.

An often unconsidered form of unilateral neglect is the neglect of proprioceptive information that presents clinically as proprioception impairment (Rode, Pagliari et al. 2017). The equally complex anatomy of the proprioceptive senses mean that proprioception impairment is as varied in presentation as unilateral neglect. Proprioception impairment can affect the threshold of movement detection at joints, and the ability to determine the magnitude of joint movement (Mrotek, Bengtson et al. 2017, Kenzie, Findlater et al. 2019, Da Silva, Monjo et al. 2021). The perception of force and effort can be impacted, characterised by the inability to determine the magnitude of forces both imposed upon and generated by limbs and resulting in their impaired judgement and exertion in movement control (Proske, Gregory et al. 2004). However, the most varied impairments in proprioception are those related to the body representation. Deficits in body representation present as the inability to determine laterality (i.e., to discriminate between left and right) and generate mental images of body parts, skewed perception of the axes of the body, and difficulty naming or locating body parts (Razmus 2017). Independent of unilateral neglect, impaired proprioception is associated with poor motor and functional outcomes at all stages of stroke (Welmer, Von Arbin et al. 2007, Kenzie, Semrau et al. 2017), and has specifically been associated with impaired upper limb function (Rand 2018). However, little is known about the contribution of proprioception impairment to the clinical impairments present in unilateral neglect.

1.4 Assessment of unilateral neglect

1.4.1 Assessment development and types

The first standardised assessment of unilateral neglect was developed in the 1950's and was designed to assess extinction to double simultaneous stimulation of the left versus right side of the visual field and body (Bender 1952). Indeed, this test still forms the extinction item of the National Institutes of Health Stroke Scale (NIHSS), which is routinely performed to assess the initial severity of stroke, and the success of stroke medical interventions (Lyden 2017). Cancellation tasks were introduced as an additional assessment for unilateral neglect in the mid 1970's, requiring patients to locate and cross out a particular stimulus type scattered randomly amongst distractors across a printed page (Diller, Weinberg et al. 1974). At a similar time, pen and paper based line bisection tasks were introduced in which people bisect lines drawn on a sheet of paper (Bisiach, Capitani et al. 1976). These tasks form the traditional method of unilateral neglect assessment in both the literature and clinical practice (Checketts, Mancuso et al. 2021).

However, the above assessment tools have serious limitations. The NIHSS Extinction items fail to capture the full spectrum of impairments related to unilateral neglect and have poor sensitivity (31.6%) when directly compared to cancellation tasks, which has been suggested as a contributor to systematic underestimation of the clinical severity of both unilateral neglect and right hemisphere stroke (Moore, Vancleef et al. 2019). Cancellation and bisection tasks themselves have mixed reliability and no reported responsiveness (Menon and Korner-Bitensky 2004). In addition, these assessments allow for compensation in the absence of distraction, thus lacking relevance to real world settings, where distraction and unexpected stimulation are frequent (Bonato 2012, Andres, Geers et al. 2019). Furthermore, these assessments have small and non-significant correlation with the Barthel Index, a measure of independence in activities of daily living (ADLs) (Nijboer and Van Der Stigchel 2019). Given the known impact of unilateral neglect on function, assessment tools should ideally have a strong correlation to upper limb impairments and functional abilities.

The recognition of the limitations of traditional unilateral neglect assessments has led to the development of a plethora of outcome measures designed to capture elements of the condition that were previously missed. A recent review found 62 published assessment tools for unilateral neglect, of which 28 were standardised (Menon and Korner-Bitensky 2004). Of these, 20 assess near extra-personal space in isolation, two personal neglect in isolation, and five tools combine the assessment of two separate hemi-spaces. Thus, clinicians are frequently recommended to use a combination of assessment tools to ensure they capture the full gamut of impairments that are possible in people with unilateral neglect (Donoso Brown and Powell 2017).

However, there are again limitations to this recommendation. While combining assessment tools indeed increases the likelihood of capturing a wider spectrum of unilateral neglect, many standardised assessments do not directly assess the impact of unilateral neglect on the functional abilities of people with the condition. Assessing this is paramount given that the ultimate goal of rehabilitation is improvement in functional outcomes. In addition, combining multiple tests is time consuming, and not feasible for a typical clinical schedule, in which unilateral neglect is one of the many impairments that a clinician is required to assess.

There is one standardised test that attempts to capture unilateral neglect in all three spatial domains in a functional manner – the Catherine Bergego Scale (CBS) (Azouvi 2017), the implementation of which has been standardised into the Kessler Foundation Neglect Assessment Process (KF-NAP) (Chen, Chen et al. 2015). The KF-NAP has excellent sensitivity (79%) (Pitteri, Chen et al. 2018) and construct validity with pen and paper tasks (r between 0.70 and 0.72, $p < 0.01$) (Bergego, Azouvi et al. 1995), assesses both perceptual and motor performance (Pitteri, Chen et al. 2018), and can be combined with other components of a standard occupational therapy or physiotherapy functional assessments saving clinicians' time (Barrett and Houston 2019). However, neither the KF-NAP nor any other standardised assessment of unilateral neglect directly assess neglect of proprioceptive information, which is likely due to the current status of clinical proprioception assessment in general (see next section).

1.4.2 Current clinical assessment patterns

While international stroke guidelines recommend assessment of unilateral neglect using a standardised outcome measure (Royal College of Physicians 2016, Winstein Carolee, Stein et al. 2016, Stroke Foundation Australia 2017), there is little specification as to which assessment to use and at what time points this should occur. Given the restrictions of using multiple assessment procedures, it is likely that clinical assessment of unilateral neglect is often limited to a single aspect.
In addition, the multifactorial nature of unilateral neglect and the arbitrarily but specifically defined 'scopes of practice' of multiple clinical specialties (Buchan and Dal Poz 2002) mean that certain aspects of the condition have higher saliency to certain professions. Thus, it is also likely that unilateral neglect assessment in clinical practice is highly variable between professional groups.

These speculations were recently confirmed in a global survey of the assessment practices of 476 health professionals that work with stroke patients affected by unilateral neglect (Checketts, Mancuso et al. 2021). The survey found key differences between the assessment choices of health professions – occupational therapists and neuropsychologists are likely to use cognitive outcome measures, whereas physiotherapists are more likely to use functional assessment measures. Importantly, the most common cognitive assessments employed by occupational therapists and psychologists were pen and paper cancellation tasks, which while standardised, fail to capture the full spectrum of unilateral neglect.

In contrast, physiotherapists were most likely to use ADL observation and informal interview with people with stroke to determine if unilateral neglect is present.

While observation of ADLs as an assessment of unilateral neglect is functional, it is not standardised. Finally, only a maximum of 40% of all health professionals, and a maximum of 20% of physiotherapists that were surveyed used a valid, standardised, and functionally relevant assessment of unilateral neglect indicating a substantial evidence-practice gap in this area.

1.5 Assessment of proprioception

1.5.1 Assessment types

Typical clinical proprioception assessment investigates joint movement recognition and falls into three categories; threshold of passive motion detection, joint position reproduction, and movement extent discrimination (Hillier, Immink et al. 2015, Han, Waddington et al. 2016). The threshold of passive motion detection is determined by applying stimuli of either increasing or decreasing magnitude on a joint and determining the smallest angle able to be accurately perceived. Joint position reproduction involves the replication of the amplitude of a movement applied to a joint. The reproduction can be passive or active, performed with the ipsilateral or contralateral limb, and occur simultaneously or after the fact. Finally, movement extent or direction discrimination involves using an external device to indicate the magnitude or direction of a joint movement. These assessments have been extensively investigated and validated in multiple joints and disease processes (De Jong, Kilbreath et al. 2005, Lee, Kilbreath et al. 2005, Mrotek, Bengtson et al. 2017).

1.5.2 Assessment in people with stroke

In stroke populations, the Rivermead Assessment of Somatosensory Performance (RASP) and the revised Nottingham Sensory Assessment (EmNSA) are the two primary standardised clinical battery of proprioception assessments. Both use movement direction discrimination, and an ordinal grading system, defining the patient's proprioception as either normal, impaired, or absent (Winward, Halligan et al. 2002, Stolk-Hornsveld, Crow et al. 2006). Furthermore, the correlation of clinical movement detection tests to patient function and activity is low, or absent entirely (Meyer, Karttunen et al. 2014). Thus, despite the known importance of proprioception to functional outcomes after stroke, current methods of assessment fail to demonstrate this relationship and are likely to have low relevance to rehabilitation outcomes.

The other commonly used clinical test of proprioception is the Distal Proprioception Test, where the thumb or great toe is passively moved up or down and the patient is required to determine the direction of movement (Richardson 2002). However, this test has similar limitations to the RASP and EmNSA in that it has dichotomous outcomes, a subsequent large ceiling effect, and is unable to track small changes over time (Hillier, Immink et al. 2015).

1.5.3 Recent developments

In the last 10 years, robotic assessment tools have been developed to address the limitations of clinical assessment methods (Dukelow, Herter et al. 2009, Semrau, Herter et al. 2013, Cusmano, Sterpi et al. 2014). However, these are relatively new and come with limitations of their own such as higher cost, reduced portability, training requirements, and a longer set-up time. Although more accurate and reliable, robotic assessment is not yet widely available or feasible for clinicians

(Hillier, Immink et al. 2015, Findlater and Dukelow 2017). In response, an alternative has been proposed in the advent of ‘wearables’, or electronic devices that can be worn as accessories and embedded in clothing (Anowar, Ali et al. 2020).
These devices can include surface electromyography and potentiometers, but the most accurate, feasible, and low-cost, and well investigated in stroke are inertial measurement unit (IMU) devices (Maceira-Elvira, Popa et al. 2019). Relevant to this thesis, their utility in the detection of motor unilateral neglect is also established (Bailey, Klaesner et al. 2015). IMU devices combine the acceleration readings from accelerometers and the angular turning rate detection of gyroscopes and enable tri-planar tracking of human motion (for review, see Yang and Hsu 2010). Thus, they are easily adapted to clinical assessments of proprioception involving motion, but this has not yet been investigated in stroke populations.

1.5.4 Current clinical assessment patterns

Clinical proprioception assessment largely considers proprioception through the lens of Sherrington, as a muscular sense best tested by the methods above. However, assessments based on a more accurate definition of proprioception should consider assessment of the body representation (Hillier, Immink et al. 2015).
In addition, despite evidence of the impact of stroke on body representation (Razmus 2017) its evaluation is largely absent from all forms of stroke clinical assessment.

Assessments of personal unilateral neglect are among the only clinically standardised assessments of body representation in stroke. These involve the exploration of the contralesional half of the body, where a patient is asked to perform common tasks involving both halves of the body (for example, grooming) (McIntosh, Brodie et al. 2000) or by a therapist placing targets on the patient bilaterally and asking them to locate as many as possible (Cocchini, Beschin et al. 2001). However, the body representation can be assessed in a number of other ways including judgement of body part laterality, determining the location of body axes (e.g., body midline), and describing body topography (Rousseaux, Honoré et al. 2013, Razmus 2017). Of these, laterality is easily assessed clinically using picture cards or mobile apps (Wajon 2014). To date, these tools are more commonly used to assess changes in body representation in Complex Regional Pain Syndrome rather than in stroke (Kuttikat, Shaikh et al. 2017). The perception of body axes or topography has not yet been successfully translated into clinical assessment tools; however, laboratory based methods of assessment have been reported and validated in the literature (Saj, Honoré et al. 2006, Barra, Chauvineau et al. 2007).

While an in-depth review of somatosensory impairment is included in national audits of stroke rehabilitation (Stroke Foundation Australia 2017, Stroke Foundation Australia 2018), the Australian National Stroke Guideline does not include any recommendations specific to the treatment or assessment of proprioceptive impairment (Stroke Foundation Australia 2017). Similar to the Australian guidelines, proprioception is not specifically considered in other major global stroke rehabilitation guidelines, often only referring to somatosensory impairment in general (Heart and Stroke Foundation of Canada 2015, Royal College of Physicians 2016, Winstein Carolee, Stein et al. 2016). A likely contributor to the lack of clinical guidelines for assessment and treatment of proprioception is the limitations of the current clinical assessment strategies outlined above (Pumpa, Cahill et al. 2015, Carey, Lamp et al. 2016, Findlater and Dukelow 2017).

A recent survey of 172 Australian physiotherapists and occupational therapists found that over 75% of clinicians use a non-validated proprioception assessment tool – most commonly limb position matching (Pumpa, Cahill et al. 2015). Standardised assessments were rarely used, with the RASP and EmNSA only used by 7% and 6.4% of clinicians respectively, and the Wrist Position Sense Test (Carey, Oke et al. 1996) (a standardised joint position sense test) only used by 4% of clinicians. Thus, in general, clinical assessment is limited to a single proprioceptive test subtype and is likely highly variable in technique and standardisation. Importantly, the questions used in the above survey were highly directed – participants were given a set number of specific somatosensory assessment options to choose from with an 'other' option box provided. A multiple choice question format provides limited insight into the nuances of clinician decision making when managing a typical stroke case.

Aim of thesis

Therefore, the overall aim of this thesis is to address the gaps between evidence-based best practice and usual clinical practice by investigating both the relationship between unilateral neglect and proprioception, and issues with their current clinical assessment individually. Next, Chapter 2 details the methodology of this thesis and how each chapter was designed to answer these aims.

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Chapter 2: Thesis development and methodology

2.1: Theoretical foundations to the research

2.1.1 Research overview

Unilateral neglect and proprioceptive impairment are two common sequelae of stroke with negative impacts on functional recovery for stroke survivors. Sensorimotor integration is fundamental to both unilateral neglect and proprioception impairment, which suggests a relationship between them. However, exploration of this relationship is infrequent, and has resulted in significant differences between best practice as recommended by the literature and actual clinical practice (evidence-practice gaps). Additionally, evidence-practice gaps in clinical assessment of unilateral neglect and proprioception impairment as individual impairments compound the gaps in clinical assessment of their relationship. Hence, one purpose of this thesis is to explore these gaps separately to provide the foundation for translating improved assessments for both impairments into practice and improving the rehabilitation outcomes of people with stroke.

2.2.2 Principles of clinical evidence translation

Translation of research evidence into clinical practice is a process consisting of several, largely linear, stages that feed awareness of best evidence to clinicians, garner acceptance, foster adoption and adherence, and include patient participation. The evidence-to-practice pipeline model identifies stages where 'leaks' to the pipeline diminish the success of implementing evidence into practice (Glasziou and Haynes 2005). These are described in Table 2.1. To increase the success of implementation, strategies for evidence translation must take these factors and their interaction in the context of the target area into account (Iyer and Chua 2019).

Stage	Level	Description
Studies	Research	Primary research studies
Synopsis	Research	Systematic review or clinical guidelines
Evaluation	Research	Gap identification via description of current practice
Awareness	Clinician	Awareness of valid and relevant research
Acceptance	Clinician	Acceptance that the research should be implemented
Applicability	Clinician	Correct judgements about when to implement
Ability	Clinician	Confidence that implementation is within capacity
Action	Clinician	Frequent consideration and application
Agreement	Patient	Acceptance of the implementation plan
Adherence	Patient	Consistent adherence to the implementation plan
Translation	Practice	Evidence consistently used in practice

Table 2. 1: The stages of evidence translation

Importantly, there are additional complexities in evidence translation in stroke rehabilitation. Rehabilitation of stroke is the responsibility of a multi-disciplinary team (MDT), a group of diverse clinical roles that participate in and communicate about the care of stroke patients (Wagner 2000), and that also include the person with stroke, their family, and carers as critical members (Morley and Cashell 2017). For successful MDT operation, clinicians need clearly defined, explicitly delegated roles, appropriate education, a supportive culture, and clear communication and leadership (Cioffi, Wilkes et al. 2010). Some post-stroke impairments are more closely aligned with the scope of a single profession in the MDT, and are thus managed accordingly. However, other impairments such as unilateral neglect and proprioception impairment traverse the scopes of practice of multiple MDT professions (Checketts, Mancuso et al. 2021). Hence, research translation specific to stroke rehabilitation must take into account the complex interactions of the MDT.

Chapter 1 of this thesis describes a number of issues in the process of evidence translation in assessment of proprioception impairment in unilateral neglect that are important targets of translational research. These are summarised in Table 2.2, and form the basis for the course of investigation presented in subsequent chapters. Additionally, an investigation of the relationship of unilateral neglect and proprioception requires initial consideration of the separate contributions of each. Table 2.2 summarises the stages of translation applied to clinical assessment of proprioception impairment in unilateral neglect, but also separate to both unilateral neglect and proprioception.

Stage	Description	PI ~ UN	UN	PI
Synopsis	Systematic reviews or user summaries	✗	✓	✓
Evaluation	Evidence-practice gap description	✗	✓	✗
Awareness	Awareness of valid and relevant research	?	✗	?
Acceptance	Acceptance of implementation appropriateness	?	✓	?
Applicability	Correct clinical judgements in implementation	?	?	?
Ability	Confidence in capacity to implement	?	?	?
Action	Frequent consideration and application	?	✗	?
Agreement	Acceptance of the implementation plan	?	?	?
Adherence	Consistent adherence to implementation	?	?	?
Translation	Evidence consistently used in practice	?	✗	✗

Table 2. 2: Summary of translation stage completion in research about unilateral neglect and proprioception in stroke rehabilitation.

KEY: UN = unilateral neglect, PI = proprioceptive impairment, Prop ~ UN = PI in UN, ✓= present, ✗ = absent, but defined, ✓+ ✗ = partially present, ? = unknown. Targets of this thesis are highlighted in colour, mapped to those in Figure 2.1.

Using the stages of evidence translation described in Table 2.1, four phases of research were developed and are described in Figure 2.1 (over page). These phases are colour matched to the implementation gap or unknown areas identified in the translation stages in Table 2.2. At the start of this thesis, the evidence translation regarding the assessment of proprioception impairment in unilateral neglect was at a preliminary stage, and had not yet been synopsized. Thus, the first phase (Fig. 2.1) of this research was to conduct a systematic review that summarised the literature pertaining to proprioception impairment in unilateral neglect (Chapter 3, Study 1). The findings of the systematic review reinforced the gaps in translation stages, previously addressed in the literature, which formed the basis for the subsequent three phases (Fig. 2.1) of research in the remainder of the thesis. Furthermore, the translation stages were asynchronous between unilateral neglect and proprioception. Thus, individual translation stages could not be addressed within single studies for both unilateral neglect and proprioception and a staggered approach was used.

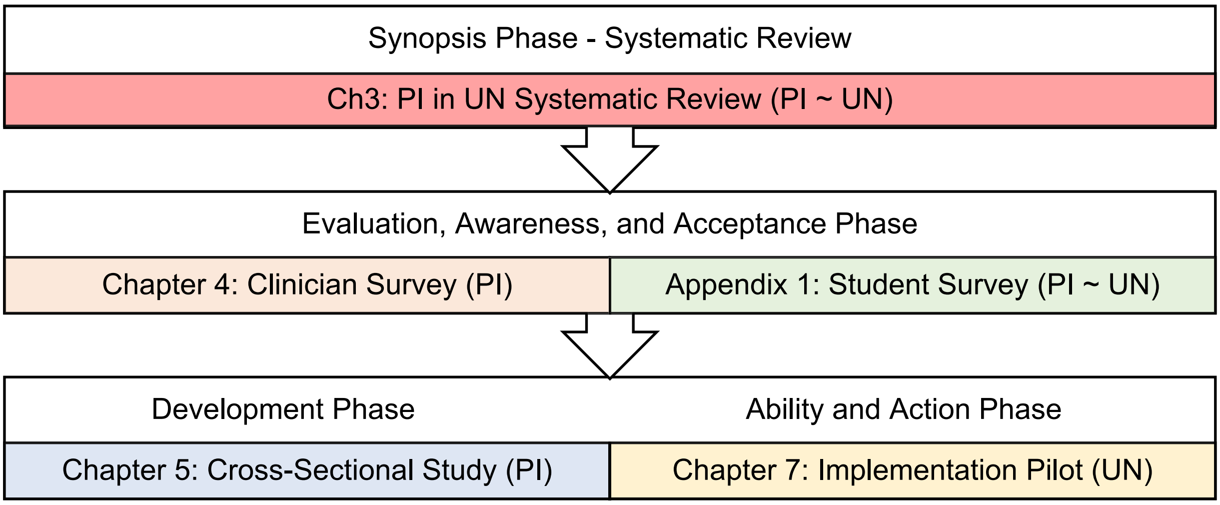

Figure 2. 1: Phases and respective chapters of this thesis.

Components of each phase are colour matched to either the identified translation stage 'leaks' or unknowns in Table 2.2. Key: PI = proprioceptive impairment, Prop ~ UN = proprioceptive impairment in UN, UN = unilateral neglect.

2.1.2 Pragmatism

Epistemology, or theories of how we create knowledge and differentiate it from opinion (Crotty 1998), underpins all research design and analysis. Historically, distinct time periods are characterised by the dominance of different paradigms and research methodologies. The late 19th and early 20th century were typified by positivism, a research paradigm that considers knowledge as singular, concrete, and discovered through observation, experimentation, and comparison (Comte and Martineau 1853). However, positivism has limited application to research seeking to investigate human experiences and decision-making which have an inherent high contextual variability. Later, the paradigm of constructivism was introduced, which argues that knowledge and meaning are formed based upon the experiences and contexts of people, societies, and cultures which generate them (Wadsworth 1996).

Positivism and constructivism were originally considered mutually exclusive (Robertson and Samy 2017). However, many research questions involve aspects of both paradigms, which resulted in the development of the theory of pragmatism. Pragmatism is characterised by the use of all necessary approaches to understand the problem or phenomenon under investigation and includes both quantitative (i.e., positivist grounded) and qualitative (i.e., constructivist grounded) methods (Morgan 2007). The translation of evidence into clinical practice involves not only the identification of biomedical 'truths', but how these truths are both interpreted and implemented by healthcare consumers and clinicians. Importantly, a pragmatic approach allows researchers to move along the continuum between evidence generation and factors affecting implementation, and thus results in an overarching research design that is fluid and responsive to the cumulative results of previous investigations (Eccles and Mittman 2006). Given the foundations of this thesis in evidence translation and its strong clinical focus, pragmatism is its underpinning epistemological paradigm.

While each study presented in this thesis describes the relevant methods used, the remainder of this chapter provides an overview of their overarching methodological considerations, commencing with a summary of the thesis aims, followed by the researcher's position and methods of bias reduction, and finishing with the rationale, specific theories and frameworks, and justification of measurement tools of each investigation.

2.1.3 Summary of thesis

Issues with processing of proprioceptive information have long been implicated as a component of the clinical presentation of unilateral neglect, but have received little attention in the literature. In addition, the clinical assessment of unilateral neglect is non-comprehensive and does not include specific tests of proprioception (Menon and Korner-Bitensky 2004). Furthermore, the clinical assessment of proprioception impairment is also non-comprehensive. In any investigation of proprioception impairment in unilateral neglect, the issues of each impairment need to be considered independently.

Hence, this thesis has four primary aims:

1) To establish the nature and extent of proprioception impairment in people with unilateral neglect after stroke.

2) To describe current clinicians' practice and knowledge of proprioception assessment in stroke populations, and clinicians' attitudes towards proprioception assessment.

3) To investigate the correlation between clinical proprioception impairment assessment with other upper limb impairments, and their ability to discriminate between people with and without unilateral neglect.

4) To identify barriers and facilitators to clinician implementation of evidence-based and unilateral neglect assessment

Chapter 3 is a systematic review of studies that have investigated the presence of proprioceptive impairment in unilateral neglect after stroke. Chapter 4 reports the results of a nationwide survey of clinicians working in stroke rehabilitation investigating their knowledge, assessment, and treatment practices pertaining to proprioception. Chapter 5 is an interim report of a clinical investigation of the current proprioception assessment used in stroke rehabilitation, and examines its quantification and the relationship to other impairments of the upper limb. Chapter 6 reports the results of a translation to practice study examining the barriers, facilitators, and clinician experience in using evidence-based unilateral neglect assessments in an inpatient and a community stroke rehabilitation setting. Appendix 1 presents data from a survey investigation with a small sample size that is thus supplementary to the above chapters. The preliminary results of this survey describe student clinician knowledge about unilateral neglect and proprioception impairment and their assessment, a potential contributor to the evidence-practice gaps in both areas.

2.1.4 Researcher position and bias reduction

Currently, in qualitative research it is acknowledged that the researcher is an explicit part of the scientific process of knowledge generation, which is not often the case in quantitative research (Flick 2002). However, quantitative research design and completion involves consideration of a number of potential sources of bias (Pannucci and Wilkins 2010), which is synonymous with the qualitative 'researcher position'. Bias can be introduced in the planning, data collection, analysis, and publication phases of research, and can be addressed through quality study design, use of established frameworks, and transparent reporting. Given that the studies in this thesis used both quantitative and qualitative methods, both 'bias' and 'researcher position' were considered as appropriate.

From the quantitative perspective, bias was addressed via the following methods. The study protocols and analysis plans for the systematic review in Chapter 3 and the clinical investigation in Chapter 5 were pre-registered in

PROSPERO (2021) and Open Science Framework (2021), respectively.
Pre-registration reduces publication bias by enabling researchers to identify all studies related to a particular intervention, and by creating accountability for research teams to report deviations in methodology and statistical analysis from that which was originally planned (Abaid, Grimes et al. 2007).

In the quantitative clinical investigation in Chapter 5, personnel collecting dependent outcome measures (upper limb function and position matching) were kept blind to the participant's KF-NAP score, which was used to assess unilateral neglect in each participant. Assessor blinding was maintained to prevent outcome assessment bias introduced by knowledge of participant factors (Noseworthy, Ebers et al. 2001). Analysis of the study data in Chapter 5 was conducted in collaboration with an engineer who was blind to other participant clinical data, for a similar reason. Additionally, general steps to reduce bias and increase research reproducibility including exact reporting of all p-values, statement of significance level, report of confidence intervals, standard deviations, and presentation of graphical data in a format that shows the range of data points with means and confidence intervals were addressed (Yosten, Adams et al. 2018). Finally, all source code for Python-based analyses are available in the appendices of this thesis.

Researcher position was considered within and between studies of both qualitative and quantitative nature in the context of its possible influence on the collection of data and interpretation. During data collection, I was working in one of the rehabilitation wards in which the investigation in Chapter 5 was conducted, and had taught members of the focus groups in the implementation pilot in Chapter 6, creating a power imbalance with some stroke-survivor and clinician participants.
In response, a two part, 'arms-length' consent process was used in the investigations in these chapters, where potential participants were first approached by another

senior therapist working on the ward rather than myself as their physiotherapist or past university lecturer. I also acknowledge that I have a strong belief in the importance of evidence-based clinician assessment of proprioception impairment and unilateral neglect, and in the need to change practice in this area. Thus, a participatory design was chosen for focus groups in Chapter 6, which attempted to create a shift in power where focus group participants led the group discussions, with only occasional guidance from myself as their facilitator (Baum, MacDougall et al. 2006). Care was taken not to project my own views on unilateral neglect into the discussion, but instead to echo and confirm the views of group members.

2.2: Methodological foundations and reflexivity of research design

2.2.1 Synopsis phase - Systematic review

Research Question Generation. The preliminary literature review for this thesis (Chapter 1) showed that the 'synopsis' phase of the evidence translation process was established for unilateral neglect and proprioception impairment individually, but not for their relationship. Additionally, the 'higher level' aspects of proprioception that include integration of body representation were rarely considered in the proprioception literature. Thus, the first study of this thesis consisted of a systematic review with the aim to determine whether proprioception, explicitly defined as including the body representation, is more impaired in people with unilateral neglect compared to those without it after a stroke.

Study Design: The review was planned and conducted using the methodology recommended in the Cochrane Handbook for Systematic Reviews (Higgins JPT 2021). Given the research team's limited experience in conducting systematic reviews, Professor Arianne Verhagen was approached for her expertise in this methodology (Verhagen, Bierma-Zeinstra et al. 2013, Verhagen 2017), and subsequently became an author in the review. A librarian from the University of Technology Sydney assisted in search strategy development and database selection (Grossetta Nardini, Batten et al. 2019), and screening occurred using Covidence, a Cochrane endorsed web-based platform specifically designed for systematic review management (VERITAS Health Innovation LTD 2021). The Cochrane Handbook does not make recommendations for tools to assess quality and risk of bias of cross-sectional studies, therefore, an extensive literature search was conducted to determine the most appropriate tool for the appraisal of the studies included in the review. The Appraisal Tool for Cross-Sectional Studies (AXIS) was selected as it was developed by an international panel of 18 experts using three rounds of the Delphi process, who also developed a detailed explanatory document for researcher implementation (Downes, Brennan et al. 2016). Finally, the review was reported according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) statement {Liberati, 2009 #256}.

2.2.2 Evaluation, awareness, applicability and acceptance phase - Survey research

Research Question Generation: Previous literature and the results of the synopsis phase (Chapter 3) of this thesis suggested that people with unilateral neglect after stroke are more likely to have impaired processing of multiple types of proprioceptive information than those without unilateral neglect. However, there was substantial heterogeneity in the assessment tools used for both impairments in the reviewed literature. Previous investigations had shown that this was mimicked in clinical practice of unilateral neglect assessment (Checketts, Mancuso et al. 2021). However, it was unknown if this was also true for the clinical proprioception assessment after stroke. Thus, the aim of Study 2 (Chapter 4) was to describe the current clinician assessment of, knowledge of, and attitudes to proprioception impairment in stroke rehabilitation. The results of this chapter in conjunction with the findings of previous investigations showed that noticeable clinician knowledge gaps exist in regards to proprioception *and* unilateral neglect knowledge (Pumpa, Cahill et al. 2015, Evald, Wilms et al. 2020). Importantly, clinicians tend to rely on their own clinical experience and the knowledge of their colleagues rather than ongoing formal education to increase their knowledge (Doyle 2014, Pumpa, Cahill et al. 2015, Evald, Wilms et al. 2020).

In this context, a likely but as yet unestablished contributor to clinician knowledge gaps could be pre-registration university education. Subsequently, another study (Appendix 1) was planned with the aim to describe the knowledge of Australian physiotherapy and occupational therapy final year students about their clinical decision-making, knowledge of, and attitudes to unilateral neglect and proprioception. Due to the small sample size and limited ability to draw conclusions from the data (Draugalis and Plaza 2009), the results of this study are presented as preliminary, supplementary data in Appendix 1. The studies in Chapter 4 and Appendix 1 were each designed using the rationale and methods described in the following paragraphs.

Study Design: Survey research is an accepted form of investigation of real world phenomena, and is typically conducted with observations from a subset of the population of interest (Stopher 2012). Internet-based surveys are self-administered, can be undertaken at the time of the respondent's choosing, and have the potential to be interactive (Stopher 2012). In developed countries such as Australia that have a high density of internet access (86% - Australian Bureau of Statistics 2018), and in populations of working age with high technological literacy (e.g., healthcare clinicians and university students) they are a feasible method of sample capture.

Surveys typically involve quantitative data capture. However, in the case of exploratory research, the use of qualitative open-ended questions is common (Creswell and Hirose 2019). Additionally, case vignettes are commonplace in the clinical education of a variety of healthcare professionals (Kathiresan and Patro 2013), and are a valid proxy for clinical decision-making (Peabody, Luck et al. 2004, Korner-Bitensky, Desrosiers et al. 2008, Korner-Bitensky, Barrett-Bernstein et al. 2011). Thus, the surveys used in Chapter 4 (clinicians) and Appendix 1 (students) combined qualitative and quantitative data collection and analysis, and included a case vignette to describe current clinical practice decision-making of clinician and student knowledge, respectively.

Professor Annie Rochette from the Centre for Interdisciplinary Research in Rehabilitation of Greater Montreal was approached for her expertise in survey methodology (Rochette, Desrosiers et al. 2007, Korner-Bitensky, Desrosiers et al. 2008) and subsequently became a part of the study team. Case vignettes used in survey research should not be too far from current experiences (Stopher, 2012). Thus, the vignettes of people with stroke used in Chapter 4 (clinicians) and Appendix 1 (students) were developed in consultation with allied health students and independent experienced rehabilitation clinicians respectively to ensure their representativeness. Two case vignettes were developed for the clinician survey, one specific to an inpatient and one to a community-based person with stroke to reflect the differences between impairment severities in these settings. For the supplementary student survey, a simpler, single case vignette was developed to reflect the lower levels of clinical expertise in this population.

Finally, piloting surveys prior to their deployment often results in significant modification and allows pre-emptive identification of problems (Biemer and Lyberg 2003). Hence, both surveys were piloted on a sample of four clinicians or students prior to their deployment with associated focus groups that used cognitive debriefing techniques (Beatty and Willis 2007). Participant insights were incorporated to the final version of each survey.

Framework analysis: Framework analysis is an appropriate method to analyse themes emerging from relatively homogenous textual data in fields with well-established theories (Gale, Heath et al. 2013). Additionally, the framework method is not aligned with a particular epistemological approach and is instead a flexible tool that can be adapted to many qualitative approaches (Gale, Heath et al. 2013). Thus, the framework method was selected for data analysis of Chapters 4 and 6 - the 'Evaluation, Awareness, and Acceptance' and 'Ability and Action' phases of the research - as it is well aligned with the content and overarching pragmatism of this thesis. Coding frameworks for both proprioception and unilateral neglect were created from discussion with all members of the research team and were based on established literature (Proske and Gandevia 2012, Barrett and Houston 2019). Analysis was conducted according to conventional tenets of thematic analysis, whereby two members of the research team independently extract and code data from each survey using the "de-contextualization, re-contextualization, categorization, and compilation" process (Bengtsson 2016). Disagreements were resolved through consensus with a third member of the research team. An 'other' category was included in each coding framework to capture any outlying themes.

Finally, data saturation, or the point in the research process when no new information is discovered in data analysis, is an important component of qualitative research (Faulkner and Trotter 2017). In the surveys used in this thesis, analysis of all data sets was completed and then saturation point was calculated post-hoc. The methods described by Guest, Namey, and Chen (2020) were used, in which the number of new themes in a defined 'run' of surveys proportional to the number of themes in an initial ‘base’ sample is calculated until no new themes emerge. A ‘base’ of ten, and a ‘run’ of five surveys were used, which was selected to confirm saturation while describing current clinical practice via report of the percentage of responses that fell within each framework component.

2.2.3 Ability and action phase: Focus groups

Research question generation: A secondary finding of the systematic review (Chapter 3) and both surveys (Chapter 4, Appendix 1) in this thesis was that while there were comprehensive and clinically feasible unilateral neglect assessments that were simply not used in practice, such assessment tools did not yet even exist for proprioception. Thus, implementation research that aimed to improve both impairments in tandem was deemed inappropriate. Instead, a pilot implementation study specific to unilateral neglect was planned (Study 4, Chapter 6). The aim of this study was to identify determinants important to clinician uptake of evidence-based unilateral neglect assessment, to propose reasons for the current evidence-practice gap, and identify factors that would assist in future implementation work aiming to narrow it.

Study design: Focus groups are an established method of exploring a specific set of people's views and experiences, and capitalise on interaction effects to describe both consensus and diversity within a group (Kitzinger 1994). Focus groups were selected as opposed to individual interviews as the interaction of clinicians is central to multidisciplinary stroke rehabilitation, and therefore to their decision-making. It is important to take into consideration the likely impact of the moderator and the match between this individual's characteristics and those of the group they are running (Barbour 2007). In this case, the research team decided that my experience as a stroke rehabilitation clinician but parallel research background would create an ideal ratio of ‘sameness’ and ‘otherness’ as the group moderator (Hurd and McIntyre 1996). Focus groups are recommended to be small (between 3 and 12 participants), mediated face-to-face (in-person or online), and run between one to two hours (Tracey, 2013). The study ran from March 2020 to January 2021 during the SARS-COV2 pandemic, necessitating an online method of delivery, with groups of four to six clinicians, over one hour to fit in with timeframes already allocated for in-service education at each site.

Focus group moderators can use either a general topic guide or a specific question route to facilitate discussions, with a topic guide allowing for greater fluidity in discussion flow (Litosseliti 2003). As this study was exploratory, a topic guide with pre-determined prompting questions to increase the depth of each component was selected. Importantly, determinant frameworks and implementation theories have been recommended to guide and understand factors that impact implementation of evidence into clinical practice (Michie, Johnston et al. 2005, Eccles, Armstrong et al. 2009). The Theoretical Domains Framework (TDF) is an established and well investigated tool that unites multiple theories of behaviour change into a single 14 domain framework to describe the cognitive, affective, social, and environmental influences on clinical behaviour (Cane, O'Connor et al. 2012). Additionally, the TDF has been extended into a guide for researchers describing the user-process to facilitate its use in implementation research (Atkins, Francis et al. 2017). Additionally, this guide typically recommends data collection via interviews and focus groups. Therefore, the TDF was implemented to generate the focus group topic guide, with specific prompts mapped to each element of the framework.

Analysis: The selected analysis for the focus group transcripts followed the same principles as described in Section 2.2.2, however, instead with the TDF as the applied framework. As this study was a pilot investigation, no quantification of saturation occurred.

2.2.4 Development phase - Cohort study

Research Question Generation: As described above, results of the first three studies of this thesis highlighted that there was a dearth of comprehensive clinical proprioception assessments, and that in response most clinicians perform a non-standardised position-matching task. Thus, the correlation of the current method of clinical proprioception assessment to other upper limb impairments is unknown and so too is their continued clinical utility. Additionally, the systematic review (Chapter 3) showed that proprioception impairment is more severe in people with unilateral neglect. However, the ability of this form of position matching to discriminate between people with and without unilateral neglect was a previously unestablished component of the translation process in this area (Table 2.3). Subsequently, the aim of the final study of this thesis was to determine the correlation of current clinical proprioception assessment with upper limb impairments and the ability of these assessments to discriminate between people with and without unilateral neglect.

Stage	Description	Proprioception
Research	Investigation of current clinical assessment method	✗
Synopsis	Systematic reviews or user summaries	✓
Evaluation	Evidence-practice gap description	✓
Awareness	Awareness of valid and relevant research	✗
Acceptance	Acceptance of implementation appropriateness	✓
Applicability	Correct clinical judgements in implementation	✗
Ability	Confidence in capacity to implement	?
Action	Frequent consideration and application	?
Agreement	Acceptance of the implementation plan	?
Adherence	Consistent adherence to implementation	?
Translation	Evidence consistently used in practice	✗

Table 2. 3: Summary of translation stage completion at the end of the 'Evaluation, Awareness, Applicability and Acceptance' phase of thesis

Gaps addressed in previous phases highlighted in orange. Additional gap highlighted in blue. KEY: ✓ = present, ✗ = absent, but defined, ? = unknown.

Study design: When aiming to establish correlations or comparisons and where a randomised controlled trial is not feasible, a number of research designs are available including cohort, case-control, and cross-sectional studies (Lau and Kuziemsky 2017). These studies can be prospective or retrospective. However, retrospective designs are limited by the accuracy and availability of historical records. Cross-sectional and case-control studies have the limitation of describing a single time-point (Levin 2006) and discrepancies in exposed and non-exposed case matching (Levin 2006). Additionally, in stroke rehabilitation, and particularly in sensorimotor impairment, impairment severity changes significantly over time (Winward, Halligan et al. 2007, Borschmann and Hayward 2020). Thus, in associated research it is important to include multiple time points. In response, a prospective cohort study was planned for the final study of this thesis. Three time points were selected, based on participant rehabilitation phases (admission to, discharge from, and six-month follow-up) rather than absolute time-point post-stroke. The aim of this strategy was to increase the consistency of participant function at each point of data collection as there is a known timeline variability in recovery of sensorimotor impairments in stroke between people (Winward, Halligan et al. 2007), while admission and discharge from a rehabilitation unit are determined by a uniform set of clinical criteria. Finally, recruitment of a healthy control group, age-matched to a pair of stroke affected participants (one with unilateral neglect, one without) was planned. Outcome measures were planned to be collected at time points held constant with their age-matched participants.

Clinical outcome measures

Kessler Foundation - Neglect Assessment Protocol (KF-NAP):

Most unilateral neglect assessment tools have significant limitations, including underestimation of impairment severity (Moore, Vancleef et al. 2019), variable reliability and responsiveness (Menon and Korner-Bitensky 2004), issues with compensatory behaviours that positively skew scores (Bonato 2012, Andres, Geers et al. 2019), and poor correlations with functional outcomes (Nijboer and Van Der Stigchel 2019). There is one standardised test that attempts to assess unilateral neglect in all spatial domains in a functional manner – the Catherine Bergego Scale (CBS; Azouvi 2017), the implementation of which has been standardised into the Kessler Foundation Neglect Assessment Process (KF-NAP; Chen, Chen et al. 2015). The KF-NAP has excellent interrater reliability ($r = 0.96$, $p < 0.000$) and construct validity with pen and paper tasks (r between 0.70 and 0.72, $p < 0.01$), and correlates well with functional outcome measures (0.75, $p < 0.01$) (Bergego, Azouvi et al. 1995). Given the focus of stroke rehabilitation on recovery of function, the KF-NAP was selected as the assessment of unilateral neglect for Study 5 (Chapter 6).

IMU devices: Current clinical proprioception assessment is not quantified, and as such difficult to track changes over time and correlate to other impairments. Joint angles are typically quantified via goniometry, but this measurement method requires high clinician skill in surface anatomy and manual handling in passive motion assessment that is complex and often requires two clinicians (Keogh, Cox et al. 2019). Additionally, clinical goniometry assessment has a measurement error of ~ 12 degrees (Santos, Ferreira et al. 2012), that is within the healthy participant matching error range of eight and sixteen degrees (Li and Wu 2014, Van de Winckel, Tseng et al. 2017, Ingram, Butler et al. 2019), and thus has limited discriminant ability between impaired and healthy populations.

As detailed in Chapter 1, an accurate, feasible, and low-cost alternative to goniometer assessment of joint position are inertial measurement unit

(IMU) devices (Maceira-Elvira, Popa et al. 2019). Additionally, their validity and reliability in the detection of non-use and motor unilateral neglect is also established (Uswatte, Giuliani et al. 2006, Bailey, Klaesner et al. 2015) and they represent a potential method of integrating proprioception and unilateral neglect assessment. Hence, an IMU device was selected as the method of quantifying position-matching ability using the techniques described by clinicians in the survey study (Chapter 4). An engineer specialised in constructing and running an IMU device for tracking of biological movement was recruited to build the hardware and software for the device used in the study. The full specifications of the device are described in Chapter 5.

Upper Limb – Physiological Profile Assessment (UL-PPA): Issues with the upper limb after stroke can be classified into impairments, activity limitations, and participation restrictions (World Health Organisation, 2021), and each are important to consider in stroke rehabilitation. While clinical assessment of activity limitations and participation restrictions are well established, that of upper limb *impairments* after stroke have several issues. Traditional assessments of somatosensory impairments in light touch, two-point discrimination, and pressure perception have poor correlation to functional recovery (Meyer, Karttunen et al. 2014). Additionally, standardised upper limb-specific impairment batteries such as the Fugl-Meyer Assessment and the Action Research Arm Test take up of 40 minutes to administer, require multiple pieces of equipment, and are validated as functional measures only when the full battery is administered (Gladstone, Danells et al. 2002, Kim, Her et al. 2012, Amano, Umeji et al. 2020).

Uni- and bimanual co-ordination are highly correlated to upper-limb functional recovery after stroke and are simple to test clinically (Pelton, van

Vliet et al. 2012, Kantak, Jax et al. 2017, Lai, Sung et al. 2019). The Upper Limb Physiological Profile (UL-PPA) is a standardised battery of 15 tests that includes tests of uni- and bimanual coordination, developed at Neuroscience Research Australia (Ingram, Butler et al. 2019). Normative values for healthy aged individuals and those with upper limb impairment, correlations of each individual test item to upper limb function, and standard test application protocols have previously been published (Ingram, Butler et al. 2019). Additionally, the UL-PPA contains a test of upper limb activity limitation – shirt donning and buttoning. The strength tests in the UL-PPA were deemed unsuitable for the severity of weakness typical of a person with stroke in an inpatient setting (bicep and handgrip dynamometry in antigravity position). Additionally, the button-press test of reaction time would have been confounded by paresis. Finally, in reliability studies of the original UL-PPA, the differences in mean scores between people with and without upper limb impairment on two point (-0.2, 95%CI [0.7 – 0.3]) and two line discrimination [0.1, 95%CI [-0.01 – 0.2]), and arm stability tests (-0.9, 95%CI [-13.0, 11.3]) were small and non-significant (Ingram, Butler et al. 2019). Thus, to maximise relevance to stroke-severity and function five sub-tests from the UL-PPA were selected for use:

i. Upper limb dexterity assessment (loop and wire task)
ii. Two-hand co-ordination (bimanual pole test)
iii. Finger tapping
iv. Overall upper limb function (shirt buttoning)
v. Sensation (Von Frey Filament, thenar eminence, assessed for purposes of covariate entry into analysis below

Pictorial descriptions of all tests are in Figure 2.1. Testing of all items was conducted according to published protocols, described in Appendix 2.A.

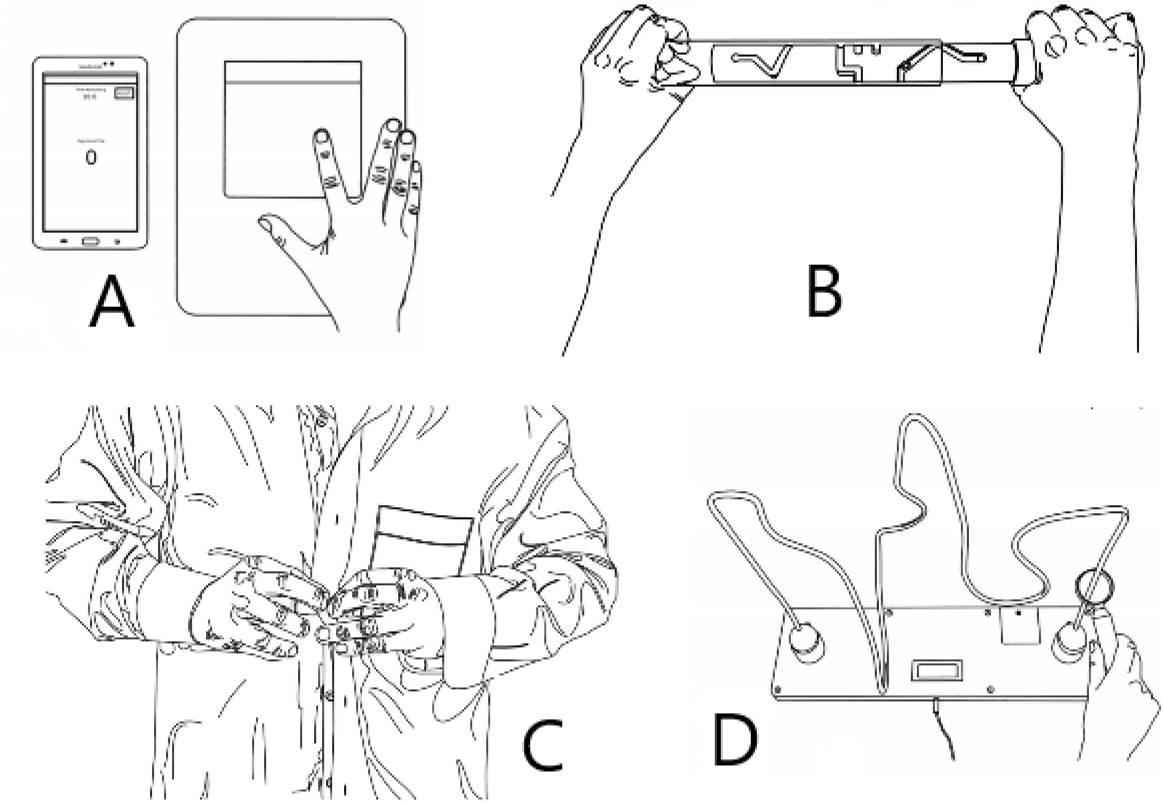

Figure 2. 2: UL-PPA test items used, reproduced with permission from L.A. Ingram.

A: Finger tapping. The participant tapped their dominant index finger up and down onto the tapping sensor as many times as they could over a 10s period. **B: Bimanual pole test.** Holding the swivel stick with one hand at each end, the participant moved through the maze as fast as possible by flexing and extending their wrists in a coordinated manner. The time taken (in seconds) to move the screw from right-to-left and return was recorded as the test score **C: Shirt task.** The standing participant picked up a folded unbuttoned long sleeve shirt and put it on as fast as possible. The test was completed when all six buttons were done-up in their corresponding holes. **D: Loop and wire test**. The participant held the handle attached to the ring and attempted to move the ring through the copper wire maze as fast and as accurately as possible. Two trials were completed, one in each direction

Analysis: Given the study design tested multiple outcome measures, in multiple groups, across multiple time points, a mixed-model analysis was planned (Maurissen and Vidmar 2017). Model fixed factors were group (control, stroke nil neglect, stroke with neglect) and time point (baseline, discharge and follow-up) and random factors were participant, sensory impairment, and lesion location. A mixed-model analysis formed the basis for the sample size calculation, which occurred using the GLIMMSPE program (Kreidler, Muller et al. 2013), an open source software for such calculations with mixed models. Sample size was calculated using neurological deficit as the predictor (either control, stroke or stroke with unilateral neglect, with significance set at 0.05 and power at 0.9). The Hotelling-Lawley Trace was used for statistical analysis. Estimates of position match deficit and upper limb impairment were based on the data from previous similar studies (Cusmano, Sterpi et al. 2014, Nijboer, Kollen et al. 2014). The recommended sample size was 10 participants per group, which was increased to 15 per group to allow for participant drop-out.

Methodological modifications: In March 2020, n = 20 participants had been recruited (6 with unilateral neglect, and 14 without), of which n = 12 had completed admission and discharge assessments, and n = 4 had completed all assessment time points. At the onset of the SARS-COV2 pandemic, the strict government mandated healthcare regulations in Australian hospitals resulted in the complete cessation of recruitment for the study due to the research team being external to the hospitals in which the study recruited. Government restrictions remained in place up until the time of writing. Similar restrictions were in place at the University level, where all face-to face research was interrupted, and as such control participants were also unable to be recruited. At this point, the study was converted to a cross-sectional correlational study. Additionally, the study engineer that had designed and provided the IMU devices for the study left the project and the university abruptly in February 2020 and it was later discovered that their device analysis code was incorrect. In response to this, a new study engineer was recruited (Mr Sam Gilbert, The University of Sydney) and once he had analysed the data from the IMU devices, it was discovered that data from a prototype version of the device that was used for the first 10 people recruited was unusable. Thus, data from ten participants was unable to be included in the analysis, four of whom had unilateral neglect. As such, the study results presented in Chapter 5 are for the remaining 10 participants, and do not reflect the original study design due to circumstances outside of the research team's control.

2.3 Ethical considerations

The key issues of safety and privacy for research participants were considered in all studies of this thesis, in ways appropriate to each study design. For studies that involved clinicians or patients from health facilities ethical approval was sought and gained from the primary site Local Health District (LHD) Human Research Ethics Committee (HREC). Then, Site Specific Assessments (SSA's) were approved for all study sites and ratification was obtained from the UTS HREC. For studies conducted outside health organisations, full ethical approval from the UTS HREC was obtained. Any protocol changes were approved through subsequent application amendments. Protocol and approval numbers are reported in Table 2.4.

Chapter	Primary Approval	Ratification	SSA
Four	UTS HREC, ETH19-4402	Nil	Nil
Six	ISLHD-HREC, ETH17/331	UTS HREC, ETH18/2639	Site 1: STE05989 Site 2: STE05990 Site 3: STE15715
Seven	SESLHD-HREC, ETH01573	UTS HREC, ETH20-5290	Site 1: STE02576
Appendix 1	UTS HREC, ETH20-4951	Nil	Nil

Table 2. 4: HREC approval numbers for each thesis chapter
Key: ISLHD: Illawarra Shoalhaven Local Health District, SESLHD: South Eastern Sydney Local Health District

Privacy, confidentiality, and voluntary participation were all important principles in the design and conduct of the research included in this thesis.
All participants gave full, written, informed consent for their participation in each study after reading an HREC approved participant information statement, which clearly stated that the decision to participate was voluntary and non-binding.
No identifying information was provided in any publication or report arising from this work. No identifying data were collected for either survey study. All focus group data was audio and video recorded for transcription using password protected, UTS hosted Zoom (Zoom Communications Inc, 2021) meetings, and de-identified on transcription. Paper-based data collection forms were securely stored in a locked filing cabinet at UTS, while electronic information was stored on the password protected UTS hosted CloudStor server (AARnet 2021) including focus group recordings that were automatically stored from Zoom onto the platform.

2.4 Chapter summary

This thesis has a foundation in evidence translation to clinical practice, and is thus underpinned by the epistemological paradigm of pragmatism. To achieve the aims of this thesis, four phases of research were developed: Synopsis; Evaluation, Awareness, and Acceptance; Ability and Action; and Development. The first phase, the Synopsis phase, aimed to establish the nature and extent of proprioception impairment in people with unilateral neglect after stroke. Chapter 3 describes the systematic review undertaken to address this aim.

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Chapter 3: Proprioception in unilateral neglect after stroke - A systematic review

Fisher, G., Quel de Oliveira, C., Verhagen, A., Gandevia, S., & Kennedy, D. (2020). Proprioception impairment in unilateral neglect after stroke: A systematic review. *SAGE Open Medicine, 8*, 2050312120951073. doi:10.1177/2050312120951073

Author contribution statement

As primary supervisor, I confirm that Georgia Fisher made the following

contributions:

- Formulation of objectives
- Database searches
- Data extraction and data analysis/interpretation in collaboration with co-authors
- Writing of the first draft of the paper, with subsequent drafts developed in
- collaboration with co-authors
- Journal revisions and resubmissions.

Date: 12th May 2021

Dr David Kennedy

Systematic Review

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Proprioceptive impairment in unilateral neglect after stroke: A systematic review

Georgia Fisher[1], Camila Quel de Oliveira[1], Arianne Verhagen[1], Simon Gandevia[2,3] and David Kennedy[1,2]

Abstract

Introduction: Unilateral neglect is a debilitating condition that can occur after stroke and can affect a variety of domains and modalities, including proprioception. Proprioception is a sensorimotor process essential to motor function and is thus important to consider in unilateral neglect. To date, there has not been a comprehensive review of studies examining the various aspects of proprioceptive impairment in unilateral neglect after stroke. This review aimed to determine if people with unilateral neglect have more severe proprioceptive impairments than those without unilateral neglect after stroke.
Methods: The MEDLINE, Embase, Scopus, CINAHL and Web of Science databases were searched from inception to September 2019 using an a priori search strategy. Two independent reviewers screened abstracts and full texts, and extracted data from the included full texts. A third reviewer resolved disagreements at each step. Risk of bias was assessed using the AXIS Quality Assessment tool.
Results: A total of 191 abstracts were identified, with 56 eligible for full-text screening. A total of 18 studies were included in the review and provided evidence that people with unilateral neglect have more severe proprioceptive impairment than people without unilateral neglect. This impairment is present in multiple subtypes of unilateral neglect and aspects of proprioception. Most studies had a moderate risk of bias.
Conclusion: People with unilateral neglect after stroke are more likely to have impaired processing of multiple types of proprioceptive information than those without unilateral neglect. However, the available evidence is limited by the large heterogeneity of assessment tools used to identify unilateral neglect and proprioception. Unilateral neglect and proprioception were rarely assessed comprehensively.
PROSPERO Registration: CRD42018086070.

Keywords
Rehabilitation, sensorimotor, neurology, unilateral neglect, proprioception, stroke, systematic review

Date received: 5 April 2020; accepted: 24 July 2020

Introduction

Unilateral neglect (UN) is an umbrella term for a range of clinical presentations, characterised by the failure to report, respond, or orient to novel or meaningful stimuli presented on the side opposite to the brain lesion.[1] Depending on the method used for assessment, UN is estimated to affect 23.5%–67.8%[2,3] of people after stroke. However, the most commonly used assessments (cancellation tasks and National Institutes of Health Stroke Scale (NIHSS) Item 11) indicate the incidence is ~30%.[4,5] UN is linked to greater length of hospital stay, higher incidence of falls, and a reduced likelihood of home as a discharge destination.[2,6–9] These negative sequelae are largely due to the poor functional outcomes that are associated with UN,

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which persist at 1-year post-stroke in 30%–60% of patients.[10–12] Despite the high incidence and negative functional consequences of UN, there is no consensus about effective yet clinically feasible assessment and treatment strategies for the condition.[13–17]

The lack of appropriate assessments and effective treatment strategies is an indication of the complexity of UN. UN is often associated with larger lesion volumes[3] and is not the result of lesions in a single location. Rather, it is the result of impaired functional connectivity between brain regions associated with attention, sensorimotor and visual processing, notably the frontoparietal networks.[18–20] As a result, symptoms of UN are varied and can present in a range of domains (visuospatial, auditory and sensorimotor) and spaces (personal, peri-personal and extra-personal).[21,22]

Clinical assessment of UN should target a combination of these domains and spaces, and yet, many current standardised clinical assessments are limited to only one.[13] The most common form of UN assessment uses pen-and-paper tasks, including line bisection, shape cancellation, or figure copying.[14] These tasks are unable to capture visuospatial neglect in the peri-personal and extra-personal spaces and do not account for auditory or sensorimotor domains.[13] Given this limited assessment scope, it is not surprising that UN is often considered a singular condition and associated solely with visuospatial impairment, neglecting other domains, and thus, the heterogeneous nature of the condition.[9,23]

Importantly, a sensorimotor impairment in UN that is often clinically neglected is proprioception.[24] Proprioception, as defined by Sherrington in 1906, derives from the Latin word *proprius*, meaning 'one's own', combined with the concept of perception and thus refers to 'perceiving one's own self'.[25] Proprioception is largely considered as the processes enabling joint movement, position detection and muscle force judgement (for review, see Hillier et al.[25]). However, information about the size and shape of body parts is crucial for proprioception.[26] Explicitly, to sense the position and movement of 'one's own self' is impossible without the information about what that 'self' is. Therefore, an updated and emerging definition of proprioception includes the body representation, defined as the stored internal model of the body and its parts.[26–28] Distinct methods of assessing body representation include judgement of laterality, body axes and body topography.[29,30]

Standardised clinical assessments of proprioception typically involve the detection or judgement of passively imposed joint movements in the absence of vision.[31,32] These capture a patient's ability to detect when and where a body part is moving, without accounting for body representation.[33] Skilled movement emerges from the judgement of movement direction, magnitude and the nature of the moving parts, provided by the body representation. Given that stroke rehabilitation focuses largely on the restoration of skilled movement, it is important to consider impairments in all aspects of proprioception. In the context of the complex presentation of UN, it is conceivable that multiple aspects of proprioception are impaired. However, this is unknown because, to date, no review examining proprioception in UN has been conducted.

Impaired proprioception is associated with poor motor and functional outcomes at all stages of stroke.[34,35] Thus, it should be an essential target in stroke rehabilitation, particularly in patients with UN. Therefore, the primary aim of this systematic review is to determine whether proprioception, including the body representation as part of the definition, is more impaired in people with UN compared to those without after a stroke. The secondary aims are to identify the assessments used to detect UN and its domains (e.g. spatial, extra-personal).

Methods

Protocol and registration

The protocol for this systematic review is registered in PROSPERO, under the registration number CRD42018086070 and can be accessed at the following link: https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=86070.

Eligibility criteria

Studies were included if they met the following criteria: (1) cross-sectional design or intervention studies that provided cross-sectional data at baseline, (2) participants were adults aged 18 years and over, (3) participants had first-time stroke confirmed on medical imaging, (4) employed at least one standardised assessment of UN, and (4) at least one assessment of proprioception and (5) had data reported for participants with UN (UN+) and without (UN−). There was no restriction on publication year or language. Studies were excluded if they used clinical tests that assessed only balance and/or vestibular function and/or sensorimotor function that was not specific to proprioception.

Search strategy and study selection

This review followed Cochrane Methodology and Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) reporting guidelines.[36] The CINAHL, Embase, MEDLINE, Scopus and Web of Science electronic databases were searched from inception to 10 September 2019 using a pre-established search strategy developed by all members of the study team and reviewed by a university librarian (Supplemental Appendix 1). Two review authors (G.F. and D.K.) screened abstracts and full texts independently, and a third review author (C.Q.d.O.) resolved disagreements at each step of study selection. Screening was conducted using the Covidence software. Studies in languages other than English were translated using an online translation service.

Data extraction

Two review authors (G.F. and C.Q.d.O.) independently extracted data using a standardised excel spreadsheet based on the Cochrane Data Extraction Template.[37] Extracted information included studies' authors, year, aims, setting, population, procedures; participant's recruitment, demographics and baseline characteristics, and completion rates; type of outcome measures used to assess UN and proprioception, assessment data for UN and proprioception with time points of collection; and the suggested mechanisms of interaction between proprioception and neglect. Determination of UN was based on standardised and validated clinical or laboratory tests developed to assess UN, such as Albert's Test,[38] Rivermead Behavioural Inattention Test (BIT)[39] and Catherine Bergego Scale (CBS)[40] (for summary, see Menon and Korner-Bitensky[13]). Assessment of proprioception included standardised tests in any of the following categories: (1) movement detection/direction discrimination, for example, the distal proprioception test;[41] (2) joint position judgement or reproduction for example, the Wrist Position Sense Test;[42] (3) force judgement or matching, for example, finger force reproduction as per Walsh et al.;[43] and (4) tests of body representation, for example, the Recognise™ App for hand laterality.[44] Assessments of proprioception that had not been formally validated were eligible for inclusion, given the lack of research into tests of certain aspects of proprioception. Where information was not available in the published study, details were requested from the corresponding author.

Risk of bias assessment

Risk of bias was evaluated by two review authors (G.F. and C.Q.d.O.), independently using the Appraisal tool for Cross-Sectional Studies (AXIS), a 20-item scale developed using a Delphi panel consensus assessing 5 domains – Introduction (1 item), Methods (10 items), Discussion (5 items), Conclusion (2 items), and Other (2 items).[45] The AXIS requires a Yes/No/Unsure assessment for each item, for example, 'Was the sample size justified?' and 'Were the results for the analyses described in the methods presented?' The full list of AXIS items is reported in Supplemental Appendix 4. Disagreements were resolved through discussion and when necessary, with a third review author (D.K.). Prior to discussion, percent agreement between the two reviewers on AXIS items was 90.28%. The AXIS acknowledges the issues with the summation of checklists for study quality,[46,47] and as such, does not have published cut-off scores to categorise studies as low, medium, or high risk of bias.[45] Therefore, the authors used a quartiles system for categorising risk of bias according to the number of AXIS items met (low risk >15, moderate risk 10–15, high risk 4–9 and very high risk <4).[48]

Summary measures and data synthesis

A descriptive synthesis of (1) between-group differences of UN+ and UN− stroke patients, and (2) types of assessments of UN and proprioception used in the included studies was conducted. The summary of study results was presented in separate tables for continuous (mean values and standard deviations, medians and interquartile range (IQR)) and dichotomous data (percentages and total number of participants). Effect size was calculated using Hedges g for continuous outcomes due to small and uneven group sizes[49] and odds ratios for dichotomous outcomes.[50] Risk of bias assessment was descriptively synthesised and presented in tabular format.

Results

Study selection

A total of 284 titles and abstracts were identified, with 191 eligible for abstract screening after duplicate removal, and 56 eligible for full-text screening. A total of 18 studies were included in the review[23,51–67] (see Figure 1). The predominant reasons for exclusion at full-text review were inadequate data reporting and a lack of a measure of proprioception. The full list of excluded studies and the reasons for their exclusion can be found in Supplemental Appendix 2.

Study characteristics

Population. The complete characteristics of the participants included in the studies are summarised in Table 1. A combined total of 959 participants were included in the studies, 246 in the UN+ group and 713 in the UN− group. All studies had a small sample size (mean = 50, SD = ±68, range = 6–281). The mean age and standard deviation were 60.3 ± 5.4 years (UN+ = 60.9 ± 5.6, UN− = 59.8 ± 5.4), and the majority of participants were male (65%). Most studies recruited participants in the sub-acute phase (3 weeks to 6 months post-stroke); however, two studies[59,63] collected data from participants in the chronic phase (more than 6 months after stroke). Five studies[23,53,64–66] recruited stroke populations in different phases (chronic, acute, sub-acute), and one study[67] limited recruitment to the acute phase (less than 3 weeks post-stroke).

Proprioception assessment. Proprioception was assessed by 13 different methods across the studies, as described in Table 2. Three studies[62,63,67] assessed solely the detection or discrimination of movement. Five studies[60–62,64,65] assessed proprioception via a limb-matching task. Of the four studies[51,54,59,67] that examined laterality, three[51,54,59] used a hand laterality task and one[67] utilised a laterality task in which participants were required to point to the left or right hand of human stick figure drawings in various orientations. Five studies[52,55,56,58,66] used an assessment that required

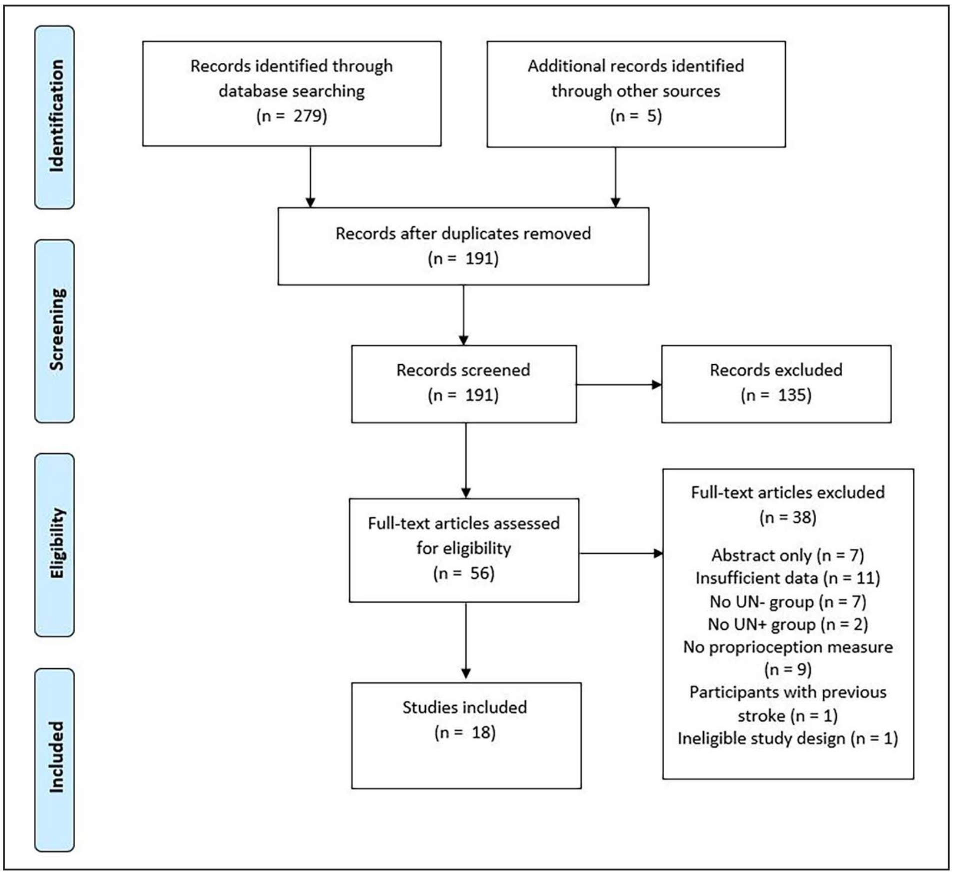

Figure 1. Flow of studies through review.

participants to identify the location of the body midline or a body axis. Finally, three studies[23,53,57] examined perceptions of body topography by asking participants to arrange tiles printed with body parts, detect targets placed on their body and localise points stimulated on their trunk, respectively. A single study[67] reported two distinct proprioception outcomes, laterality and movement detection. No study investigated force matching.

Risk of bias

According to the AXIS risk of bias assessment, 2 studies were rated as low risk of bias,[52,66] 12 as moderate risk of bias[23,51,54,56,58–65,67] and 3 as high risk of bias[53,55,57] (see Table 3, with full AXIS items and result reported in Supplemental Appendices 3 and 4). The two studies using the CBS as a measure of UN had an AXIS rating of low[52] and high risk of bias.[57] The main sources of risk of bias were sampling strategy, and consistency in reporting participant characteristics and results for all planned analyses. All studies defined their target population, reported internally consistent results, and justified their discussion and conclusions. Only one study[52] justified their sample size and reported non-response to recruitment. Twelve studies[23,51,53–58,60,61,65,66] failed to report their methodological limitations and four studies[53,57,60,61] did not employ a validated assessment tool for UN. Five studies[23,53–56] did not present results for all planned analyses and six[55,57–59,63,67] did not provide sufficient participant demographic data. Finally, seven studies[51,53,55,57,58,63,65,67] used convenience samples.

Synthesis of results

Proprioceptive impairment in UN. The majority of studies in this review support the existence of more severe proprioceptive impairment in UN+ compared to UN−. The two studies with low risk of bias reported conflicting results on the relationship between proprioceptive impairment and UN. One study[52] reported a body axis judgement error correlation of $r=-0.61$ and $r=-0.56$ for the CBS and Line Bisection Test, respectively, indicating that individuals with UN had more severe proprioceptive impairment. Another study[66] reported a mean difference of 2.4 cm in forearm bisection measurement between people with and without UN, with a small effect size indicating

Table 1. Characteristics of included studies, by proprioceptive test type.

Author	Setting	Time since stroke	Sample size		Age (mean, SD)		Lesion side	
			UN+	UN−	UN+	UN−	UN+	UN−
Movement detection/judgement								
Meyer et al.[62]	Inpatient rehab	Sub-acute	27	95	68 (60.2–77.7)[a]	66.7 (58.7–75.7)[a]	NR	NR
Schmidt et al.[63]	NR	Chronic	7	15	61.7 (14.8)	66.3 (12.2)	R=7	R=15
van Stralen et al.[67]	ASU	Acute	9	47	58.9 (12.4)	61.5 (16.1)	R=8, 1=NR	R=14, L=33
Joint position matching								
Borde et al.[61]	NR	NR	6	3	63.3 (9.4)	62.33 (5.77)	R=6	R=3
Borde et al.[60]	Inpatient rehab	Sub-acute	10	20	63.4 (8.8)	62.5 (11.9) + 61.2 (15.5)[b]	R=10	R=10, L=10
Semrau et al.[65]	ASU, Inpatient rehab	Acute, sub-acute	35	123	59 (20–86)	63 (18–89)	R=31, L=4	R=67, L=55, B=1
Semrau et al.[64]	ASU, Inpatient rehab	Acute, sub-acute	59	222	62.32 (15.19)	60.64 (14.46)	NR	NR
Laterality								
Baas et al.[51]	NR	NR	7	15	51.47 (13.62)	61.29 (7.89)	R=7	R=15
Coslett[54]	NR	Sub-acute, chronic	3	3	63.67 (10.41)	58.67 (11.37)	NR	NR
van Stralen et al.[67]	ASU	Acute	9	47	58.9 (12.4)	61.5 (16.1)	R=8, 1=NR	R=14, L=33
Vromen et al.[59]	Inpatient rehab	Chronic	8	12	55.3 (8.4)	59.5 (6.9)	R=8	R=12
Body axis/midline								
Barra et al.[52]	NR	Sub-acute	10	8	63.6 (7.53)	53.12 (18.26)	R=7, L=3	R=3, L=5
Heilman et al.[55]	NR	NR	5	5	48 (10.3)	58.6 (6.27)	R=5	L=5
Richard et al.[56]	Inpatient rehab	Sub-acute, chronic	8	8	61.13 (12.45)	52.13 (13.61)	R=8	R=8
Saj et al.[58]	Inpatient rehab	NR	6	6	58 (12.7)	59.2 (11.2)	R=6	R=6
Tosi et al.[66]	Inpatient rehab	Acute, chronic	7	38	68.42 (7.23)	65.97 (12.5)	R=7	R=16, L=21, B=1
Body topography								
Cocchini et al.[53]	Inpatient rehab	Sub-acute	14	24	67.21 (8.43)	58.00 (10.7) + 59.45 (15.9)[b]	R=14	R=13, L=11
Di Vita et al.[23]	NR	Sub-acute, chronic	7	16	65.29 (10.29)	64.44 (13)	R=6, L=1	R=12, L=4
Rousseaux et al.[57]	NR	NR	9	6	53.1 (13.2)	46.3 (9.3)	R=9	R=6

SD: standard deviation; UN: unilateral neglect; UN+: participants with UN; UN−: participants without UN; NR: not reported; ASU: acute stroke unit; R: right; L: left; B: bilateral.
[a]Median and IQR presented.
[b]Two UN− groups, first listed (R) side lesion, second (L) sided lesion. Acute defined as <3 weeks post-stroke, sub-acute 3 weeks to 6 months post-stroke, and chronic >6 months post-stroke.

greater proprioceptive impairment in UN+ group (Hedges g=0.22). Of the 13 studies with a moderate risk of bias, 77% (n=10) reported medium or large effect sizes indicating more severe proprioceptive impairment in people with UN.

The studies with the largest sample size[64,65] reported large and moderate effect sizes (Hedges g=1.59 and 1.43, and 0.63, respectively) indicating greater proprioceptive impairment in people with UN than those without. All three studies with a high risk of bias[53,55,57] reported significantly more severe proprioceptive impairment in UN+. A descriptive synthesis of the findings of the included studies' results is presented in Table 4 (continuous outcomes) and Table 5 (dichotomous outcomes) broken down by proprioceptive test subtype.

UN assessment. There were a total of 18 different assessment tools used to assess UN, with 12 studies[23,51–54,56–61,63] using more than one outcome measure to assess UN (see Table 2). Nine studies[53–56,58,60,62,63,67] used pen-and-paper tests alone to identify UN, and two studies[51,66] used outcome measures that assessed personal neglect solely. Two studies[59,61] used a combination of a pen-and-paper task with a self-reported measure of UN and an environmental observation task, respectively. Two studies[64,65] used a behavioural assessment in isolation (the BIT), while two studies[52,57] added a functional assessment of UN (the CBS) to pen-and-paper cancellation and bisection tasks.

Discussion

Summary of evidence

We found moderate risk of bias in the majority of studies that demonstrated that people with UN after stroke have

Table 2. Assessment descriptions.

Author	UN test(s)	Type of UN assessment	Proprioception test(s)
Movement detection			
Meyer et al.[62]	SCT	Pen and paper	Em-NSA, TFT (0–3)
Schmidt et al.[63]	LeCT, SCT, LBT, Figure Copying, Reading Test	Pen and paper	Arm Position Test–Error
van Stralen et al.[67]	SCT	Pen and paper	RASP
Joint position matching			
Borde et al.[61]	LCT, Observation, Environment Description, Double Letter Cancellation	Pen and paper, Extra-personal	Upper limb position reproduction, TFT
Borde et al.[60]	LBT, LeCT	Pen and paper	Upper limb position reproduction
Semrau et al.[65]	BIT	Behavioural	Robotic Arm Position Matching Task, TFT
Semrau et al.[64]	BIT	Behavioural	Robotic Arm Position Matching Task
Laterality			
Baas et al.[51]	Fluff test (primary), LBT, BCT	Personal	Hand Laterality
Coslett[54]	LBT, SCT, LCT	Pen and paper	Hand Laterality
van Stralen et al.[67]	SCT	Pen and paper	Bergen Laterality Test
Vromen et al.[59]	SCT, subjective neglect questionnaire	Pen and paper, self-report	Hand Laterality
Body axis/midline			
Barra et al.[52]	BCT, CBS, LBT	Pen and paper, functional	Longitudinal Body Axis
Heilman et al.[55]	LBT	Pen and paper	Pointing to body midline
Richard et al.[56]	BCT, Scene Copy, LBT (2/3)	Pen and paper	Pointing to body midline
Saj et al.[58]	BCT, LBT, Scene Copy	Pen and paper	Longitudinal Body Axis
Tosi et al.[66]	Biasch's Test	Personal	Arm bisection task
Body topography			
Cocchini et al.[53]	SCT, LCT	Pen and paper	Body Exploration Fluff Test
Di Vita et al.[23]	LeCT, LCT, Use of Common Objects Test, Sentence Reading, Wundt–Jastrow Area Illusion	Personal	Body Topography
Rousseaux et al.[57]	LBT, BCT, CBS	Pen and paper, functional	Tactile Stimulation Localisation

UN: unilateral neglect; SCT: star cancellation test; Em-NSA: Erasmus Modifications to the Nottingham Sensory Assessment; TFT: thumb finding test; RASP: Rivermead Assessment of Somatosensory Perception; LCT: line cancellation; LeCT: letter cancellation; LBT: line bisection test; BIT: behavioural inattention test; BCT: bell cancellation; CBS: Catherine Bergego Scale.

more severe proprioceptive impairments than those without. The assessment of UN was commonly limited to pen-and-paper tests designed to capture peri-personal hemi-spatial UN with minimal usage of UN tests that assess the impact of UN on functional activities. Multiple subtypes of proprioception were impaired, including movement detection, joint position matching, and the judgement of laterality, body axes and body topography. Deficits in spatial orientation and exploration in UN may be due to the disruption of distributed cortical networks controlling attention anchored in an egocentric frame of reference.[68] Importantly, this egocentric frame of reference depends extensively on proprioceptive, visual and vestibular inputs.[69] The results of this review suggest that proprioceptive deficits may underlie the disruption to the egocentric reference frame contributing to other impairments seen in UN.

Proprioception assessment

Proprioception is a complex sensorimotor process, with multiple aspects that contribute to adequate motor function. The finding that multiple types of proprioceptive impairment are present in people with UN is important for two major reasons. First, despite its importance to function, the majority of Stroke Guidelines[17,70–72] do not include any recommendations for assessment or treatment of proprioceptive deficits, and subsequently, it is absent from national audits of stroke rehabilitation. Thus, it is likely that proprioceptive impairments are not being assessed and subsequently treated in this population. Second, the standardised clinical tools to test proprioception such as the Erasmus Modification of the Nottingham Sensory Assessment and the Rivermead Assessment of Somatosensory Perception solely assess simple movement detection. These tools use an ordinal grading system, defining

Table 3. AXIS risk of bias assessment summary – percentages of items satisfied.

Author	Intro	Methods	Results	Conclusions	Other	Risk
Baas et al.[51]	100%	60%	75%	50%	50%	Moderate
Barra et al.[52]	100%	90%	80%	100%	100%	Low
Borde et al.[61]	100%	80%	90%	50%	0%	Moderate
Borde et al.[60]	100%	70%	100%	50%	100%	Moderate
Cocchini et al.[53]	0%	20%	50%	50%	0%	High
Coslett[54]	100%	70%	75%	50%	0%	Moderate
Di Vita et al.[23]	100%	70%	75%	50%	100%	Moderate
Heilman et al.[55]	100%	40%	25%	50%	50%	High
Meyer et al.[62]	100%	80%	75%	100%	100%	Moderate
Richard et al.[56]	100%	80%	50%	50%	50%	Moderate
Rousseaux et al.[57]	100%	60%	50%	50%	50%	High
Saj et al.[58]	100%	60%	50%	50%	100%	Moderate
Schmidt et al.[63]	100%	50%	50%	100%	100%	Moderate
Semrau et al.[65]	100%	70%	75%	50%	50%	Moderate
Semrau et al.[64]	100%	70%	75%	100%	50%	Moderate
Tosi et al.[66]	100%	90%	80%	50%	100%	Low
van Stralen et al.[67]	100%	70%	75%	100	100%	Moderate
Vromen et al.[59]	100%	80%	75%	100%	100%	Moderate

the patient's proprioception as normal, impaired or absent (reducing sensitivity to change)[31,32] and have no correlation with patient function and activity.[73] In addition, over 75% of Australian physiotherapists and occupational therapists report using non-validated proprioception assessment tools.[74] Thus, standardised clinical assessments of proprioception fail to capture multiple aspects of the sense and have limited clinical utility. Furthermore, it is unknown what aspects of proprioception are assessed in clinical practice.

UN assessment

The predominant bias of UN assessment to the visuospatial domain suggests that the processing of proprioceptive information is impaired in this type of UN. The studies in this review that did use assessments of other aspects of UN support the notion that proprioceptive information is also neglected in other domains of the condition. However, further evidence is required in order to draw conclusions about proprioceptive impairment outside the traditional definition of visuospatial UN.

This is relevant for two reasons. First, the tendency of researchers and clinicians to consider UN a *visuospatial* disorder alone means that rehabilitation targets impairments only in this domain and that proprioceptive deficits are rarely considered. Second, multiple issues such as poor reliability, lack of ability to detect change, and the allowance for compensation to skew results limit the usefulness of pen-and-paper assessments of UN.[13,75] Moreover, these tests correlate weakly with functional outcomes,[76] which is important given the negative impact of UN on patient functional capacity. Also, the use of pen-and-paper assessments fails to capture a subset of patients with milder presentations of UN, which still likely contribute to functional deficits. However, in the acute stroke setting, there are more significant functional restrictions, and thus, these tests may be useful as a screening tool for UN at this stage. Where possible, assessment using an ecological tool such as the CBS would provide better insight on the impact of UN on function during the rehabilitation process. Importantly, only two included studies used the CBS, one rated as high and one as low on the AXIS scale.[52,57] Thus, the presence of proprioception impairment in ecologically defined UN is largely unknown.

Proprioception and UN in clinical practice

The results of review suggest that higher levels of proprioceptive impairment could be a contributing factor in the poorer functional recovery seen in people with UN after stroke. However, despite being the most comprehensive tool available, the CBS does not directly measure the level of proprioceptive impairment present in UN. There is a clear need for a clinical assessment of UN that includes tests that are sensitive to impaired proprioception.

However, the clinical assessment of proprioception is currently inconsistent, frequently non-standardised and there is little data available on what constitutes a minimal clinically important difference (MCID). Importantly, assessment is typically focused solely on position detection. Thus, it is unsurprising that investigation of proprioceptive treatment often has a similar focus.[77,78] Broadening the scope of clinical assessment to include multiple aspects of proprioception is likely to broaden the scope of investigation of treatment strategies. For example, recent studies using somatosensory stimulation (mostly neuromuscular electrical stimulation)[79,80] to provide increased proprioceptive input show promising results in people after stroke. Improvements are thought to be due, in part, to the reintegration of the internal representations

Table 4. Comparison of proprioceptive impairments between UN+ and UN− (continuous outcomes).

Study	Proprioception outcome	UN+		UN−		Hedge's g	Impaired group (effect size)
		Mean (SD)	N	Mean (SD)	N		
Movement detection							
Meyer et al.[62]	Em-NSA (median, IQR)	*7.0 (2.0–8.0)*	*27*	*8.0 (7.0–8.0)*	*95*	UTD	UN+ (p < 0.05)[a]
	TFT Score (0–3) (median, IQR)	*1.0 (1.0–2.0)*	*27*	*0 (0–1.0)*	*95*	UTD	UN+ (p < 0.05)[a]
Schmidt et al.[63]	Arm Position Test–Error	7.5 (1.0)	7.0	4.5 (0.6)	15	3.88	UN+ (large)
Joint position matching							
Borde et al.[61]	Reproduction Error n – paretic upper limb	7.8 (2.5)	6	5 (5)	3	0.73	UN+ (medium)
	Reproduction Error n – healthy upper limb	3.3 (3.5)	6	1.7 (4.6)	3	0.37	UN+ (small)
	TFT Error	7.5 (2.7)	6	6.7 (2.9)	3	0.26	UN+ (small)
Borde et al.[60]	Reproduction Error Total n	12.9 (7.7)	10	9.8 (7.8)	10[b]	0.38	UN+ (small)
	Reproduction Error No Vision n	7.2 (5.1)	10	6.2 (5.4)	10[b]	0.18	Nil
Semrau et al.[65]	TFT Score (0–3)	1.3 (1.1)	35	0.7 (0.9)	123	0.63	UN+ (medium)
Semrau et al.[64]	Kinesthetic Score Vision (lower = better)	3.9 (1.7)	59	1.8 (1.2)	222	1.59	UN+ (large)
	Kinesthetic Score No Vision (lower = better)	4.3 (1.4)	59	2.4 (1.3)	222	1.43	UN+ (large)
Laterality							
Baas et al.[51]	Hand Laterality % Error	25 (5)	7	14 (3)	15	2.85	UN+ (large)
Coslett[54]	Hand Laterality (L) % Error	41.7 (13.5)	3	6.7 (9.9)	3	2.37	UN+ (large)
	Hand Laterality (R) % Error	16.3 (9.1)	3	7.3 (8.1)	3	0.84	UN+ (large)
Vromen et al.[59]	Hand Laterality % Error	37.6 (21.5)	12	14.1 (14.7)	8	1.18	UN+ (large)
Body axis / midline							
Heilman et al.[55]	Pointing to body midline–Midline Deviation	8.8 (NR)	5	-1.2 (NR)	5	UTD	UTD
Richard et al.[56]	Pointing to body midline–Midline Deviation	9.4 (12.5)	8	1.6 (1.8)	8	0.83	UN+ (large)
Saj et al.[58]	Longitudinal Body Axis Translation Head	2.3 (2.0)	6	-0.3 (1.4)	6	1.39	UN+ (large)
	Longitudinal Body Axis Translation Trunk	5.9 (5.8)	6	-0.5 (1.1)	6	1.42	UN+ (large)
	Longitudinal Body Axis Rotation Head	-4.6 (2.2)	6	-2.5 (1.5)	6	-1.03	UN+ (large)
	Longitudinal Body Axis Rotation Trunk	-4.6 (3.3)	6	-2.3 (1.9)	6	-0.79	UN+ (medium)
Tosi et al.[66]	Arm Bisection Task	69.7 (11.7)	7	67.3 (10.7)	37	0.22	UN+ (small)
Body topography							
Di Vita et al.[23]	Body topography % Error	42.9 (27.5)	7	16 (17.2)	16	1.17	UN+ (large)
Rousseaux et al.[57]	Localisation – Total Deviation	1.8 (11.4)	9	0.2 (7.8)	6	0.16	Nil
	Localisation – Left Point Deviation	13.4 (13.2)	9	4.5 (9.5)	6	0.78	UN+ (medium)

UN: unilateral neglect; UN+: participants with UN; UN−: participants without UN; SD: standard deviation; Em-NSA: Erasmus Modifications to the Nottingham Sensory Assessment; IQR: interquartile range; UTD: unable to determine; TFT: thumb finding test; L: left; R: right; NR: not reported.
Effect size determined using cut offs of 0.2 for small, 0.5 medium, and 0.8 large as reported by Lakens.[49]
[a]More impaired group determined by p values in study due to median and IQR reporting.
[b]Data reported for UN− group with right hemisphere damage only.

of the stimulated body parts. There is thus a clear need for a simple but comprehensive battery of proprioceptive tests to address the issues with clinical assessment of proprioception in general stroke populations. Once established, these tests could be incorporated into the clinical assessment of UN to enable identification of the multiple sensorimotor impairments present in this population.

Limitations of the study

Adopting a broad definition of proprioception is both a strength and limitation of this review. On one hand, the unification of multiple components of an essential sensorimotor process allows more functional, and thus clinically relevant, conclusions to be drawn. However, it also limits the strength of the conclusions of this review, due to the heterogeneity in data. This is a strong argument for further research in UN that comprehensively defines proprioception.

A further limitation of this review is the small sizes of the UN+ groups in the included studies (mean = 13 SD = ±14, range = 3–59). Eight studies with a collective sample size of 504 participants were excluded at full-text review due to insufficient reporting of data. All authors were contacted to request data, but the data were either unavailable or no reply was received. The inclusion of these data may change the strength of or the findings of the

Table 5. Comparison of proprioceptive impairments between UN+ and UN− (dichotomous outcomes).

Study	Proprioception outcome	N+		N-		Odds ratio (95% CI)	More impaired group
		%	N	%	N		
Movement detection							
Meyer et al.[62]	Em-NSA	48.1	27	15.8	95	4.95 (1.94–12.61)	UN+
	TFT (0–3)	77.8	27	47.4	95	3.89 (1.44–10.49)	UN+
van Stralen et al.[67]	RASP–Impaired	100	9	25.7	35	53 (2.81–1001.40)	UN+
Joint position matching							
Semrau et al.[65]	Robotic Arm Position Matching Task–Failure	100	35	59	123	48.78 (2.92–813.68)	UN+
Semrau et al.[64]	Robotic Upper Limb Position Match–Impaired+/−vision	85	59	38	222	9.12 (4.27–19.51)	UN+
Laterality							
van Stralen et al.[67]	Bergen Laterality Test Total Failure	25.7	9	11.1	35	2.21 (0.34–14.59)	Nil
Body topography							
Cocchini et al.[53]	Body Exploration Fluff Test–Impaired	71.4	14	16.7	24	12.5 (2.57–60.70)	UN+

UN: unilateral neglect; UN+: participants with UN; UN−: participants without UN; CI: confidence interval; Em-NSA: Erasmus Modifications to the Nottingham Sensory Assessment; TFT: thumb finding test; RASP: Rivermead Assessment of Somatosensory Perception.

present review. In addition, the data of this review come from studies with a predominately moderate risk of bias which limits the strength of the conclusions.

Finally, heterogeneity of studies and the reporting of data did not allow for meta-analysis. There is a clear need to establish consensus on standard assessments of both UN and proprioception in research and clinical settings to reduce heterogeneity, which would allow stronger conclusions in future reviews.

Conclusion

We found that people with UN after stroke are more likely to have impaired processing of proprioceptive information than those without UN. These impairments occur across a variety of different subtypes of UN and aspects of proprioception. Assessment of both UN and proprioception is highly inconsistent, which likely reflects current clinical practice. Future investigations in this area should prioritise comprehensive and functional assessments of UN that include an assessment of proprioception.

Clinical messages

- In UN after stroke:
  - Proprioceptive impairment is likely common and should be specifically assessed.
  - Proprioceptive impairment can present in multiple ways, including (but not limited to) deficits in movement detection and position matching but also in body representation.
  - Assessment of both UN and proprioception is frequently non-comprehensive, which likely reflects clinical practice.

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Supplemental material

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Chapter summary

This chapter (Chapter 3) described a systematic review of proprioceptive impairment in unilateral neglect after stroke. This review found that people with unilateral neglect after a stroke have more frequent and severe proprioceptive impairment than those people who do not have unilateral neglect. A secondary finding of the review was the significant heterogeneity of assessment tools used to assess proprioception. At present, it is not known if this is also the case in clinical practice which was the basis for the Evaluation, Awareness, and Acceptance phase of this thesis. The next chapter (Chapter 4) describes this phase, a survey investigation of clinical proprioception assessment in stroke rehabilitation.

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Chapter 4: Proprioception assessment in stroke rehabilitation: a survey of Australian physiotherapists and occupational therapists

Author contribution statement

As primary supervisor, I confirm that Georgia Fisher made the following contributions:

- Formulation of objectives
- Creation of the human research ethics application and liaison with the appropriate Human Research Ethics Committees for approval
- Survey design and deployment management
- Data collection and analysis in collaboration with CQO
- Writing of the first draft of the paper, with subsequent drafts developed in collaboration with co-authors

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Dr David Kennedy

Abstract

Proprioceptive impairment is a common and functionally important sequela of stroke. There is a significant difference between best-practice as recommended by the literature and actual clinical practice (evidence-practice gap) in proprioception assessment after stroke. Standardised assessment tools fail to capture all aspects of the sense and are rarely used in clinical practice (Hillier, Immink et al. 2015, Pumpa, Cahill et al. 2015). However, the methods used by clinicians to assess proprioception in their stead, and thus the precise nature of the evidence-practice gap are unknown. The aim of this study was to describe the clinical assessment and knowledge of proprioception of physiotherapists and occupational therapists working in stroke rehabilitation in Australia. A cross-sectional online survey of Australian physiotherapists and occupational therapists was conducted from March to October 2020, containing questions about a) decision-making of clinical assessments of a case study of a patient with proprioception impairment due to stroke; and b) knowledge of proprioception. Respondents were blind to the study aims while answering clinical decision-making questions.

A total of 165 survey responses were registered, of which only 58 contained complete datasets suitable for analysis. Participants were asked to indicate the percentage of people with stroke that they routinely assess for proprioception impairment, the mean of which was 64.2% (95%CI 56.3 - 72.1%, N=58). However, in the case study only 55% (n = 32) of respondents selected a proprioception assessment. The majority of respondents understood proprioception to be the sense of joint / limb (n = 38, 65.5%) or body (n = 27, 46.6%) position and used ‘eyeball’ judgements of limb matching accuracy (56%, n = 33) or passive movement direction judgement (44.8%, n = 26) to assess the sense.

The findings in this chapter suggest that proprioception is likely under-assessed in clinical stroke rehabilitation, and where it is assessed, it is non-standardised, easily confounded, and fails to account for the different components of the sense. The results of the survey demonstrate that proprioception impairment was poorly defined, which may reduce the ability of rehabilitation clinicians to target it in their treatment and subsequently the recovery of function in people with stroke.

Introduction

Impairment in the sense of proprioception is a common sequela of stroke that affects approximately half of all survivors (Meyer, De Bruyn et al. 2016). Proprioception is responsible for accurate signalling and representation of the shape, position, and movement of the body in space (Proske and Gandevia 2012, Proske and Gandevia 2018), and thus its impairment is associated with poor recovery of upper and lower limb motor function (Rand 2018, Gorst, Rogers et al. 2019) and reduced independence in activities of daily living after stroke (Rand 2018).

Proprioception describes a group of sensorimotor processes (Proske and Gandevia 2012) which have historically been considered as the sense of speed and degree of joint movement, the magnitude of muscular force, and the coordination of muscular contraction timing. A number of receptors and signals contribute to these processes, particularly the muscle spindle and the Golgi tendon organ (Proske and Gandevia 2012, Hillier, Immink et al. 2015). However, the inputs from these receptors are significantly limited in providing accurate position and movement sense without their integration into representations of the body and environment stored in suprasegmental areas (Proske and Gandevia 2018). Thus, there is an emerging acknowledgement of the importance of the cortically stored copy of the nature and dimensions of the body in proprioception, termed the body representation (Longo, Azañón et al. 2010).

Current stroke rehabilitation guidelines recommend a thorough clinical assessment of all functionally relevant impairments by a multidisciplinary team, to identify the unique impairment profile of each patient and enable tailored rehabilitation (Razmus 2017). Within this team, the assessment and management of impaired proprioception falls into the scope of practice of physiotherapists and

occupational therapists. Assessments can be done solely by each of these professions or in conjunction. Potential forms of proprioception assessment are as diverse as the nature of the sense itself. However, common forms of assessment involve testing the sense of joint movement and position via either a) the detection or identification of the direction of passively imposed motion, or b) the accuracy of matching joint positions within or between limbs (Hillier, Immink et al. 2015).
In addition, the sense of muscular force can be assessed by the accuracy of judgements about the magnitude of force or the reproduction of forces passively imposed on, or actively produced by the body (Docherty, Arnold et al. 2004, Proske, Gregory et al. 2004, Bank, Van Rooijen et al. 2014). Finally, the body representation can be accessed via tasks involving the judgement of limb laterality, and the location of body axes and anatomical landmarks (Longo, Azañón et al. 2010, Rousseaux, Honoré et al. 2013, Razmus 2017). Thus, clinical proprioception assessment in people with stroke should include each of these assessment types to capture the complexity of the sense.

However, there are significant issues in proprioception assessment after stroke. First, a lack of organisational and structural support for clinicians. Despite the inclusion of proprioception assessment in clinical audits of stroke care (Stroke Foundation Australia 2019, Checketts, Mancuso et al. 2021),the Australian Stroke Guideline makes no reference to the specific assessment or treatment of proprioception impairment (Razmus 2017). Instead, general recommendations for somatosensory impairment direct clinicians to implement standardised assessment tools. However, standardised assessments of proprioception are infrequently used in clinical practice, and more than half of clinicians are unaware of the evidence for best practice in this area, and instead base their clinical decisions on the knowledge of their colleagues (Pumpa, Cahill et al. 2015). Second, clinically available standardised assessments of proprioception for people with neurological conditions are limited to movement direction or position matching accuracy, neglecting the other aspects of the sense (Connell and Tyson 2012). These standardised assessments grade a person's proprioception as normal, impaired, or absent and subsequently lack sensitivity to detect and track impairment magnitude over time, (Winward, Halligan et al. 2002, Stolk-Hornsveld, Crow et al. 2006).

There is a clear need for translational research to address the issues in clinical assessment of proprioception after stroke. Research must first identify the precise nature of the gaps between the evidence-base, clinician knowledge and attitudes, and current clinical practice to enable accurate and effective research targets to be established (Ebener, Khan et al. 2006, Graham, Logan et al. 2006) with the ultimate aim of improving patient outcomes. To date, no study has identified these factors in proprioception assessment in stroke rehabilitation. Thus, the aims of this study were to describe the following about physiotherapists and occupational therapists and their practice patterns working in stroke rehabilitation in Australia:

a) Current application of proprioception assessment in clinical practice;
b) Knowledge of theoretical aspects of proprioception and its clinical assessment;
c) Attitudes towards proprioception assessment.

Methods

Design:

A cross-sectional design using an online survey.

Population:

Clinicians were eligible to complete the survey if they a) were an Australian Health Practitioner Registration Agency (AHPRA) registered physiotherapist or occupational therapist, b) had been employed in a rehabilitation setting (subacute or community) for at least 6 months in the past year, c) had a minimum of three months experience working with people with stroke, and d) were not currently participating in the development of clinical guidelines for stroke.

Survey structure:

The survey was open from February to October 2020 and consisted of three sections with different question types (Appendix 4A):

1) Basic clinician demographic information (multiple choice), including qualifications, years of clinical experience, workplace type, and employment type.
2) Case vignette interpretation (open-ended), including questions about impairments and assessment choices in a case study of a person with stroke.
3) Questions about knowledge of and attitudes to proprioception (visual analogue scales and open-ended), including the perceived importance of proprioception, assessments used in clinical practice, and confidence in assessing and treating impairment of the sense.

Two case vignettes (Appendix 4B) describing a typical person with stroke in both inpatient and community settings were selected as a proxy for clinical practice (Peabody, Luck et al. 2004, Korner-Bitensky, Desrosiers et al. 2008, Korner-Bitensky, Barrett-Bernstein et al. 2011). Respondents were blinded to the specific aims of the study when answering the case vignette questions via the survey title being made generic to stroke rehabilitation, and the survey logic preventing return to a previous section after moving to the next.

Survey development

Demographic questions were based on those included in a Canadian National Survey of stroke clinicians (Korner-Bitensky, Barrett-Bernstein et al. 2011). Two case vignettes were developed, one representing a hospital-based patient and one a person with stroke living in the community. Specific cues relevant to proprioception and to somatosensory impairment in general were inserted into the vignettes, similar to the methods previously reported by Korner-Bitensky and colleagues (Korner-Bitensky, Desrosiers et al. 2008). Three physiotherapists and two occupational therapists with clinical experience that ranged from new-graduate to greater than ten years were consulted to ensure the saliency of the cues and vignette readability.

Questions regarding attitudes towards knowledge and assessment of proprioception were developed through consensus of a study author with subject matter expertise (SG) and a variety of practicing clinicians. The full survey was piloted on a sample of four clinicians (two physiotherapists and two occupational therapists) for clarity and time taken to respond. The clinicians reported the survey could be completed in approximately 20 minutes, however, the survey was also designed such that they could save and return to complete it, allowing flexibility in completion to accommodate clinical schedules. A focus group was conducted with these clinicians using cognitive debriefing techniques to supplement evaluation responses. On the basis of the recommendations of this group, the research team then revised the survey into its final online form. The survey was made available to clinicians using the Qualtrics software platform (SAP SE 2021).

Participant recruitment:

The sample of clinicians for survey piloting was recruited from the professional networks of the research team. The study sample was collected via advertisement through the mailing lists and social media pages of physiotherapy, occupational therapy, and stroke organizations in Australia. In addition, the survey link was distributed to the physiotherapy and occupational therapy department heads of Australian hospitals with a dedicated rehabilitation unit. Participants were eligible to win one of four $25 gift cards as an incentive to answer the survey. There was no sample size calculation as the study aim did not include hypothesis testing.
The study was approved by the University of Technology Low Risk Research Ethics Committee, approval no. UTS-ETH19-4402 and UTS-ETH20-4768

Data analysis:

Qualitative survey data analysis:

A framework analysis methodology (Gale, Heath et al. 2013) was used to evaluate the surveys open ended questions using NVivo software (QSR International 2021). A coding framework (Appendix 4C) was developed a priori by all members of the research team in consultation with subject matter experts and using theoretical reviews of proprioception (Proske and Gandevia 2012, Hillier, Immink et al. 2015, Proske and Gandevia 2018). There was scope for the generation of novel codes for data that did not fit the pre-determined codes for each question. Two members of the research team (GF, DK) independently extracted and coded the data from each survey (Bengtsson 2016) via the process of analysis set out by Gale et al. (Gale, Heath et al. 2013). Disagreements were resolved through discussion. Raw counts of the frequency of each code were calculated and illustrative quotes extracted for each question.

Quantitative survey data analysis:

Raw counts of each category in the demographic questions were calculated. Normality tests were conducted for each question using the SciPy module in Python software (Appendix 4D), with appropriate descriptive statistics (means and standard deviations for normally distributed, and medians and interquartile ranges for non-normally distributed) and confidence intervals for each question then calculated.

Results

Clinician characteristics

A total of 165 surveys responses were registered, of which only 58 contained complete datasets suitable for analysis. There were missing data from one participant in two questions of the survey that are noted in the tables throughout. The average time taken to complete the survey was 76 minutes, likely reflecting sporadic completion over a clinical day. Table 4.1 illustrates the characteristics of the 43 physiotherapists and 15 occupational therapists who responded to the survey completely.

Case vignette interpretation

Proprioception was identified as an impairment in the patient's initial clinical assessment in the vignette by 55% (n = 32) of survey respondents. However, only 36% (n = 21) listed a tool specific to proprioception as their assessment choice. An additional 17% (n = 10) of respondents listed proprioception as a target of their subsequent clinical assessment, with only 50% (n = 29) of these respondents selecting to evaluate proprioception with an appropriate assessment tool. Thus, only 44% (n = 26) of respondents correctly identified proprioception as an impairment in the case study and suggested an appropriate assessment tool to evaluate the sense in their initial or subsequent clinical assessments.

Clinician Characteristics	n	%	Workplace Characteristics	n	%
Occupation			Works within a MDT		
Physiotherapist	43	74	Yes	49	84
Occupational Therapist	15	25	No	9	15
Work Type			Workplace affiliated with a University		
Full-time	40	69	Yes	19	32
Part-time	16	27	No	35	60
Casual	1	1	Unsure	4	6
Self-employed	1	1			
Qualification			Practice Area		
Undergraduate	33	56	Inpatient rehabilitation	25	43
Post-graduate - Masters	16	27	Outpatient - Public Hospital	8	13
level	2	3	Inpatient Acute Care	7	12
Post-graduate - Doctorate	7	12	In-home rehabilitation	7	12
level			Community Clinic	11	19
Other					
Geographic Location			Student placements in workplace		
Metropolitan	39	67	Yes	55	94.8
Regional	14	24	No	3	5.2
Rural	5	8			
Daily Stroke Patient Caseload			Allocated Professional Development Time in the workplace		
< 3	36	62	Yes	31	53.4
3-5	18	31	No	27	46.6
5-10	4	6			
Years of Experience			Research Conducted in the Workplace		
< 3 years	3	5	Yes	17	29.3
3-5 years	6	10	No	41	70.7
5-10 years	18	31			
> 10 years	31	53			

Table 4. 1: Demographic Characteristics of Survey Respondents

Proprioception knowledge and assessment (open-ended questions)

Clinicians predominately understood proprioception to be the sense of joint / limb (65%, n = 38) or body (46%, n = 27) position (Table 4.2). Perception of body or limb position relative to the space they occupy was identified by 75% (n = 43) of the respondents. A smaller percentage (24%, n = 14) described proprioception as a sense of body movement, and a single respondent identified judgement of muscle force as a component of the sense. Only 5% (n = 3) of respondents identified the anatomical or physiological processes involved in proprioception, including the muscle spindle and either the Golgi tendon organ or joint receptors.

When asked to describe a complete proprioception assessment, responses of clinicians were limited to limb position matching (56%, n = 33), passive movement direction judgement (44%, n = 26), or passive movement detection (17%, n = 10). However, 48% (n = 32) of respondents also identified assessments not specific to proprioception as part of a complete proprioception assessment. These were predominately observation of patient performance during tests of coordination (e.g., finger to nose) or functional tasks (e.g., gait analysis) (43%, n = 25). Only four respondents reported knowledge of a standardised published proprioception assessment (7%).

How would you best define proprioception?		
	Count	**% Responses**
Components	N = 55	N = 94.8%
joint or limb position	38	66
body position	27	47
position in space	43	74
position alone	13	22
body movement	14	24
force awareness / judgement	1	2
balance	1	2
other sensory process	1	2

Table 4. 2: Proprioception definition codebook and frequencies
Multiple answers were permitted, as such the combined totals do not equal the number of study participants.

A similar finding emerged from the questions that asked clinicians to describe the assessments of proprioception that they used in their day-to-day clinical practice (Table 4.3). Most respondents reported either the use of a limb position matching task (53%, n = 31) or patient verbal judgement of the direction of passive movement (40%, n = 23). The majority of respondents performed these assessments using a between limb task (67%, n = 39), with the clinician passively moving either the paretic or healthy limb into a position and asking the patient to actively copy the

position (64%, n = 37). Only 9% (n = 5) of the participants reported use of a standardised measurement of position matching, with the remainder either reporting 'eyeballing' of the match (47%, n = 27) or an unclear method of measurement (28%, n = 16). More than half of the clinicians also reported use of a non-specific assessment of proprioception in their clinical practice (55%, n = 32), again predominately observation of functional or coordination tasks (45%, n = 26).
Full counts of respondent numbers per code are reported in Appendix 4E.

Knowledge of and attitudes to proprioception (VAS questions)

All data were normally distributed on testing, and thus means, standard deviations, and confidence intervals were calculated for each question.
The maximum possible value for all VAS questions was 10 except for the percentage of patients in which clinicians routinely assessed proprioception, which was 100.
Two data points were missing in the question pertaining to clinician confidence in treating proprioception.

List the ways that you assess proprioception of a patient after a stroke in *your clinical practice*.		
	Count	**% Responses**
Proprioception Assessment Tool	41	70.7
matching task	31	53.4
movement direction judgement (passive)	23	39.7
movement detection (passive)	3	5.2
Romberg's test	2	3.4
Thumb finding test	2	3.4
Non-specific Assessment Tool	32	55.2
functional observation	13	22.4
co-ordination task observation	12	20.7
other non-specific	11	19.0
balance observation	6	10.3
subjective history	1	1.7
No Assessment	5	8.6

Table 4. 3: Proprioception assessment in clinical practice codebook and frequencies
Multiple answers were permitted, so that combined totals do not equal the number of study participants.

On a scale from ‘Not at all confident (0)’ to ‘Completely confident (10)’, clinicians rated themselves as a mean of 7.5 (SD 2.5, 95%CI 6.83 - 8.16) in assessing proprioception and 5.6 (SD 2.1, 95% CI 5.1 - 6.2) for treating the phenomenon.

Clinicians rated the importance of proprioception assessment in this population as a mean of 8.1 (SD 1.8, 95%CI 7.6 - 8.5) on a scale from ‘Not important at all (0)’ to ‘Extremely important (10)’. Finally, in the knowledge questions, clinicians reported routinely assessing proprioception in an average of 64.2% of the patients in their caseload (SD 29.8%, 95%CI 56.3 - 72.1%).

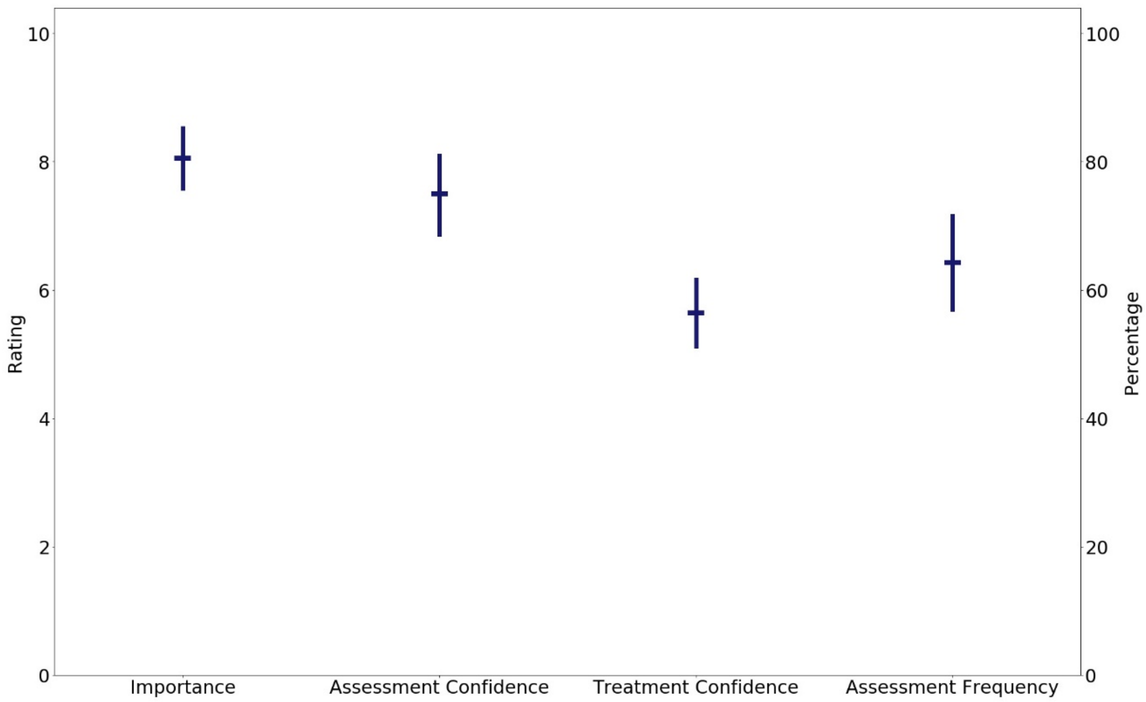

Figure 4. 1 Means and 95% confidence intervals of clinician self-rating for VAS questions
Assessment frequency was rated as a percentage of total assessments, while all other questions were a self-rating out of 10. For importance n = 56, all other questions N = 58.

Discussion

Current clinical practice:

Clinicians in the present study reported to assess proprioception in people with stroke routinely 64% of the time, which was ~10% lower than the rates described in previous studies using similar methodologies in a similar population of clinicians (Doyle, Bennett et al. 2013, Pumpa, Cahill et al. 2015). However, this is the first study to examine both *if* and *how* this assessment occurred using open-ended questions based on a case study, while keeping clinicians naive to the study purpose. As such, clinician answers on the case vignette questions are likely closer to their actual clinical decision-making (Peabody, Luck et al. 2004). Thus, it is likely that proprioception is considerably under-assessed in people with stroke, due to inconsistencies in both identification of the clinical indication for assessment and appropriate selection of assessment tools.

When directly asked to describe how they assessed proprioception in their clinical practice, no clinician reported use of a standardised proprioception assessment tool or battery such as the Nottingham Sensory Assessment or the Rivermead Assessment of Somatosensory Performance. Of importance, is the high percentage (55.2%, n = 32) of clinicians that reported use of non-specific tests of proprioception, mostly involving observation of functional tasks. At present, there are no specific signs of proprioception impairment in functional task observation described in the literature. Subsequently, these tests leave assessment to clinical judgement alone that is largely based on knowledge and experience and thus, variable between clinicians. The frequent use of subjective or non-standard assessments suggests that clinicians working with people with stroke recognise the functional importance of proprioception, but lack appropriate clinical assessment tools to quantify it.

Similarly to previous investigations (Pumpa, Cahill et al. 2015), where proprioception was specifically assessed, 70% of clinicians (n = 40) reported use of joint position matching, movement detection, or movement direction judgement tasks. When doing so, most clinicians impose a passive movement to either the affected or intact side and ask the patient either a) to match the position with their contralateral limb (63.8%, n = 37) or b) to verbally indicate if their joint has moved or the gross direction of the movement (n = 19%, n = 11). These methods of assessing proprioception are problematic for several reasons. Firstly, the technique in which clinicians conduct a position matching or movement detection assessment were non-standardised in application and evaluation which reduces the accuracy and reliability of their results. When assessing proprioception with a joint position match test, the vast majority of clinicians reported to judge accuracy through 'eyeballing' the result (46.6%, n = 27), with only 8.6% (n = 5) reporting use of a goniometer or other measurement device. 'Eyeballing' precludes accurate assessment of the error of the match, and instead gives dichotomous results (accurately matched vs. not accurately matched) similar to the assessment of the ability of a patient to detect the direction of joint movement (i.e., verbalised direction correctly vs. incorrect). Thus, proprioceptive assessment in clinical practice is a screen for impairment rather than an assessment of impairment magnitude. Assessment designed to screen for impairment prevents quantification of proprioceptive impairment, the ability to track it over time and subsequently, assess the progression of people with stroke and impact of their rehabilitation.

Secondly, the most used clinical assessments of proprioception reported in the survey do not control for the contractile state of the muscle. Muscle thixotropy describes the way muscle mechanical properties (stiffness) reduce with movement. The degree of stiffness is dependent on the history of movement (Campbell 2019). The thixotropic regions of muscle spindles make them sensitive to small changes and are affected both by previous stretch of the extrafusal fibres and by previous activation. Spindle sensitivity can affect the accuracy of proprioception. In relation to proprioception assessment, the perception of joint position is affected by whether a muscle has previously contracted or was passively held in a lengthened or shortened position (Proske, Wise et al. 2000, Proske, Tsay et al. 2014). Passively held positions introduce slack into the muscle and result in a longer time to movement detection, while previously contracted muscles have a higher level of resting activity in muscle spindles, hence are more sensitive to length change, and provide a more rapid signal of movement (Proske, Tsay et al. 2014). Thus, the contractile state of the muscle can be controlled and made uniform by performing a standardised contraction and length change (in that order) prior to placing a limb in test positions (Proske and Gandevia 2018). However, in this study no clinician reported controlling for the contractile state of the muscle as a part of their clinical position-match assessment, nor in describing a complete proprioception assessment. Thus, the clinical assessments of proprioception reported by study participants are affected to an unknown degree by the effects of thixotropy and are, therefore, inaccurate.

Finally, and perhaps most importantly, is the physiological basis of position matching or movement detection. These methods assess simple detection or ability to match signals arising predominantly from the muscle spindles (Proske and Gandevia 2012). Evidence for this can be found in the difference in error magnitude between tasks where the position of the reference arm is indicated via a match with the contralateral limb, and those in which the position of the reference arm is indicated via a pointing task (Velay, Roll et al. 1989). Position errors in pointing indicator tasks are significantly higher than limb matching tasks and are not influenced by muscle pre-conditioning or vibration, indicating that the muscle spindle is not the principle determinant of position sense (Tsay, Allen et al. 2016). It is accordingly postulated that there are two distinct forms of coding of position in space; a basic sense of relative joint angles and a more complex integrated sense of the location of the joints in space, with the latter being more relevant for patient's functional outcomes (Proske and Gandevia 2018). Thus, current clinical testing of proprioception represents only a lower order component of the sense and neglects the integration of low-level position perception into the awareness of the body or the space around it. This is a potential reason for the lack of correlation between movement detection and position-matching tasks and functional performance (Dukelow, Herter et al. 2012, Meyer, Karttunen et al. 2014), which limits their relevancy to rehabilitation outcomes.

Clinician knowledge of and attitudes to proprioception

A more complete picture of clinician knowledge and attitudes to proprioception assessment could be gained by considering multiple survey questions in parallel. The majority of clinicians in this study (74.1%, n = 43) understood proprioception to be a sense of the location of the body and its limbs in or relative to the space around it, while a smaller proportion (22.4%, n = 13) defined it as a basic position or movement sense in the absence of spatial or body representation integration. Reference to the anatomical processes underlying proprioception was infrequent (13.5%, n = 8), as was the knowledge that proprioception includes a sense of movement (24.1%, n = 14) and muscle force (1.7%, n = 1). From this, we can infer that gaps in clinician knowledge may be specific to the anatomy and physiology of proprioception, the influence of thixotropy, and of the inclusion of judgement of muscle force and movement in the sense. Additionally, the difference between self-reported and case vignette assessment of proprioception potentially indicates that more than half of clinicians lack knowledge specific to its clinical presentation and miss cues that indicate the need for assessment. Thus, these areas represent targets for clinician education and professional development.

Future directions

An area for future research commonly identified in clinical proprioception is the complete psychometric evaluation, technological innovation, and translation to clinical practice of current standardised assessments of position matching, such as the Rivermead Assessment of Somatosensory Performance (Suetterlin and Sayer 2014, Hillier, Immink et al. 2015). However, the results of this study in combination with the recent advancements in the understanding of proprioception (Longo, Azañón et al. 2010, Proske and Gandevia 2012, Proske and Gandevia 2018) indicate the need for an entire paradigm shift. Clinical proprioception assessment should move away from the simplistic concept of position matching, towards tests that are relevant to function. While assessments of this nature do exist (Ingram, Butler et al. 2019), they are laboratory-based and have yet to be combined and translated into forms accessible and feasible for everyday clinical use. Additionally, addressing the gaps in clinician knowledge of the proprioceptive sense and its impact on the recovery of function after stroke through education is an important undertaking to ensure adequate understanding of the rationale behind novel integrated proprioception assessments and in turn, for the development of treatment strategies.

Limitations

Despite not having a targeted sample size, this study had a small sample size and a high rate of attrition (65%) which prevents the generalisation of the findings. Neither AHPRA, the Australian Physiotherapy Association, nor Occupational Therapy Australia collect data on the specific practice area of their members. The number of therapists currently working with stroke clients and therefore eligible to participate could therefore not be determined, precluding calculation of the survey return rate or comparison between respondents and non-respondents.

Furthermore, the SARS-COV-2 pandemic occurred after two months of recruitment. The perceived importance of answering a survey while maintaining clinical loads in the face of high levels uncertainty and policy change in this time would have been understandably low. The high attrition rate in the study could have been due to the length of time taken to complete the survey or clinician tendency to complete the survey in between clinical tasks which is suggested by the average survey completion time of 76 minutes. The pilot focus group reported the survey duration as acceptable, however this group was likely more motivated than the average clinician to complete the survey. Thus, the relatively small sample size of N = 58 clinicians was another, albeit unavoidable, limitation of this study.

Conclusion

Proprioception is likely under-assessed in clinical stroke rehabilitation, and where assessment does occur it is non-standardised, easily confounded, and fails to address proprioception as an integrated process. Clinicians perceived proprioception assessment to be important; however, they are not supported by the availability of guidelines and clinical assessment tools to assess the sense fully in clinical practice. Future research should focus on the development of clinical assessments of proprioception that take into account the integration of position sense in relation to the body and space, quantify the deficits in position sense, and the requirements for sustainable translation of these into clinical practice. Improved clinical assessment of proprioception impairment in people with stroke has the potential to improve rehabilitation outcomes and thus reduce the burden of disease in this population.

Chapter summary

Clinical assessment of proprioception is typically achieved using a non-standardised test, commonly a joint position matching. Standardised assessments of proprioception have tenuous links to upper limb impairment, which may explain their infrequent use in practice. However, as typical clinical assessment is unstandardised and largely investigated, it is unknown if it has a different relationship with upper limb impairment. This was the foundation of the next phase of research in this thesis.
The next chapter (Chapter 5) describes the Development phase, a cohort study of people with stroke that aimed to investigate the relationship between upper limb impairment and clinical position matching assessment.

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Chapter 5: Clinical proprioception assessment and upper limb function after stroke - an interim report

In addition to Ms Fisher and the supervisory team, Mr Sam Gilbert substantially assisted in the data analysis in the manuscript that follows. Ms Muneeba Chaudry and Ms Katja Valente assisted with data collection.

Author contribution statement

As primary supervisor, I confirm that Georgia Fisher made the following contributions to the chapter following:

- Formulation of objectives
- Creation of the human research ethics application and liaison with the appropriate Human Research Ethics Committees for approval
- Data collection with assistance from Ms Muneeba Chaudry and Ms Katja Valente
- Data analysis in collaboration with Mr Sam Gilbert
- First draft of the chapter

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Dr David Kennedy

Abstract

Impairment in proprioception, the sense of position and movement occurs in approximately 48% of stroke survivors and is predictive of poor treatment outcomes and upper limb recovery. Proprioception is essential for skilled and coordinated movement. However, current clinical proprioception assessment occurs using position matching tasks that likely have limited relevance to upper limb coordination, and thus to functional rehabilitation. Due to their current subjectivity, the correlation between impaired proprioception and upper limb co-ordination remains unknown. Additionally, there is high variability in position matching accuracy between healthy individuals who, conversely, also have high internal consistency. It is not known if this also is the case in people with stroke. Therefore, the aim of this prospective, multicentre, cross-sectional study was to determine the correlation of quantified clinical proprioception assessment with upper limb impairment. Participants with first time stroke completed a series of 35 randomised bilateral upper limb position matching tasks of seven unique positions, and a subset of tests from the Upper Limb Physiological Profile Assessment (UL-PPA). Pearson's correlations were calculated between average angular position match error and UL-PPA scores. Study recruitment was suspended due to governmental restrictions in response to the SARS-COV19 pandemic and so preliminary results for ten participants at their admission time point are presented. Only radial deviation match error was significantly correlated with impairment in bimanual coordination ($r = 0.84$, $p < 0.001$, 95% CI 0.41 - 0.97), no other position matching error had a significant correlation with any test of upper limb co-ordination or function. Position matching errors were highly variable between participants, but also within participants for different movements. This study provided preliminary data showing the limited utility of

current clinical upper limb proprioception assessment for the rehabilitation of people after stroke, and suggests that people with stroke are inconsistent in their ability to match proprioceptive signals. The results support the consideration of alternate, functionally relevant, standardised assessments that use variability of performance as an outcome measure. Similar investigations in larger sample sizes are required to confirm these preliminary findings.

Introduction

Although rehabilitation of the upper limb is an essential component of stroke rehabilitation (Stroke Foundation Australia 2017), evidence of the most effective interventions is still limited, which may contribute to the highly variable degrees of upper limb recovery of people with stroke. For example, 71% of the patients with acute-phase mild to moderate upper extremity paresis recover at least some dexterity at 6 months after stroke (Nijland, van Wegen et al. 2010), while 60% of severely affected patients fail to recover dexterity in the same time frame (Kwakkel, Kollen Boudewijn et al. 2003).

Skilled upper limb movement is principally the domain of the parietal cortex, a brain region with multiple functions and diffuse cortical connections (He, Snyder et al. 2007). The parietal cortex is largely responsible for sensorimotor integration, defined as the consolidation of different sources of sensory stimuli and their transformation into motor action (Machado, Cunha et al. 2010). Upper limb movement typically involves the interaction of the hand with objects in space, and for skilled, effective movement, visual, auditory, and somatosensory information must be integrated via the parietal lobe (Rushworth, Nixon et al. 1997). Somatosensory information includes the senses of touch, pain, position, and movement, recovery of which is a prerequisite for full motor recovery of the paretic upper limb (Zandvliet, Kwakkel et al. 2020). Importantly, impairment in the sense of position and movement, or ‘proprioception’, occurs in approximately 48% of stroke survivors (Semrau, Herter et al. 2018) and is predictive of poor treatment outcomes and functional recovery at all stages after stroke (Park, Wolf et al. 2008).

Proprioception is an umbrella term for the sense of joint movement, position detection and muscle force judgement, and involves the integration of these inputs with the 'body representation', defined as the stored internal model of the body and its parts (Longo, Azañón et al. 2010, Puig-Pijoan, Giralt-Steinhauer et al. 2018). In Chapter 3, clinicians working in stroke rehabilitation reported the importance of proprioception to the rehabilitation outcome of people with stroke. However, clinical proprioception assessment has multiple issues. Mention of proprioception assessment is absent from most international stroke rehabilitation guidelines (Razmus 2017), and the available standardised clinical assessment tools use an ordinal grading system with poor sensitivity to change (Winward, Halligan et al. 2002, Stolk-Hornsveld, Crow et al. 2006) and weak correlation to patient function and activity (Meyer, Karttunen et al. 2014).

Robotic assessment has been investigated and validated as a potential solution (Dukelow, Herter et al. 2010). However, this technology remains restricted by high cost, specialised technical training requirements, and low portability (Hillier, Immink et al. 2015). Subsequently, most clinicians assess proprioception using a non-standardised tool, most commonly a subjective judgement of position matching or movement detection ability (Chapter 3, and ref. Pumpa, Cahill et al. 2015). Assessment most typically involved the therapist moving the paretic upper limb of a person with stroke to a position, asking them to copy it with the other upper limb, and then making an 'eyeball' judgement of accuracy. As this method is not typically standardised and quantified in clinical settings, it is unknown if it has higher correlation to upper limb impairment than the ordinal standardised clinical assessment tools (e.g., the Rivermead Assessment of Somatosensory Performance (Winward, Halligan et al. 2002)). If a significant correlation does exist, quantification of existing methods of position matching would be a viable target for future implementation research in this area.

Recent evidence has proposed that proprioception has two distinct forms of neural coding of limb position in space; a basic sense of relative joint angles, and an integrated, more functionally relevant sense of position in space that incorporates the basic sense into perceptions of muscle force magnitude and timing, and the cognitive representation of the body to achieve skilled movement (Proske and Gandevia 2018). Thus, current clinical proprioception assessment is potentially sensitive to only a lower order, less functionally important component of the sense. However, due to the subjectivity of current clinical assessment methods, the correlation of proprioception assessment and upper limb impairment is unknown.

Additionally, recent studies suggest that there is a high variability in position matching accuracy between healthy individuals, but that these same individuals are highly internally consistent – that is, they make similar magnitude errors between tests (Qureshi, Butler et al. 2019, Rana, Butler et al. 2020). It is unknown if these results apply for people with stroke. These findings are important to determine the relevance of proprioception assessment to clinical practice, the differences between healthy and neuro-atypical people, and to determine the need for and nature of novel methods of proprioception assessment that capture a spatially integrated sense of position and movement.

Inertial measurement units (IMUs) are a low cost, easy to use, and portable solution to the lack of quantification of current methods of clinical proprioceptive assessment (Anowar, Ali et al. 2020, Feuvrier, Sijobert et al. 2020). While investigation into their psychometric properties is preliminary, IMUs have acceptable reported reliability in both healthy and stroke-affected populations, and are appropriate for use in both inpatient and community settings (Cho, Jang et al. 2018, Kobsar, Charlton et al. 2020, Milosevic, Leardini et al. 2020). Thus, the aim of this study was to quantify proprioception impairment in people with stroke assessed via an upper limb position matching task similar to current clinical practice, correlate this with upper limb coordination and function, and examine the between and within participant variability.

Methods

Design

A multicentre, cross-sectional study

Participants

Participants with stroke were consecutively recruited by ward physiotherapists at their admission to the inpatient rehabilitation wards of three major hospitals in New South Wales, Australia (Prince of Wales Hospital - November 2018 to March 2019, St George Hospital - November 2018 to March 2020, and Balmain Rehabilitation Hospital – November 2019 to March 2020). Participants were eligible for inclusion in the study if they: a) were aged 18-90 and between 7 days and 3 months post first-time stroke (to capture the early sub-acute phase (Bernhardt, Hayward et al. 2017) of stroke), had a stroke confirmed by medical imaging, d) were willing and able to provide informed consent, and e) were able to follow 2-step instructions or had a Montreal Cognitive Assessment (MoCA) > 20. Exclusion criteria were a) having suffered a Transient Ischaemic Attack (TIA) or stroke mimic, b) presenting with Glasgow Coma Scale (GCS) < 14 at the time of screening, c) being enrolled in another physiotherapy research trial at the same facility, or d) were medically diagnosed with clinical signs of delirium or depression.

All participants received usual care for their duration of involvement in the study by a multidisciplinary rehabilitation team. The study was approved by the South Eastern Sydney Local Health District and University of Technology Sydney human research ethics committees (approval numbers ETH17/331 and ETH18/2639, respectively). All participants provided written informed consent in accordance with the Declaration of Helsinki.

Outcome Measures

Demographic and clinical data

Participant demographic data along with mode of acute stroke treatment, acute stroke severity measured by the National Institute of Health Stroke Scale (NIHSS) both at time of presentation and following treatment, and results of medical imaging (magnetic resonance imaging, computed tomography perfusion, computed tomography angiography) were collected from the medical records of each participant.

IMU device

The IMUs used for this study were developed and custom built by an engineer, and had been used in previous investigations of motion tracking (Hayati, Walker et al. 2018). Each device had dimensions of 2.5 x 2.5 x 0.5 cm and weighed less than 50g, allowing them to be comfortably fitted to the hands of participants. They included sensors measuring linear acceleration, body rotation and magnetic heading in three axes, sampling at 185Hz. Each type of sensor has a different sensitivity to change in position and, consequently, a different susceptibility to measurement noise. The selection of a combination of sensors outputs to use to determine the IMUs position in space provides a balance between sensitivity and noise in positional measurement (Maceira-Elvira, Popa et al. 2019). For this study, the measures of linear acceleration and body rotation were used to determine IMU position, as per established convention (for review, see Yang and Hsu 2010).

Upper limb position matching

An IMU device was strapped to the volar surface of both hands of each participant using a Velcro strap. Participants were seated with their elbows resting comfortably on a table in front of them. The starting upper limb position for each trial was shoulder neutral, arm resting comfortably on the table directly in front of the participant, wrist neutral, and the hand in natural resting position. Figure 5.1 depicts an exemplar position of the participant. Five sets of seven movements (Table 5.1) were conducted for each participant, with the order of movements randomised using an online random number generator (https://www.random.org/) within each set (see Table 5.1 for an example of a movement set).

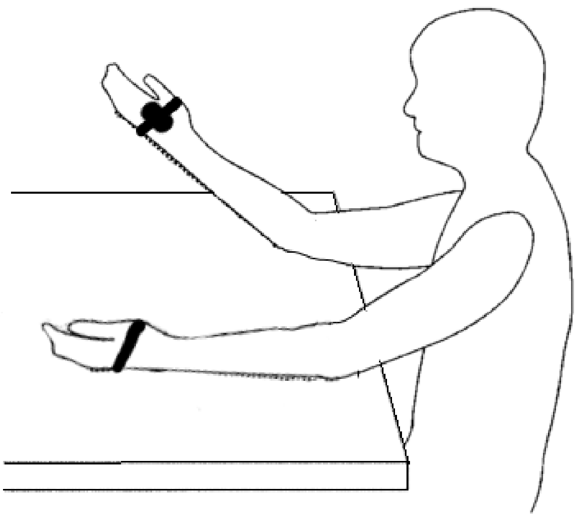

Figure 5. 1 Example participant position (elbow flexion)

The right arm is held in the test position, and the left in the starting position. Note that experimenter is not shown, who would be holding the right arm in position at the wrist and stabilising at the elbow. The IMU device is shown on the right hand, and the straps used to secure the device are shown on both hands.

Before each trial, both participant arms were passively flexed and extended five times by the experimenter to control for the effects of muscle thixotropy (Proske and Gandevia 2018). Each of the seven protocol movements were then passively imposed in a random order on the paretic arm of the participant, who was then instructed to “match the position of your affected arm with your unaffected and stop when you think they are the same.”

	Set 1
Movement 1	Wrist Extension
Movement 2	Elbow Flexion
Movement 3	Radial Deviation
Movement 4	Elbow Flexion + Pronation
Movement 5	Shoulder external rotation
Movement 6	Shoulder internal rotation
Movement 7	Wrist Pronation

Table 5. 1: Example of an Upper Limb Position Matching trial set.

There was no time limit on matching. Participants were permitted a maximum of three trials with vision to allow them to become familiar with the assessment procedures. They then completed the five sets (Table 5.1) of seven trials with vision occluded. Hand position of the experimenter during testing was kept constant across all participants, who were also allowed as many rests as necessary within the test procedure.

Upper limb coordination and function

The Upper Limb Physiological Profile Assessment (UL-PPA) is a set of 15 tests developed by Neuroscience Research Australia (Ingram, Butler et al. 2019). It is designed to assess the upper limb impairments of strength, dexterity, co-ordination, sensation, proprioception, and vision. Normative values for healthy aged individuals and those with upper limb impairment, and standard testing protocols have previously been published with the entire protocol taking between 30 and 45 minutes to complete (Ingram, Butler et al. 2019). Uni- and bimanual co-ordination are highly correlated to recovery of upper-limb function after stroke (Pelton, van Vliet et al. 2012, Kantak, Jax et al. 2017, Lai, Sung et al. 2019), while other impairments such as coarse and light touch, and pressure sense have low correlation to recovery (Meyer, Karttunen et al. 2014). Due to this, and also to minimise participant fatigue, the following co-ordination tests and the functional task of the UL-PPA were used as outcome measures.

i. Upper limb dexterity assessment (loop and wire task)
ii. Two-hand co-ordination (bimanual pole test)
iii. Finger tapping
iv. Overall upper limb function (shirt buttoning)
v. Sensation (Von Frey Filament, thenar eminence)

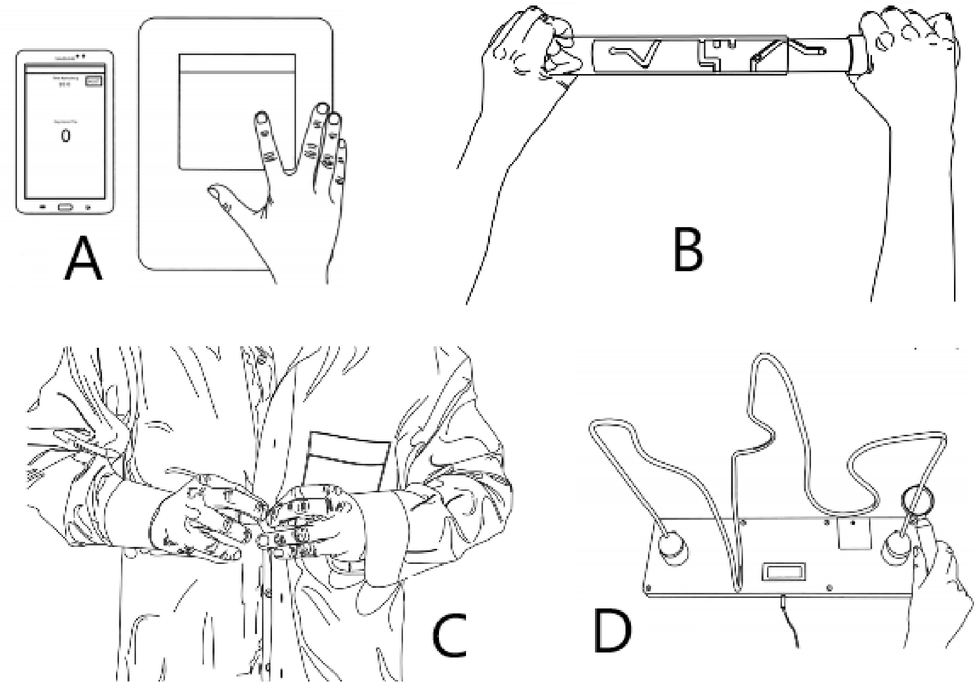

Figure 5. 2 UL-PPA test items used

A: Finger tapping. The participant tapped their dominant index finger up and down onto the tapping sensor as many times as they could over a 10s period.

B: Loop and wire test. The participant held the handle attached to the ring and attempted to move the ring through the copper wire maze as fast and as accurately as possible. Two trials were completed, one in each direction.

C: Shirt task. The seated participant picked up a folded unbuttoned long sleeve shirt and put it on as fast as possible. The test was completed when all six buttons were done-up in their corresponding holes.

D: Bimanual pole test. Holding the swivel stick with one hand at each end, the participant moved through the maze as fast as possible by flexing and extending their wrists in a coordinated manner. The time taken (in seconds) to move the screw from right-to-left and return was recorded as the test score.

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Study procedure

All new admissions to the rehabilitation wards at each site were screened against the inclusion and exclusion criteria by physiotherapists involved in their care. Eligible participants were provided with a brief study overview by the senior physiotherapist at each site and then gave written informed consent to be contacted by an investigator. An investigator attended the site and gained full informed consent from the participant. If possible, assessment procedures occurred on the same day as consent. Outcome measures were collected within four days of admission to the rehabilitation ward. Rehabilitation admission based time points were selected over absolute post-stroke time point as recovery of sensorimotor impairments is variable between individuals at absolute post-event time points (Winward, Halligan et al. 2007), while admission and discharge from a rehabilitation unit are determined by a uniform set of clinical criteria.

IMU output analysis

Analysis of the IMU output was performed using Python (Python Software Foundation, version 3.8). The complete source code for the analysis is attached in Appendix 5A. The IMUs output linear acceleration and rotation around each of three axes labelled X, Y, and Z. At the start of each Upper Limb Position Matching trial, the IMU was positioned such that, for the left arm, this set of three axes corresponded to the anatomical axes as shown in Figure 5.2. For the right arm, the IMU output axes were adjusted to match the reference axes shown in Figure 5.2 by inverting the Z axis.

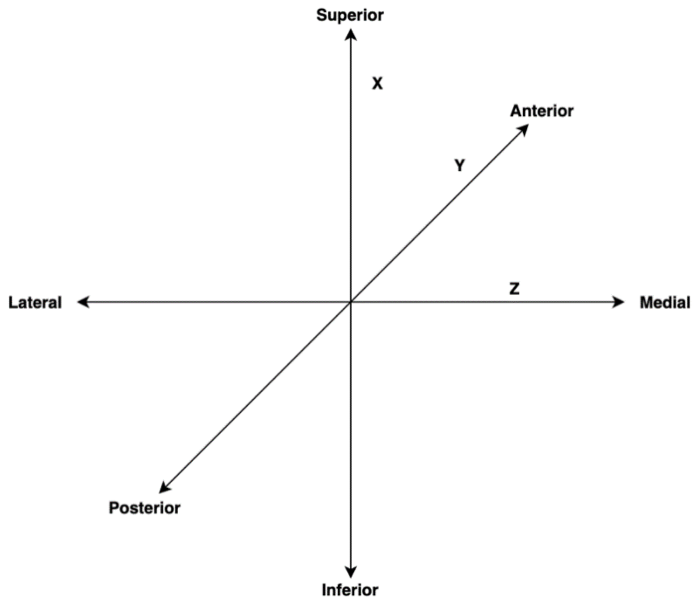

Figure 5. 3 IMU output axes (X, Y and Z).

Axes referenced to anatomical axes at the starting position for each upper limb Position Matching trial for the left arm. IMU output for the right arm was adjusted to match this reference by inverting the Z axis. Starting position for each trial was shoulder neutral, elbow at 90º of flexion, wrist neutral, and the hand in natural resting position. Analysis of IMU output was performed to report change relative to this starting position.

For each trial, the IMU analysis reports upper limb position as the angular displacement of the limb, relative to the starting position shown in Figure 5.2, around the principle axis of rotation. The principle axis of rotation specifies the axis about which the IMU analysis reports angular displacement for each of the seven movements performed in a block and are shown in Table 5.1,

Movement	Description	Repetitions	Principle Axis
1	Full pronation to table	5	Z
2	~ 20 degrees external rotation	5	Y
3	~ 20 degrees internal rotation	5	Y
4	Maximum pronation, 30 degrees wrist extension	5	X
5	Maximum radial deviation	5	X
6	45 degrees elbow flexion, neutral wrist	5	X
7	45 degrees elbow flexion, full wrist pronation	5	X

Table 5. 2: Principal axis of rotation for each of 7 movements performed within an upper limb position matching trial block.

The elapsed time (T), as measured by the IMU, at the end of each movement for each hand, for each trial was determined by visual inspection of the raw IMU acceleration data. End of movement was defined as the point at which the acceleration reached a new steady state value after the start of movement.

Angular displacement around each axis was calculated using each of the measured linear acceleration and body rotation. A time T, angular position around each axis (A_R, in degrees), determined by linear acceleration (R, in G/s) was calculated:

$$A_{Rx} = 180\frac{\arccos\left(\frac{R_x}{R}\right)}{\pi} - A_{x0}$$

$$A_{Ry} = 180\frac{\arccos\left(\frac{R_y}{R}\right)}{\pi} - A_{y0}$$

$$A_{Rz} = 180\frac{\arccos\left(\frac{R_z}{R}\right)}{\pi} - A_{z0}$$

Where A_0 is the angular rotation at the IMU starting position around a given axis and R is the acceleration vector in three dimensions at the time of measurement:

$$R = \sqrt{R_x^2 + R_y^2 + R_z^2}$$

Separately, angular position around each axis (A_G, in degrees), determined by body rotation (G, in deg/s) was calculated for a given timepoint T as:

$$A_{Gx} = \int_0^T G_x\, dt$$

$$A_{Gy} = \int_0^T G_y\, dt$$

$$A_{Gz} = \int_0^T G_y\, dt$$

Measurement of angular displacement using linear acceleration and rotation were then combined to give a balanced estimate of angular position (A):

$$A_x = \frac{A_{Rx} + 5A_{Gx}}{6}$$

$$A_y = \frac{A_{Ry} + 5A_{Gy}}{6}$$

$$A_z = \frac{A_{Rz} + 5A_{Gz}}{6}$$

Angular displacement for each arm for a given movement was reported as either A_x, A_y or A_z, as per Table 5.1.

Statistical analysis

Summary statistics were calculated for all demographic data. All UL-PPA tasks had scoring systems that classified a higher score as more impaired. However, some participants were unable to complete some of the tasks. Thus, continuous data was unable to be used, as these participants could not be given a score of 0. After consultation with a statistician, UL-PPA test scores were converted to an ‘impairment ranking’ of one to five, with each rank indicative of the number of standard deviations outside of the healthy aged normative value that a participant score fell. A rank of five was the ceiling score, and represents people with scores five or more standard deviations outside of the healthy normative score. Mean and standard deviation of position match error was calculated for each movement, for each participant.

Spearman’s correlations were used to determine the relationship between UL-PPA impairment rank and the participant’s mean position matching score for each movement with significance set at $p < 0.01$ due to the small sample size. Bonferroni corrections were made for multiple comparisons. All analyses were conducted in Python (Python Software Foundation 2021), and the source code is reported in Appendix 5B.

N	Age	Gender	Handedness	Lesion Side	Acute Rx	TSO (days)	Lesion Location	Stroke Type
P01	85	F	R	L	Nil	17	BG, P, O	I
P02	52	M	R	R	Nil	17	VAD, C, F	I
P03	69	F	R	L	IV Hydralazine	NR	Th, BG	H
P04	60	F	R	R	ECR	14	F, P, In, Th	I + H
P05	68	M	R	R	Nil	9	Md, P	I + H
P06	61	F	R	R	ECR	16	F, BG, In	H
P07	80	M	R	L	tPA	8	F	I + H
P08	62	M	R	L	Nil	4	Pons	I
P09	66	F	R	R	Nil	NR	Pons	I
P010	69	F	R	R	Thrombolysis	6	Th, O	I
Mean (SD)	67 (9.6)	F: 6 M: 4	R: 10	R: 6 L: 4		11 (5.2)		I: 5 H: 2 I+H: 3

Table 5. 3: Participant demographics.
KEY: C = cerebellum, BG = basal ganglia, ECR = endovascular clot retrieval, F = frontal, H = haemorrhagic, I = ischaemic, In = insula, I + H = ischaemic to haemorrhagic transformation, IV = intravenous, Md = medulla, O = occipital, P = parietal, Rx = treatment, TSO = time since onset (days), VAD = vertebral artery dissection

Results

Participant demographics

Nineteen participants were recruited (mean age 71.1 SD ±11.69 years, nine males). Due to an engineering error, data from the prototype IMU device used in the first ten participants was unusable and these participants were subsequently excluded. The included ten participants (n = 6 female and 4 males) had an average age of 67 (SD ±9.6) years, were all right handed, and were on average 11 (SD ±5.2) days post-stroke. Lesions varied between sides and location both within and between participants. The most commonly affected brain region was the frontal lobe; however, parietal, cerebellar, thalamic, insular, and brainstem lesions were also present. There was a near-even frequency of ischaemic, haemorrhagic, and ischaemic to haemorrhagic transformation strokes as demonstrated in Table 5.3.

Position matching errors

Position matching errors were highly variable between participants and movements (Table 5.4). The maximum average position error was 48.0 degrees (P02, elbow flexion) and minimum 0.1 degrees (P03, internal rotation). The maximum standard deviation per movement was 49.4 degrees (P03, wrist pronation) and minimum 2.8 degrees (P01, internal rotation). For all participants combined, the range of the average signed error (i.e. with either positive or negative direction from the origin included) was -12.2 degrees (elbow flexion) to 13.1 degrees (wrist pronation). Mean angular difference between upper limbs and their standard deviations are presented for each movement (Fig 5.3).

		P01	P02	P03	P04	P05	P06	P07	P08	P09	P10	All
Wrist Pronation	$\bar{x}$	23.8	-6.1	12.9	13.0	35.6	-8.8	-6.9	-34.5	30.6	71.8	13.1
	SD	31.2	6.3	49.4	37.3	39.3	28.8	24.8	10.9	3.7	4.5	23.6
Shoulder Ext. Rot.	$\bar{x}$	-1.9	3.8	5.7	-7.2	4.5	-9.5	13.0	8.1	6.7	33.7	5.7
	SD	11.1	2.8	13.0	11.3	20.9	8.4	14.7	7.4	14.8	3.9	10.8
Shoulder Int. Rot.	$\bar{x}$	9.6	-1.9	-0.1	7.3	-0.2	-4.0	-0.3	-13.1	4.4	13.5	1.5
	SD	2.8	2.2	15.7	6.1	14.6	10.7	14.2	5.0	11.9	17.6	10.1
Wrist Extension	$\bar{x}$	0.2	-19.3	-4.4	6.3	-24.2	16.4	-19.4	6.8	-3.4	-14.9	-5.6
	SD	20.2	13.1	48.7	33.4	13.3	14.2	17.1	10.7	5.9	11.0	18.8
Radial Dev.	$\bar{x}$	-1.1	-2.3	-3.2	44.2	-8.8	33.6	-8.0	8.9	7.5	-5.1	6.6
	SD	5.0	2.5	13.3	70.8	10.6	34.0	20.2	5.3	10.8	6.2	17.9
Elbow Flexion	$\bar{x}$	15.6	-48.0	-18.6	32.5	-17.7	0.8	-27.4	-25.4	-3.0	-30.7	-12.2
	SD	26.1	15.7	18.7	7.1	20.6	45.1	13.1	19.6	21.4	18.7	20.6
Elbow Flexion + Pronation	$\bar{x}$	4.7	8.6	3.7	37.0	-6.6	-1.5	-14.3	14.9	-23.6	-16.9	0.6
	SD	13.8	9.8	6.1	45.3	6.8	37.8	16.4	29.7	12.9	6.3	18.5

Table 5. 4 Signed mean ($\bar{x}$) errors and standard deviations (SD) for position match error in degrees for movements between participants.

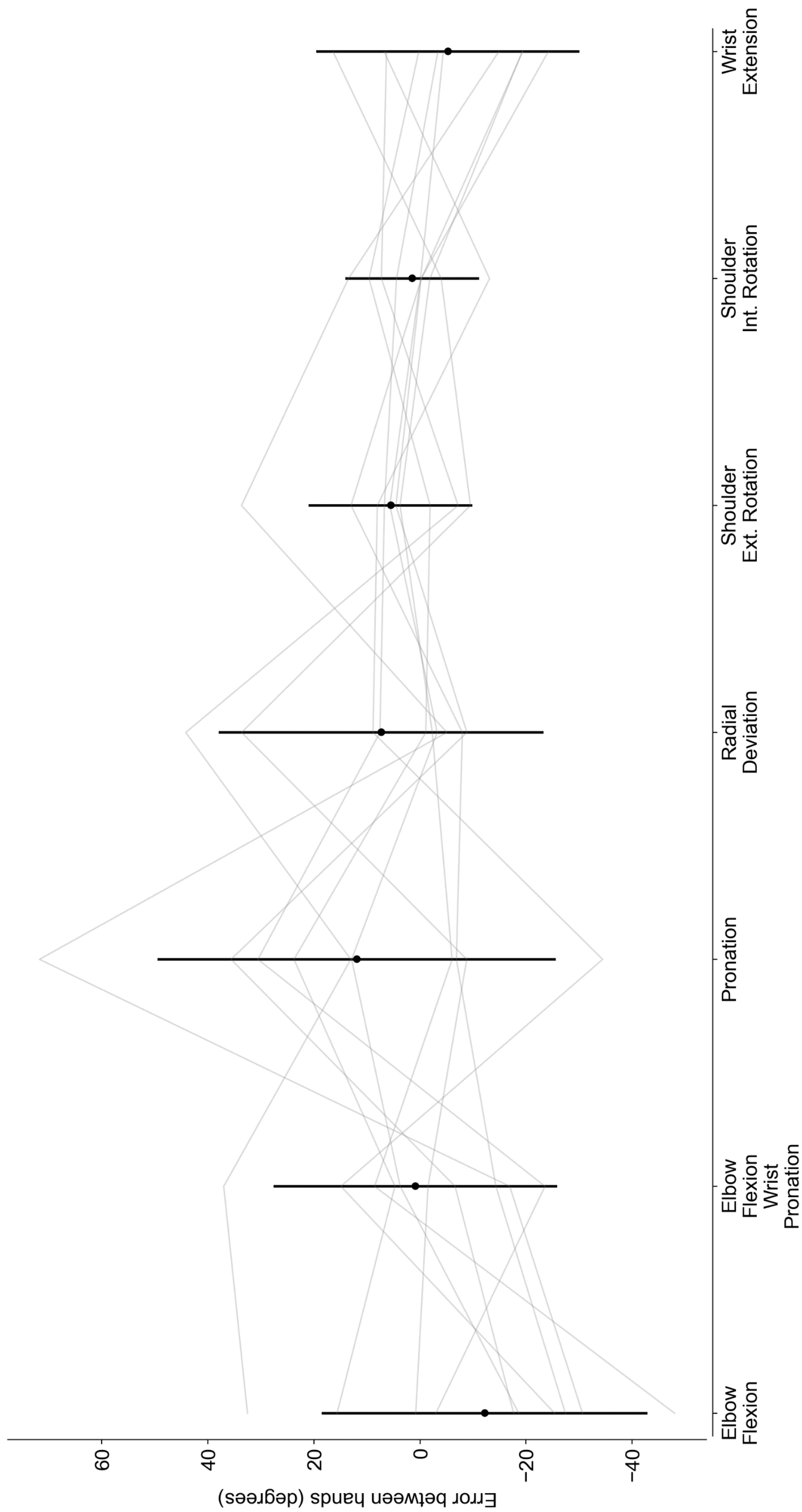

***Figure 5. 4** Mean angular difference (black circle) between upper limbs and standard deviations (black bar) for each movement.*

Individual participant data is represented by grey lines.

UL-PPA scores

One participant (P03) was unable to complete the UL-PPA on the day of testing due to fatigue. The other nine participants ranged from 'normal (1)' to 'severely impaired (5)' in all UL-PPA items, except the shirt task where most participants scored 'severe impairment'. On average, in the three other tests, participants were least impaired in the wire task, moderately impaired in the finger tapping and bimanual rod tasks, and highly impaired in their composite score. UL-PPA impairment rankings for each participant are displayed in Table 5.5.

	Shirt	**Finger Tapping**	**Wire Touches**	**Bimanual Task**	**Tactile Sensitivity**	**Total Score / 25**
P01	5	5	4	5	5	24
P02	2	1	1	2	2	8
P03	Missing	Missing	Missing	Missing	Missing	NA
P04	5	5	5	5	5	25
P05	5	1	1	1	1	9
P06	5	5	1	5	5	21
P07	5	2	1	2	5	15
P08	3	4	1	1	1	10
P09	5	5	5	5	1	21
P10	4	2	2	1	1	10
$\bar{x}$	5	3	2	3	3	16

Table 5. 5: Impairment Rankings in each UL-PPA task for each participant.

Key: 1 = no impairment, 2 = mild impairment, 3 = moderate impairment, 4 = high impairment, 5 = severe impairment.

Position matching error vs. UL-PPA impairment rankings

The majority of correlations between UL-PPA scores and position matching error were non-significant. Only one strong statistically significant correlation emerged, between wrist extension and the wire touch task (r = 0.64, p = 0.0077, 95%CI -0.04 - 0.92). Only elbow flexion position matching error correlated with total UL-PPA score (r = 0.91, p = 0.0044, 95%CI 0.62 – 0.98). Figure 5.6 shows an exemplar scatterplot and line of the best fit between wrist extension absolute position matching error and UL-PPA items.

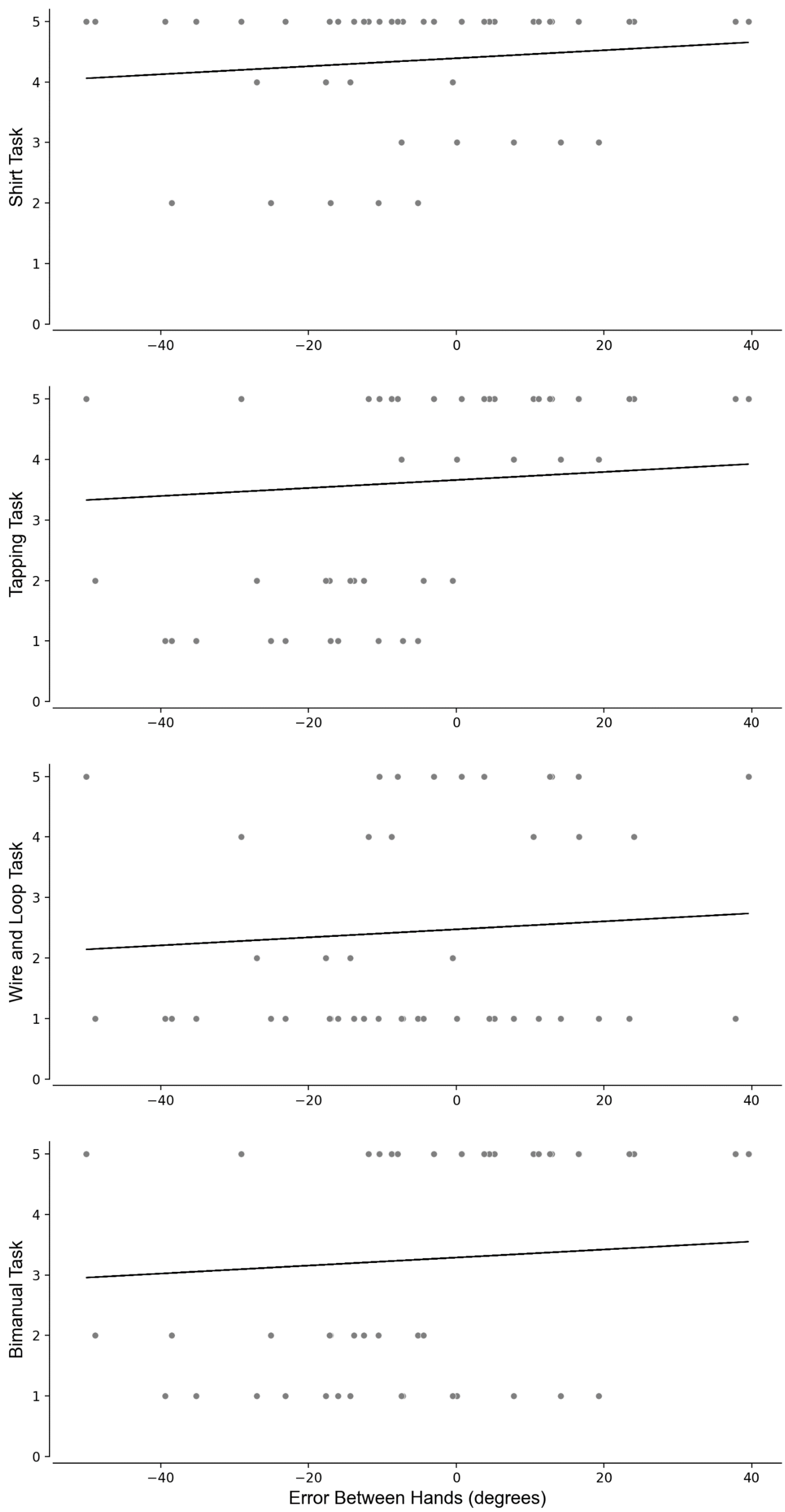

Figure 5.5: Example plots (wrist extension) of relationship between UL-PPA impairment scores and position matching error. Individual participant data points are shown as grey circles, and the line of best fit as black lines.

Discussion

The results of this study provided preliminary data on the inconsistent and weak relationship between clinical proprioception assessment using position matching tasks and upper limb impairment after stroke. Given the correlation of upper limb coordination recovery of upper limb function after stroke (Pelton, van Vliet et al. 2012, Kantak, Jax et al. 2017, Lai, Sung et al. 2019), the poor relationship between upper limb coordination and clinical proprioception assessment also suggests that the latter may not assess proprioception in a manner sensitive to patient function. However, proprioception is essential for skilled motor control and upper limb function – without it we are incapable of control of any movement in the absence of vision (Cole and Sedgwick 1992). Additionally, in the context of improvement in functional outcomes as the primary focus of all stroke rehabilitation, assessment tools should provide a functionally relevant measure of their target impairments. The preliminary results here presented suggest that current clinical proprioception assessment fails to do so, and is potentially redundant to the goal of rehabilitation. A possible explanation of this is that clinical position matching is not sensitive to proprioception as an integrated sense, one that involves the perception of body position in the space in which it moves (Proske and Gandevia 2018).
The exploration of clinical tests that do assess these integrated aspects of proprioception is an important area for future research.

Additionally, the results suggested that individuals with stroke are highly variable on matching accuracy both between different movements and separate trials of the same movement. The ability of position matching tasks to discriminate between healthy aged and those with upper limb impairment has previously been reported to be poor (Ingram, Butler et al. 2019). In healthy aged populations, mean signed errors in upper limb matching tasks range from approximately three to eight degrees at the elbow, and five to eighteen degrees at the wrist (Li and Wu 2014, Van de Winckel, Tseng et al. 2017, Ingram, Butler et al. 2019). Standard deviations of the same measurements range between two and five degrees at the elbow, and eight and twelve degrees at the wrist (Li and Wu 2014, Van de Winckel, Tseng et al. 2017, Ingram, Butler et al. 2019). Despite participants in this study presenting with high levels of upper limb impairment, on average, participants scored position matching errors within, or close to, the healthy aged average range. The present study provided preliminary data that, despite their more pronounced functional impairment, position matching as it is currently applied may not be able to detect functionally relevant differences between people with stroke and those without. Given the focus of rehab on functional ability, it is essential that assessment at the level of impairment has relevance to that of function. Thus, the results of this study provide further, but cautious, support for the development of improved measures of proprioception with a higher functionally discriminative ability in both healthy and clinical populations.

Although the current study had a small sample size, there was considerable variability within and between participants in the accuracy of position matching. Additionally, the variability in match accuracy between different movements of the upper limb was high even when these movements occurred at the same joint. While it is possible that this variability is a result of issues with the reliability of the IMU device, similar reports of high *between*-person variability have been reported in healthy populations (Qureshi, Butler et al. 2019, Rana, Butler et al. 2020). However, these studies also reported a low *within-person* variability, hypothesised to be due to a highly accurate ability to match proprioceptive signals in healthy individuals.

The high within-subject variability in this data suggests that this signal matching is inconsistently, rather than uniformly impaired in people with stroke. The variability in performance of people with stroke could indicate the level of impairment in proprioception; however, current methods of proprioception focus on the degree of error alone (Winward, Halligan et al. 2002, Stolk-Hornsveld, Crow et al. 2006). As such, within-person variability represents a potential target to increase the accuracy of future proprioception assessment tools developed for neurologically impaired individuals.

The participants in this study all had moderate to severe impairment in their scores on the UL-PPA tasks, most likely due to the sample average of 11 days post-stroke. Upper limb recovery is infrequent, and can occur for months after stroke (Houwink, Nijland et al. 2013). Importantly, motor recovery is variable between individuals with stroke and is only partially explained by acute-stage clinical variables (Prabhakaran, Zarahn et al. 2008). In this context, it is important to include multiple follow-up points in any study of stroke rehabilitation in order to clarify the degree of recovery and the factors that influence it, and if these are variable between individuals. The original study design was planned to include such follow-ups, with measurements taken at rehabilitation unit admission, discharge, and six months after admission. However, this was impossible due to the impact of the SARS-COV19 pandemic restrictions in Australian healthcare system. It is possible that variability in position matching accuracy would decrease over a six month period post-stroke, and that UL-PPA scores would be more strongly correlated with position matching accuracy with the decrease in severity of other confounding impairments (e.g., strength) over time. However, other measures of proprioception show within-person variability well into chronicity in people with stroke (Lodha, Misra et al. 2013, Chow and Stokic 2014). The inclusion of follow-up time points in the present study would have shown if this is also true for position matching, and added further support for the use of within-person variability as a marker of proprioceptive impairment. Thus, there is a need for future studies investigating the relationship between upper limb impairment and proprioception in the late sub-acute and chronic stages of stroke recovery.

Limitations

The primary limitation of this study is the small sample size and absence of follow-up assessment time points that occurred due to recruitment cessation in response to the SARS-COV19 pandemic. Thus, all results are preliminary in nature and must be interpreted with caution. The large standard deviations in this study indicate need for larger studies investigating current methods of clinical proprioception assessments in order to confirm or refute the findings reported here. However, these standard deviations may be an indication of high within subject variability that is symptomatic of a cerebral lesion.

A second limitation came from the ability of some participants with stroke to keep their paretic limb passive. Despite the effects of spasticity having previously been shown to have little impact on position matching (Mochizuki, Centen et al. 2019), motor commands and subsequent active movement alter the accuracy of position matching ability (Laufer, Hocherman et al. 2001). Motor activity assessment (e.g., via electromyography) was absent from the outcome measures of this study and its impact on the study results cannot be determined. Over-activation of the motor system in active movement is common in people with stroke (Ward, Newton et al. 2006). However, over-activation has not yet been established in passive movement tasks. Additionally, electromyography is beyond the scope of most clinical settings. Subsequently, unwanted motor activation may reduce the pragmatism of position matching as an assessment of proprioception and should be established in passive movement in people with stroke.

Conclusion

This study provides preliminary evidence that current clinical assessment of upper limb proprioception, in particular position matching, may have limited relevance to other upper limb impairments in the rehabilitation of people after stroke. The disconnect between position matching as an assessment of proprioception and functional outcomes could be due to position matching only detecting the basic aspects of proprioception, and thus failing to accurately assess the integrated sense of position in space needed for function. However, further investigation is needed in larger samples to confirm this. Additionally, there was high between and within subject variability in the accuracy of position matching which represents a possible target for future assessment of upper limb proprioception in people with stroke to track recovery. These results indicate the need for alternate, clinically relevant, and standardised assessments of proprioception for people with stroke.

Such assessments should target multiple aspects of proprioception, most notably muscle force judgement and body representation, and should examine within-person variability as a measure of impairment. Such assessments should also be investigated in the sub-acute and chronic stages of stroke, to ascertain the change in variability over time. Finally, outcome measures should be designed to have relevance to functional tasks (e.g., judgement of the distance between limbs, or of grasp aperture).

Chapter summary

The relationship of clinical position matching assessment and upper limb impairment was not well clarified in previous research. Preliminary data in this chapter show that this relationship is weak in people with stroke. Additionally, this chapter provided evidence that people with stroke show a high within-person variability in their performance of position matching. Their performance may also be confounded by poor control of motor activation. These findings should be investigated in a larger cohort, which is beyond the scope of this thesis. Conversely, clinical assessment of unilateral neglect is standardised and has established relationships with functional outcomes. However, clinical assessment is often limited to a single type of unilateral neglect that varies between professions. This formed the basis for the next phase of research in this thesis, the Ability and Action phase. The next chapter details a mixed-methods investigation that aimed to establish the determinants underpinning decision making in current clinical unilateral neglect assessment.

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Chapter 6: Clinician experience of unilateral neglect assessment in stroke rehabilitation - a pilot study

In addition to Ms Fisher and the supervisory team, Associate Professor Emma Power and Ms Annaleise Getley assisted in the protocol development of the chapter that follows. Ms Annaleise Getley also assisted as one of the primary site contacts.

Author contribution statement

As primary supervisor, I confirm that Georgia Fisher made the following contributions to the chapter following:

- Formulation of objectives
- Creation of the human research ethics application and liaison with the appropriate Human Research Ethics Committees for approval
- Data collection in collaboration with Camila Quel de Oliveria and Annaleise Getley
- Data analysis in collaboration with Camila Quel de Oliveria
- First draft of the chapter

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Dr David Kennedy

Abstract

Unilateral neglect is a frequent sequela of stroke that significantly interferes with functional recovery. Unilateral neglect is a highly heterogeneous condition, and therefore, comprehensive assessment is essential to identify and manage all possible impacts on the function of a person with stroke. While assessment tools that allow a comprehensive assessment of unilateral neglect have been developed, their uptake in clinical practice is low leading to an important disparity between literature recommended best-practice and clinical practice (evidence-practice gap).
The barriers and facilitators to practice change in this area have not yet been investigated using a validated theoretical framework. Therefore, this study aimed to describe the perceived determinants important to clinicians to implement evidence-based unilateral neglect assessment using the Theoretical Domains Framework (TDF).

A mixed-methods multi-site study with an explanatory sequential design was conducted. Physiotherapists and occupational therapists from one inpatient (n=4) and one community rehabilitation site (n=6) were provided with a brief educational intervention about unilateral neglect and the prevalence of the assessment of unilateral neglect in their clinical practice was observed for 3 months. A clinical file audit was conducted prior to and during the study period to document the incidence and types of unilateral neglect assessment employed by clinicians before the educational intervention and three months after.

Focus group interviews were conducted after the study period and revealed that physiotherapists were most likely to implement the Dublin Extrapersonal Neglect Assessment, while occupational therapists continued use of their previous assessments (pen-and-paper tasks) in their practice. Evidence translation was

influenced by TDF determinants common to other areas of stroke rehabilitation, including time constraints, organisational and social support, available resources, and therapist’s confidence and skills. However, the primary barrier identified was ‘perceptions of assessments being another professions responsibility’, and a facilitator was ‘positive beliefs about patient consequences’. Barriers and facilitators varied between the hospital and community settings.

Overall, implementation was influenced by a number of specific behavioural determinants, including clinician knowledge, healthcare system role delineation, and implementation setting. Larger studies are required across a more diverse number of sites and health professions to firmly establish barriers and facilitators in this area, and provide the foundation for sustainable and effective practice-change interventions.

Introduction

Unilateral neglect is a complex impairment of functional connectivity between brain regions that are associated with attention, sensorimotor and visual processing of the side opposite a brain lesion (Doricchi and Tomaiuolo 2003, He, Snyder et al. 2007, Smith, Clithero et al. 2013, Mengotti, Käsbauer et al. 2020). Unilateral neglect can thus impair multiple perceptual processes (e.g., visuospatial, motor, representational, and proprioceptive) and occur in multiple spaces (e.g., personal, peri-personal, and extra-personal) (Punt and Riddoch 2006, Guariglia, Palermo et al. 2013, Rode, Pagliari et al. 2017). Because of this multifactorial presentation, unilateral neglect significantly impairs multiple aspects of function, and results in poorer rehabilitation outcomes for people with the condition after stroke (Cherney, Halper et al. 2001, Jehkonen, Laihosalo et al. 2006, Tarvonen-Schröder, Niemi et al. 2020).

Rehabilitation of unilateral neglect is typically managed by physiotherapists and occupational therapists. However, clinical management has not progressed in tandem with the new evidence-based knowledge. Instead, clinicians commonly assess and treat unilateral neglect as an impairment in visuospatial attention alone (Evald, Wilms et al. 2020, Checketts, Mancuso et al. 2021). The focus on visuospatial unilateral neglect has resulted in a significant evidence-practice gap (Barrett and Houston 2019). Clinical assessment of unilateral neglect is either absent entirely (Menon-Nair, Korner-Bitensky et al. 2006, Menon-Nair, Korner-Bitensky et al. 2007), or is a) standardised, but restricted to upper limb tasks in the peri-personal space, or b) non-standardised general clinical observation (Plummer, Morris et al. 2006, Evald, Wilms et al. 2020, Checketts, Mancuso et al. 2021). Effective stroke rehabilitation is predicated on accurate impairment characterisation, and thus people with unilateral neglect continue to have poorer functional outcomes than those without it after stroke (Chen, Chen et al. 2015, Bosma, Nijboer et al. 2020, Tarvonen-Schröder, Niemi et al. 2020).

The evidence-practice gap in unilateral neglect assessment is not due to a dearth of available assessments; there are over 28 standardised and validated tools to assess the condition (Menon and Korner-Bitensky 2004, Barrett and Houston 2019). Rather, it seems to be that a widespread lack of clinician knowledge of both the available assessment tools and the heterogeneous nature of unilateral neglect is present, likely from students in pre-registration university courses to senior clinicians and policy makers (see Chapter 4, Appendix 1, and Plummer, Morris et al. 2006, Evald, Wilms et al. 2020, Evald, Wilms et al. 2020). However, a lack of knowledge alone does not drive evidence-practice gaps, which instead arise from the interaction of multiple factors (Linton 2002, Craig, Dieppe et al. 2008) that are associated with the management of unilateral neglect.

First, few assessments are sensitive to all or even multiple aspects of the condition (Menon and Korner-Bitensky 2004). Thus, even clinicians who are aware of the options available must use multiple different tools or portions of tools to effectively assess the condition as whole (Donoso Brown and Powell 2017).
This may not be feasible in typical clinical settings where unilateral neglect is only one of the many impairments requiring assessment. Second, many unilateral neglect assessments do not directly address the impact of unilateral neglect on the functional abilities of a person with stroke (Menon and Korner-Bitensky 2004, Nijboer and Van Der Stigchel 2019). Ongoing evaluation of functional improvement is essential in rehabilitation to meet stroke-survivor centred goals. Hence, assessments of unilateral neglect that do not provide information on the functional ability of the patient may have limited perceived clinical utility. Finally, there is little policy

guidance in this area, with most stroke guidelines making a general recommendation of ‘complete a standardised assessment of unilateral neglect without specific recommendations on what tools to use, or their timing of use (Heart and Stroke Foundation of Canada 2015, Royal College of Physicians 2016, Razmus 2017, Stroke Foundation Australia 2018).

Clinical practice behaviours, and the factors and contexts that can change them are essential to understand to plan implementation research (Graham, Logan et al. 2006, Atkins, Francis et al. 2017). The Theoretical Domains Framework (TDF) is a valid and well investigated tool that unites multiple theories of behaviour change into a single framework to describe the cognitive, affective, social, and environmental influences on clinical behaviour (Cane, O’Connor et al. 2012). The TDF has been extended into a guide for use in research to deepen understanding of clinical practice behaviours through categorisation of behavioural influences into barriers and facilitators (Atkins, Francis et al. 2017). Previous studies have identified broad categories of behavioural change that influence the implementation of evidence-based unilateral neglect assessment, of which a lack of knowledge was the primary barrier (Petzold, Korner-Bitensky et al. 2014, Evald, Wilms et al. 2020, Evald, Wilms et al. 2020). However, no study to date has investigated the specific barriers and facilitators to the use of evidence-based unilateral neglect assessment in both inpatient and community settings through a validated framework. Thus, this study aimed to use the TDF to describe the perceived determinants in the experience of implementing evidence-based unilateral neglect assessments into clinical practice, with a view to providing the foundation for larger scale implementation studies.

Methods

Design

This study is a pilot multi-site observational study using mixed methods, and has been reported according to the COREQ framework (Appendix 6A) for reporting qualitative research (Tong, Sainsbury et al. 2007). The study used an explanatory design for both quantitative and qualitative data, where quantitative data was also collected sequentially (Figure 6.1) (Ivankova, Creswell et al. 2006). The study was conducted in a community rehabilitation organization with sites across multiple states, and an inpatient rehabilitation hospital that provide care for people with neurological conditions. The study was approved by the Illawarra Shoalhaven Local Health District Human Research Ethics Committee (2020/ETH01573), and ratified by the University of Technology Human Research Ethics Committee (ETH20-5290)

- Explanation of Study - Consent	1 month pre-education	- Hour length in-service style education	- Clinician trial of assessments (3 months)	- Clinician focus groups - Retrospective notes audit of pre-study and study period

Figure 6. 1: Study procedure and timeline

Population

Due to the exploratory nature of the research, a convenience sample of physiotherapists and occupational therapists was recruited from each site with the following eligibility criteria: 1) being an Australian Health Practitioner Registration Agency (AHPRA) registered physiotherapist or occupational therapist, 2) being currently employed in a rehabilitation setting that provides stroke rehabilitation services, 3) have at least six months of experience in neurological rehabilitation, and 4) be able to provide written, informed consent to participate in study. Clinicians were aware that the aim of the study was to examine clinical experience of unilateral neglect assessment, but were kept blind to precise study aims to prevent the introduction of bias in their implementation decisions (e.g., their conscious alignment with TDF determinants).

Recruitment

Staff members at each site were selected as study representatives and named authors (CQ and AG) and provided staff with an overview of the project and associated consent forms. Then, a member of the research team (GF) independently provided a written description of the study and obtained written informed consent.

Procedures

Education session

Participants at each site were provided with an hour-long educational in-service detailing a variety of evidence-based, validated unilateral neglect assessments to increase their awareness about the topic. The session included background information on unilateral neglect and a description of tools according to the modality and spatial domain they assessed. The slides of the education session are in Appendix 6B. After the session, each site was provided with a resource pack containing the slides from the session, and research articles on the assessments described. Education sessions were open to any clinician at the sites, including those who did not formally participate in the study. After running the education session, the author (GF) was available to contact for clarification of assessment evidence and procedures, but not to provide implementation advice. Furthermore, participants were unaware of the precise aims of the study. These strategies were chosen to enable as natural a description of clinical practice as possible, where clinical education typically occurs via department in-services or primarily through discussion or mentoring among colleagues. Clinicians then had three months to implement any unilateral neglect assessment of their choosing, which gave clinicians the opportunity to make concrete judgments about the use of unilateral neglect assessments, rather than from a purely hypothetical point of view.

Post-Practice Evaluation Data Collection

After a three-month clinical practice period, focus groups were run at each site to collect clinician experiences. Clinicians also completed an online demographic survey. The clinical notes of each participant were audited by their respective site representative for one month prior to the study, and during the three months of the study period to verify changes or usage of unilateral neglect assessments.

Outcome measures

Demographic online questionnaire

Clinician demographic data were collected via an online questionnaire on the REDCap platform (Vanderbilt University 2021). Demographic questions were based off those previously used in a Canadian National Survey of stroke clinicians (Korner-Bitensky, Barrett-Bernstein et al. 2011) and included information regarding workplace setting, level of qualification, years of clinical experience, and the nature of stroke care provided by the clinician.

Focus groups:

An hour-long focus group was conducted over Zoom (Zoom Communications Inc, 2021) by author GF for each site using guide questions established a priori based on the TDF (Appendix 6C). GF is a registered physiotherapist (B.App.Sc.Phty) and was practising clinically in rehabilitation at the time of the focus groups. She had previously conducted focus groups with clinicians, and had received training from author EP who has extensive experience in focus group facilitation. The participants knew that the focus group facilitator was a physiotherapist with a clinical speciality of stroke rehabilitation, and that the facilitator's research focused on improving assessment in unilateral neglect. At the start of the focus groups, the facilitator repeated these facts and gave an overview of biases related to the research. The questions were asked verbally, and repeated as necessary. One participant from each site was unable to attend the focus groups on the planned dates and instead participated in individual semi-structured interviews conducted by GF using the same guide questions and method as the focus groups. The focus groups and interviews were video and audio recorded (2021), and were reviewed by the facilitator to make field notes. Then, they were transcribed verbatim by the facilitator (GF). Participants had the opportunity of reviewing transcripts to ensure accuracy (member checking) (Birt, Scott et al. 2016).

Clinical notes audit

The clinical notes of each participating clinician at each site were audited for one month immediately prior to the educational sessions at each site, and during the three-month clinical practice period. The notes were audited by the nominated study representative for each site, who was the physiotherapy clinical lead at the inpatient site, and the non-clinical team lead at the community site. The inpatient site used paper based documentation, while the community audit was of electronic notes. The notes of each clinician were audited chronologically to find instances of care of a stroke patient, and the occurrence and type of unilateral neglect assessment was extracted. Site representatives developed their audit tools in collaboration with the facilitator, and were provided with detailed information about the type of data to extract. Information extracted included the frequency of unilateral neglect documentation, the frequency of use of standardised and non-standardised unilateral neglect assessments, and the total number of sessions delivered to people with stroke by the study participants. All audits were conducted retrospectively after the study period.

Data analysis

Demographics and Usage of unilateral neglect assessments

Descriptive statistics of clinician demographic data reported for the group as a whole, and by site were conducted with all analysis conducted in Python (Python Software Foundation 2021). The mean and standard deviation of unilateral neglect assessment incidence pre- educational session and during the 3-month clinical practice period was calculated.

Focus group

A framework analysis methodology including elements of content analysis was used to evaluate focus group transcripts (Gale, Heath et al. 2013) with coding variables based on the TDF. A category of ‘Other’ enabled scope for the generation of codes for data that did not fit within the domains of the TDF. Two members of the research team (GF and CQ) independently extracted and coded data from each transcript (Bengtsson 2016) using the process of analysis set out by Gale et al. (Gale, Heath et al. 2013). Disagreements were resolved through consensus with a third member of the research team (E.P.). The NVivo software (QSR International 2021) was used to code focus group transcriptions, and to generate the framework matrix. Raw frequencies of TDF themes and their emergent sub-themes were calculated. Quotes of participant responses illustrative of each element of the TDF were extracted. The results of the qualitative analysis are reported according to the Consolidated Criteria for Reporting Qualitative Research (COREQ), a 32-item checklist covering the three domains of (a) research team and reflexivity, (b) study design, and (c) analysis (Tong, Sainsbury et al. 2007).

Site Characteristics	Inpatient	Community
Daily frequency of care of people with stroke: (< 5, 5 – 10, 11-15)	< 5	< 5
Multi-disciplinary team / stroke unit on-site	Yes	Yes
University affiliation	No	No
Previous or concurrent stroke rehabilitation research on-site	Yes	No
Student placements	Yes	Yes
Professions on-site		
Physiotherapy	Yes	Yes
Occupational Therapy	Yes	No
Speech Pathology	Yes	No
Neuropsychology	Yes	No
Exercise Physiology	No	Yes
Clinical Psychology	Yes	No

Table 6. 1: Demographics of participating sites.

Results

Site participant characteristics

Both sites had either a multidisciplinary team or a stroke unit on site, hosted student placements, and neither were affiliated with a university. Four clinicians were recruited from the inpatient site, and six from the community site. Two clinicians declined participation at the inpatient site, due to a planned rotation to another ward in the study period. No participant dropped out during the period. Participating clinicians were mostly physiotherapists, had a broad mix of years of experience, and were employed full-time. Tables 6.1 and 6.2 display the full characteristics of sites and participating clinicians.

Clinician Demographics	Count	Clinician Demographics	Count
Profession		Employment	
OT	2	Fulltime	9
PT	7	Part-time	1
Both	1		
Qualifications		Student Supervision	
Undergraduate	4	Yes	10
Post-graduate Masters	6	No	0
Years of Experience		Weekly frequency of stroke care	
< 3 years	3	< 3	6
3 - 5 years	2	3 - 5	2
> 5, < 10 years	3	6 - 10	2
≥ 10 years	1		

Table 6. 2: Demographics of participating clinicians

Clinical notes audit

Before the education session, the incidence of use of standardised unilateral neglect assessment in clinical documentation was 19.5% at the inpatient site, and 0 at the community site. During the clinical practice period, clinicians at the inpatient site added one standardised assessment to their practice and increased assessment from an average of 35% of patients to an average of 48% of patients. Conversely, no additional assessments were observed at the community site. A summary of the study notes audit is provided in Table 6.3.

Site		Pre Study (%)	Types of Ax	During (%)	Types of Ax	Change (%)
Inpatient	OT	27.8 (30.5)	Pen + paper, observation	17.4 (15.5)	Pen + paper, observation	- 37.4%
	PT	14.7 (37.6)	Observation	80.0 (40.0)	DENA, observation	+ 444%
Community	PT	None documented	None documented	None documented	None documented	Nil

Table 6. 3: Mean percentage (standard deviation) of notes citing unilateral neglect pre and during study period for each site, and types of assessment used.

Key: DENA = Dublin Extra-personal Neglect Assessment, OT = occupational therapists, PT = physiotherapists

Focus group coding

All TDF items except *emotion* were identified in the first coding comparison. Agreement between the two extractors ranged between 89.61% and 100% across all TDF items. The two extractors then identified 34 sub-themes from the dataset (Appendix 6D), and then independently coded data from each TDF determinant into each. Agreement between extractors ranged between 88.6% and 100%. These 36 sub-themes were then collaboratively refined into the final 29 sub-themes presented (Fig. 6.2).

Influences on Implementation of unilateral neglect assessment in clinical practice period

Influences on assessment of unilateral neglect assessment were identified across 13 of the 14 domains of the TDF (Table 6.4), with the determinant 'emotion' not appearing in any of the focus groups. There were four unique stages in the assessment process that emerged from the data set; 1) Intent to use assessment tool, 2) Selection of assessment tool, 3) Use of tool and 4) Sustained use.

The percentage of occurrence in extracted codes for each sub-theme at each stage of implementation is displayed in Figure 6.3.

The primary barrier described specific to the inpatient setting was '*perceptions of assessment tools being another profession's responsibility'*, while community clinicians were most constrained by *'limitations of assessment tools for the characteristics of their patients'.* The primary facilitator was *'minimal change required to clinical practice'* for the inpatient setting, and *'previously acquired skills in any context'* for the community setting. Exemplar quotes are described in Table 6.5 (Barriers) and Table 6.6 (Facilitators).

No.	Domain	Definition
1	Knowledge	An awareness of the existence of something
2	Skills	An ability or proficiency acquired through practice
3	Social/professional role and identity	A coherent set of behaviours and displayed personal qualities of an individual in a social or work setting
4	Beliefs about capabilities	Acceptance of the truth, reality or validity about an ability, talent or facility that a person can put to constructive use
5	Optimism	The confidence that things will happen for the best or that desired goals will be attained
6	Beliefs about Consequences	Acceptance of the truth, reality, or validity about outcomes of a behaviour in a given situation
7	Reinforcement	Increasing the probability of a response by arranging a dependent relationship, or contingency, between the response and a given stimulus
8	Intentions	A conscious decision to perform a behaviour or a resolve to act in a certain way
9	Goals	Mental representations of outcomes or end states that an individual wants to achieve)
10	Memory, attention and decision processes	The ability to retain information, focus selectively on aspects of the environment and choose between two or more alternatives
11	Environmental context / resources	Any circumstance of a person's situation or environment that discourages or encourages the development of skills and abilities, independence, social competence and adaptive behaviour
12	Social influences	Those interpersonal processes that can cause individuals to change their thoughts, feelings, or behaviours
13	Emotion	A complex reaction pattern, involving experiential, behavioural, and physiological elements, by which the individual attempts to deal with a personally significant matter or event
14	Behavioural regulation	Anything aimed at managing or changing objectively observed or measured actions

Table 6. 4: TDF framework items, from Atkins, Francis et al. 2017

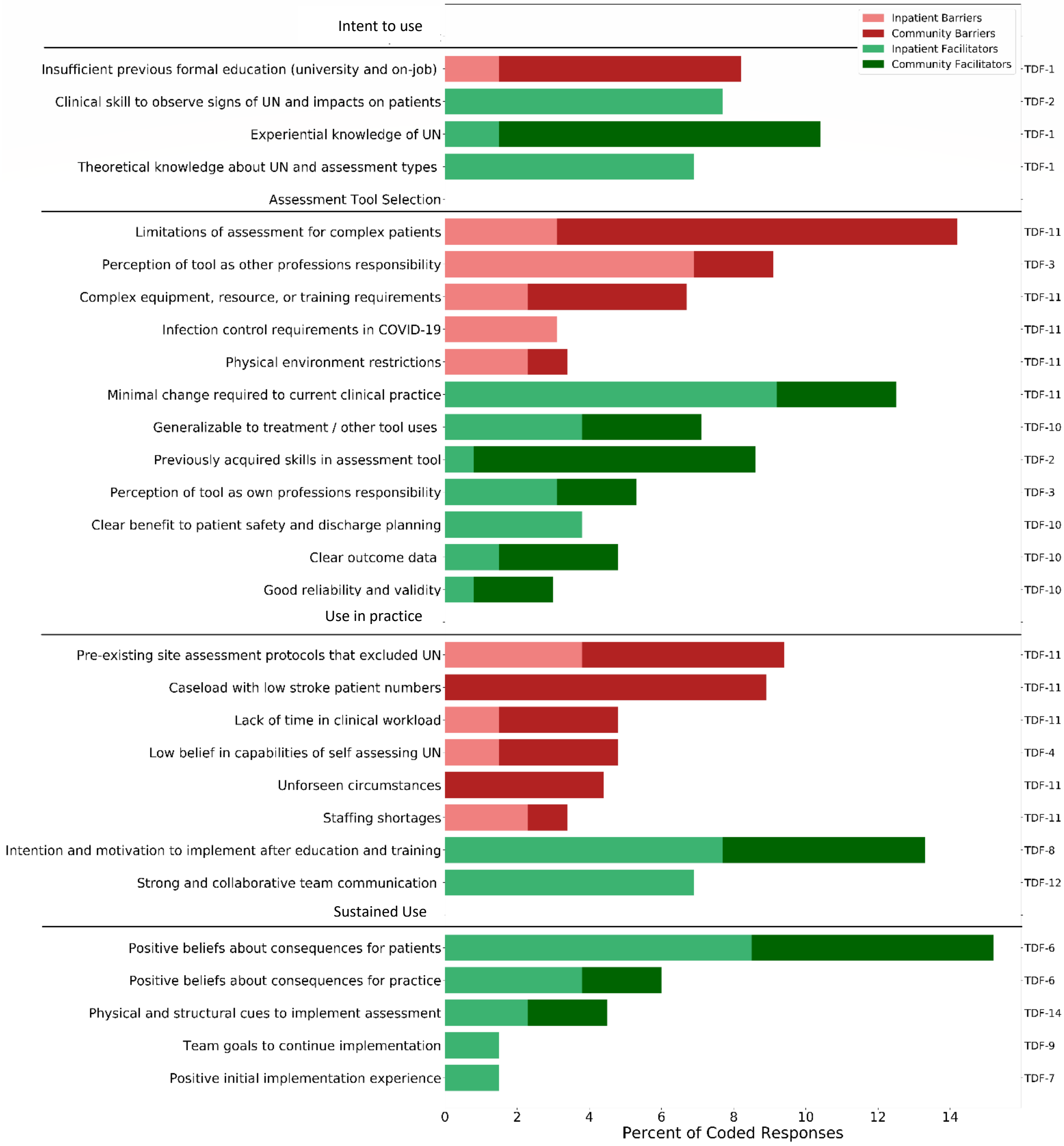

Figure 6. 2: Raw counts of frequency of occurrence of barriers (red) and facilitators (green) in each implementation stage.

TDF determinants are numbered on the right vertical axis, numbers corresponding to the table in Figure 6.2. Inpatient facilities are shown by light colour tone, and community by dark colour tone.

TDF Item	Sub-Theme	Example
Intent to use tool		
Knowledge	Insufficient previous formal education	*"I can't say I remember much from uni, or had any other formal training in the area"*
Assessment tool selection		
Environmental Context and Resources	Limitations of assessment for patients	*"he is severely impaired, he doesn't have any communication at all, so there would be no (suitable) tests for him"*
	Equipment, resource, or training requirements	*"that (assessment) would be amazing, but it's also going to take a lot of training"*
	SARSCOV-2 infection control requirements	*"from an infection control point of view, we were struggling to think about how we would get that through"*
	Physical clinic environment	*"you know in a hospital corridor there are lots of posters or things on the wall, that .. made it hard"*
Professional Role	Perception of assessment as responsibility of other profession	*"the CBS and the fluff test, those … seemed very much more within occupational therapy realm"*
Use in practice + Sustained use		
Environmental Context and Resources	Pre-existing site assessment protocols that excluded unilateral neglect	*"it's not a part of that assessment matrix that we have … so we don't really have too much scope to add more"*
	Limitations of assessment for patients	*"(clients) are just so fixated on the walking around and mobility … I feel like I am having to sell it (assessment) all the time"*
	Caseload with low stroke patient numbers	*"my clinic load is relatively stagnant and … there is not a huge number of (appropriate patients) that I had an opportunity to work with"*
	Lack of time in clinical workload	*"I think the barrier for us was not having time"*
	Staffing shortages	*"our staffing impacted making any changes to what we do currently"*
	Unforeseen circumstances	*"trying to organise everything with the (clinic) move .. we couldn't actually find time to do it properly,"*
Beliefs about capabilities	Low self-belief in capabilities of assessing unilateral neglect	*"I do think (assessing unilateral neglect) is probably more beneficial, (but) learning to do that initially is hard"*
Beliefs about consequences	Beliefs about increased workload and negative patient outcomes	*"our concern is that we rush out tools and we don't know what we are doing with them and it has implications for our patients discharge destination because you know, we've interpreted it wrong,"*

Table 6. 5: Barriers to assessment tool use and example quotes at each stage

TDF Item	Sub-Theme	Example
Intent to use tool		
Knowledge	Experiential unilateral neglect knowledge	*"then you actually got to see (patients with unilateral neglect), that's where you learn the most"*
	Theoretical unilateral neglect knowledge	*"being able to put a name to what type of unilateral neglect (a patient had) was really good"*
Skills	Clinical skill to observe signs of unilateral neglect	*"I was more aware of unilateral neglect. Yeah! Like in self-care assessments"*
Assessment tool selection		
Environmental Context and Resources	Minimal change required to current clinical practice	*"we chose that assessment because it was really easy to get together and implement, we cut out the diamonds ourselves, there was a script that you could follow"*
Memory, attention, and decision making	Generalizable to treatment / other tool uses	*"Speaking of the (test), I use it as a treatment tool now, I love it, it's so good - I do quite a lot of stereognosis training with certain clients"*
	Clear benefit to patient safety and discharge planning	*"we chose the (test) because it (had implications for patients) .. risk in navigating the environment, and their capacity to mitigate that risk"*
	Clear outcome data	*"particularly because you just print things off and .. get really clear feedback from their results,"*
	Good reliability and validity	"*the fact that they had been validated, .. gave us much more confidence to do it,"*
Skills	Previously acquired skills in assessment tool	*"because I have always done it that way (assessing unilateral neglect) it doesn't take me that much longer and so I always (assess unilateral neglect)"*
Professional Role	Perception of tool as own professions responsibility	"*we chose to use that because .. we felt that was most relevant to our general treatment goals"*
Use in practice		
Intention	Intention to implement (met)	*"(the reason we could implement unilateral neglect assessment was) we wanted to learn about it and we wanted to implement it, and we wanted to do it well for our practice"*
	Intention to implement (unmet)	"*unfortunately, (we didn't implement) many of the strategies or assessments … but that's something for us for the new year"*
Social Influences	Strong team communication and collaboration	*"we worked through all of the options and we discussed as a team … and because our nursing unit manager was happy … we could do it"*
Sustained use		
Beliefs about consequences	Positive beliefs about consequences for patients	*"It gave us evidence for pushing for the support that he (patient) needed .. it had a huge impact for him"*
	Positive beliefs about consequences for practice	*"being able to apply a number (from assessment result), backs up (clinical decisions)"*
Behavioural Regulation	Physical and structural cues to implement assessment	*"we have a morning meeting .... where we would prompt each other to (implement)"*
Goals	Team goals to continue implementation	*"so we definitely intend to… keep up that unilateral neglect assessment for any patients that come through"*

Table 6. 6: Facilitators to unilateral neglect assessment implementation and example quotes at each stage of implementation

Clinician recommendations for unilateral neglect assessments and their implementation

In addition to the factors that directly influenced participant assessment tool use, a number of recommendations were made in the focus groups of what clinicians perceived as the ideal unilateral neglect assessment tool or implementation strategy. In regards to assessment tools, clinicians perceived that the ideal assessment tool is low-cost, uses commonplace equipment, and is quick to administer, as illustrated by the quotes below.

> *"if you could do an assessment with cups or bowls that we would already have access to (that would make it easier to perform)*"

> "*also something that is not too expensive" …. "I know that (it's difficult) to get management to buy things"*

Clinicians also recommended a tool that covered multiple aspects of unilateral neglect, is functionally relevant for patients, and has clear implications for treatment planning.

> *"then linking clearly for the clinicians that if you found (a symptom of unilateral neglect) out, you'd look at (a specific) kind of unilateral neglect, (and know that) this is the gold standard treatment for that kind of unilateral neglect, or this is where you can go to discover what treatment is appropriate"*

"(Ideally we would want an assessment) that can be done at different functional levels as well, that can be done in a seated and standing position"

To use unilateral neglect assessment sustainably, clinicians recommend initial education followed by on the job training that is supported by ongoing access to online or video based training resources.

"(when we were implementing a different assessment that had video tutorial support) we could then use the video to refer back to, to say like I did it with this person and in this spot it was a bit clunky, and when we went back to the video it kind of gave us queuing and prompting which was really helpful"

"I think (assessing unilateral neglect is) something that we need more practice or training in, like if we saw it first hand, like the assessments"

Additional recommendations were implementation to be supported via their organisational hierarchy or via a key implementation clinician, with regular prompting and accountability, and to initiate implementation work outside of the first or final month of the year due to caseload and staffing changes in the health system.

"I also think (it would help) having a key contact person across the district that really has some skill level or some experience"

"a template where we could have the assessment there as a prompt (to implement every time we assessed a patient)"

Discussion

The results of this study highlighted a number of behavioural determinants that are common with previous investigations of clinical decision making in stroke rehabilitation, including time constraints, organisational and social support, available resources, and therapist confidence and skills (Jolliffe, Hoffmann et al. 2019, McCluskey, Massie et al. 2020, Nascimento 2020). However, three primary categories of determinants unique to assessment of unilateral neglect emerged, and are subsequently important in future assessment development and evidence translation in this area. They are clinician knowledge, health care system structure and healthcare setting.

Clinician knowledge

The present study provided further evidence that 'a lack of clinician knowledge' regarding unilateral neglect assessment tools is a primary barrier to their use in practice (Chapter 3, refs. Evald, Wilms et al. 2020, Checketts, Mancuso et al. 2021). Prior to the study education session, most physiotherapists and occupational therapists were only aware of pen and paper-based unilateral neglect assessments, which had implications unique to each profession. For physiotherapists, the fact that pen and paper assessments were already conducted by another profession in the multidisciplinary team likely resulted in using observation alone, instead of a standardised tool, to avoid duplication. The study education session resulted in physiotherapists selecting and implementing tools other than observation, which suggests that the education session increased awareness of the unilateral neglect assessment options. For occupational therapists, who were already using pen and paper assessments, the study education session may have induced the inclusion of other methods of unilateral neglect assessment to their clinical practice. Clinician's lack of knowledge of available options is a likely contributor to previously reported profession-specific patterns of assessment (Petzold, Korner-Bitensky et al. 2014, Evald, Wilms et al. 2020, Evald, Wilms et al. 2020, Checketts, Mancuso et al. 2021), and represents a simple target for future knowledge translation interventions.

Another barrier to using a comprehensive unilateral neglect assessment was the lack of awareness of the complexity of unilateral neglect. Given the use of a single moniker to describe multiple possible presentations, it is not surprising that clinicians often understand unilateral neglect to be limited to the visuospatial domain and only in the peri-personal space. Subsequently, they less frequently consider assessments that address other domains or spaces (Plummer, Morris et al. 2006, Evald, Wilms et al. 2020, Fisher, Quel de Oliveira et al. 2020, Checketts, Mancuso et al. 2021). Clinicians reported an increased awareness of the variable ways unilateral neglect could affect patient function and considered it a facilitator to intention and implementation of assessment. Taken together with the primary facilitator to assessment use being ‘perceived benefit of assessment to patients’, clinician education about the complexity of unilateral neglect would be an essential step for successful implementation of unilateral neglect assessment.

Healthcare system structure

The perception of a particular profession as being responsible for performing a specific unilateral neglect assessment was a key behavioural influence that emerged from this dataset. A pillar of modern healthcare is efficiency, achieved through dividing impairments between arbitrarily defined ‘scopes of practice’ of multiple clinical specialties (Buchan and Dal Poz 2002). In stroke rehabilitation this often leads to each allied health profession taking responsibility for a set of individual impairments. While this strategy has obvious benefits, it has also been suggested as a significant limitation to the provision of integrated and patient-centred healthcare (Dower, Moore et al. 2013, Leggat 2014). The tendency to allocate impairments to a single profession, and the lack of clinician knowledge of the diversity of unilateral neglect results in the allocation of standardised unilateral neglect assessment typically to either occupational therapy or neuropsychology (Checketts, Mancuso et al. 2021). Thus, the clinical presentations of unilateral neglect that fall into other professions scopes of practice receive little specialised attention, likely contributing to the significantly worse outcomes for this population (Hammerbeck, Gittins et al. 2019, Gammeri, Iacono et al. 2020, Tarvonen-Schröder, Niemi et al. 2020).

Indeed, even after the study education session had increased the awareness of unilateral neglect subtypes, clinicians remained less likely to use a tool that was perceived to be in another's professional scope of practice. Importantly, this occurred even when the tool was not in use by any other profession in the MDT, and overrode other strong behavioural facilitators relevant to patient function and tool generalisability to treatment. Despite the Catherine Bergego Scale including multiple mobility tasks that are traditionally in the physiotherapy scope of practice, it was rejected as a viable assessment tool due to the inclusion of personal care tasks that were perceived as being solely in the occupational therapy scope. In contrast, the Dublin Extra-personal Neglect Assessment includes environmental scanning that is essential for driving and navigation, which are mostly part of the occupational therapy scope of practice. However, it was perceived by occupational therapists as a mobility task, and therefore in the scope of physiotherapy, and thus, rejected as an option. Future assessment development and evidence translation will need to consider that unilateral neglect traverses multiple scopes of clinical practice and requires greater interdisciplinary interaction.

Healthcare setting

While the inpatient site was primarily limited by perceptions of scope of practice as described above, the primary barrier for the community setting was the limitations of assessment tools for the characteristics of their patients. These were commonly related to sequelae of stroke, such as speech or cognitive impairments. The study inpatient setting had speech pathologists and neuropsychologists available on site to manage language and cognitive impairments, a support system not available to the community setting, which was staffed only by physiotherapists and exercise physiologists. Thus, clinicians at this site may have lacked the education, skills, and confidence to apply unilateral neglect assessment tools that included aspects of speech or cognitive impairments. Future assessment development and implementation work in community settings needs to incorporate these knowledge and skill development needs.

Community-based clinicians' observed limitations of assessment tools were also related to perceived low client insight of assessment relevance to therapy goals, namely mobility and functional task performance. Clinicians in this setting also lacked knowledge of the potential impact of unilateral neglect on function, which limited the salience of assessment. This lack of knowledge reflects the weak relationship of clinical unilateral neglect assessment tools with functional tasks, which restricts their perceived utility for patients and clinicians alike (Petzold, Korner-Bitensky et al. 2014). It is also likely a flow on symptom of the chronic knowledge deficit and under-assessment of unilateral neglect from inpatient settings (Menon-Nair, Korner-Bitensky et al. 2006, Plummer, Morris et al. 2006, Checketts, Mancuso et al. 2021). Additionally, this is compounded by the already fragmented transition from inpatient to community rehabilitation, with people with stroke receiving rehabilitation in the community making functional gains no different to those receiving no care (Grimley, Rosbergen et al. 2020). Thus, the primary target of future implementation research should be first inpatient settings in order to provide foundational rehabilitation and then, continuity of care between inpatient and community settings to facilitate a flow on effect between these two care settings.

Limitations

The primary limitation of this study is the restriction to one inpatient and one community rehabilitation facility. SARS-COV19 restrictions limited the recruitment of sites, and thus the two included sites were selected to provide an insight into both inpatient and community rehabilitation settings. Future investigations should include a broader range of both inpatient and community facilities in order to achieve more generalisable results. The SARS-COV2 pandemic also introduced extra protocol requirements at all sites that would have limited implementation of new policy and procedures. Additionally, the study was conducted over a relatively short period that fell over the end and beginning of the calendar year, and was thus impacted by changes in patient caseloads and staff leave that are typical at this time in Australia. Additionally, one participant from each site was unable to attend the focus groups and instead shared their experiences through semi-structured interviews. This could have limited their opportunity to share views due to the differences between environments.

There were two limitations of the audit methodology used in this study. First, the notes audit was conducted after the study period for both the pre-study and study periods. As such, the findings of the audit were not used to inform the facilitation of focus groups at each site. While the methodology used maintained consistency in education, the data from the pre-study notes audit could have been used to tailor the focus groups to the experience of clinicians at each site. This could have increased the depth of data able to be captured. In the current methodology, audit data was limited to practice description alone. Second, there are a number of challenges to clinical audits that can affect the accuracy of the data collected in them (Johnston, Crombie et al. 2000). These include organisational impediments, poor planning, and a lack of expertise in data extraction. Strategies were put in place to avoid these limitations, including co-development of audit tools with site representatives and detailed instruction about data extraction. However, the audit was conducted ancillary to the auditors' normal workload which could have reduced the accuracy of the extracted data.

Conclusion

Clinician use of unilateral neglect assessment tools was influenced by a number of behavioural determinants common to other areas of stroke rehabilitation, including time constraints, organisational and social support, available resources, and therapist confidence and skills. However, the heterogeneous nature of unilateral neglect resulted in the unique influence of clinician knowledge, healthcare system role delineation, and the setting in which implementation took place on the success of implementation. Future evidence translation should include a significant component of education, be tailored to the combination of professions and the resources available at the target clinical sites to ensure effective and sustainable implementation.

Chapter summary

This chapter described an investigation of clinical unilateral neglect assessment, and the behavioural determinants of clinician decision making in this area. It described a number of determinants unique to unilateral neglect that should be considered in future research, and formed the fourth and final phase of research for this thesis. The next chapter (Chapter 7) is a synthesis of all research phases, a discussion of their relationship with each other and clinical practice, and an overview of future directions for clinical practice and research in unilateral neglect and proprioception impairment in stroke.

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Chapter 7: Discussion, conclusions and future directions

7.1 Background to thesis

Unilateral neglect and proprioceptive impairment are two related conditions that are common in people after a stroke, and that involve impairment in sensorimotor integration (Doricchi and Tomaiuolo 2003, He, Snyder et al. 2007, Longo, Azañón et al. 2010, Smith, Clithero et al. 2013, Puig-Pijoan, Giralt-Steinhauer et al. 2018, Mengotti, Käsbauer et al. 2020). Sensorimotor integration is the amalgamation of different sources of sensory stimuli and their transformation into motor action (Machado, Cunha et al. 2010) and involves many cortical inputs and outputs, including visual, auditory, and somatosensory (Machado, Cunha et al. 2010). Rehabilitation of its impairment is chiefly managed by physiotherapists and occupational therapists in both inpatient and outpatient settings. Both unilateral neglect and proprioception impairment involve interruption of complex cortical processing networks rather than a single cortical area, and thus their presentations are highly variable and significantly impact function (He, Snyder et al. 2007).

In addition to their physiology, both unilateral neglect and proprioception impairment have similar issues in their clinical assessment. Clinical assessment of both impairments lacks depth and functional relevance, and is variable across healthcare professions (Findlater and Dukelow 2017, Checketts, Mancuso et al. 2021). These likely contribute to the continuing poor outcomes of people with stroke and impairment in these areas, including longer length of stay, increased likelihood of discharge to a care facility, and higher incidence of falls (Jehkonen, Laihosalo et al. 2006, Rand 2018, Tarvonen-Schröder, Niemi et al. 2020). Importantly, the contribution of proprioception impairment to the clinical presentation of unilateral neglect is rarely considered and is thus the focus of this thesis, which first investigated the following aim:

1. To establish the nature and extent of proprioception impairment in people with unilateral neglect after stroke.

Then, based on the results of this investigation, three further aims were developed:

2. To describe current clinician practice and knowledge of proprioception assessment in stroke populations, and clinician attitudes towards proprioception assessment.
3. To investigate the correlation between current clinical proprioception assessment and other upper limb impairments of and their ability to discriminate between people with and without unilateral neglect.
4. To identify barriers and facilitators to clinician implementation of evidence-based unilateral neglect assessment.

7.2 Summary of key findings

The first step in understanding the clinical relationship between proprioceptive impairment in unilateral neglect was to review the literature to determine if people with unilateral neglect have greater proprioceptive impairment than those without. To answer this, a systematic review was conducted (detailed in Chapter 3) using the Cochrane Methodology and Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) reporting guidelines. The review included 18 studies and showed that proprioception impairment was indeed more frequent and severe in people with unilateral neglect after stroke and occurred in multiple subtypes of both impairments. However, a secondary finding was that the assessment tools used as outcome measures of proprioception impairment and unilateral neglect were highly variable and non-comprehensive.

Patterns in clinical practice of unilateral neglect assessment have recently been described on a global scale (Checketts, Mancuso et al. 2021). However, clinical practice in the assessment of proprioception in stroke had not previously been reported. Accordingly, the next study of this thesis was a survey of physiotherapists and occupational therapists currently working in stroke rehabilitation with the aim of describing their current clinical assessment of proprioception impairment (detailed in Chapter 4). To obtain the closest possible reflection of current clinical practice, clinicians were kept blind to the survey's specific purpose and asked to describe how they would assess a stroke patient presented in a case vignette that had cues to indicate impaired proprioception.

Only 55% of the respondents selected a proprioception assessment for the person described in the case study, and clinician understanding and assessment of proprioception was limited to the subjective judgement of the basic sense of relative joint angles and ignored the more complex, functionally relevant, integrated sense of the location of joints in space. The most common clinical proprioception assessment reported was a subjective ‘eyeball’ judgement of an upper limb position matching task. Thus, the novel finding of this study was that proprioception is likely widely under-assessed in clinical practice and where it is assessed, it is likely that the more complex, functionally relevant elements of the sense are not accounted for.

The subjectivity of clinical position matching assessments elucidated in Chapter 4 precludes investigation of their relationship to other impairments (e.g., co-ordination). Investigation of this relationship is important to build a complete map of the interaction of impairments present in a person with stroke that can guide the development of assessment and treatment strategies. Additionally, previous investigations of proprioception using position-matching in healthy individuals report a low level of within-subject variability, but a high level of between-person variability (Qureshi, Butler et al. 2019, Rana, Butler et al. 2020). In stroke rehabilitation this natural variability in performance could be mistaken as true impairment. Thus, Chapter 5 investigated the correlation of current clinical position-matching assessment with upper limb impairments quantified using a wearable device, and the variability in task performance between and within people with stroke. Unfortunately, study recruitment was halted due to SARS-COV19, and thus, only preliminary results are presented.

Only one statistically significant correlation emerged between matching accuracy in the movement of radial deviation and a bimanual manipulation task ($r = 0.84$, $p < 0.001$, 95% CI 0.41 - 0.97). Position matching errors were highly variable between participants and movements, with errors ranging between 44.9 degrees and 0.1 degree. Additionally, within participants, the average standard deviation was large and ranged from 19.4 degrees to 37.5 degrees for all movements. Averages for signed and absolute errors for each movement were significantly different, indicating that many participants made errors in both directions (e.g., in wrist extension, participants both under- and overshot the target angle in different trials of the same movement), providing further evidence for high variability.

Finally, the results of the previously mentioned survey of current clinical practice in unilateral neglect assessment (Checketts, Mancuso et al. 2021) indicated that despite the availability of comprehensive clinical assessment tools, their uptake was poor in clinical practice. Clinicians instead tend either to selectively assess visuospatial unilateral neglect in the peri-personal space, or assess unilateral neglect broadly through functional observation. Reasons for the mixed use of unilateral neglect assessment and poor uptake of functional assessments had not yet been described in the context of a validated behaviour change framework. Therefore, Chapter 6 used a mixed-methods investigation of clinical implementation of unilateral neglect assessment to describe determinants important to behaviour change in this area.

Several barriers common to previous investigations (Menon-Nair, Korner-Bitensky et al. 2006, Plummer, Morris et al. 2006, Menon-Nair, Korner-Bitensky et al. 2007, Evald, Wilms et al. 2020) of implementation in stroke, including time constraints, organisational and social support, available resources, and therapist confidence and skill were identified. However, many novel determinants emerged from the data analysis, most notably the perception of another profession as being responsible for performing a specific unilateral neglect assessment. Importantly, if any component of an assessment tool was perceived as another profession's domain, clinicians in the study were less likely to select the tool for implementation. Additional barriers unique to implementation of unilateral neglect assessment were the inability of most clinical assessment tools to cater for complex patients (e.g., those with cognitive or speech impairment), a widespread lack of understanding of the heterogeneous nature of unilateral neglect, and a lack of previous formal education about unilateral neglect.

The results of this thesis first show that proprioception impairment is more frequent and severe in people with unilateral neglect after stroke, but that the clinical assessment of each impairment has limitations. Previously unestablished, our investigation highlighted significant gaps in clinician knowledge and described current clinical practice in assessment of proprioception impairment Subsequent investigation of these methods suggested limited functional relevance, and the need for the development of assessments of the integrated proprioceptive sense. Finally, reasons for the previously reported poor uptake of comprehensive unilateral neglect assessment in clinical practice were investigated. Before proprioception impairment can be assessed in people with unilateral neglect, it is important for future work to address issues with assessment of both impairments.

7.3 Implications of findings

Clinician knowledge gaps

Both unilateral neglect and proprioception are common and complex impairments about which clinicians working in stroke rehabilitation have significant knowledge gaps. However, the results of Chapters 4 and 6 show that clinicians typically understand both unilateral neglect and proprioception impairment as unitary impairments rather than *sets* of sensorimotor deficits that span multiple presentations and aspects of patient rehabilitation. The results of these investigations suggested that this dissonance was due to limitations in clinician knowledge about both unilateral neglect and proprioception impairment. Thus, to reduce the magnitude of evidence-practice gaps in the assessment of both conditions, it is essential that clinicians and student-clinicians receive comprehensive education about the nature of available assessment options, their limitations, and are consulted in work aiming to develop novel, improved assessment tools.

Such education and consultation is an important first step to improving practice in this area. The results of the mixed-methods investigation of clinicians' experience in using unilateral neglect assessment tools provide some preliminary suggestions to achieve this, including use and ongoing access to demonstration videos, practical training for the whole team led by an experienced facilitator, and access to simplified summaries of the evidence.

Clinical assessment of proprioception

Improved assessment of proprioception and its relationship to unilateral neglect is an important component of improving treatment in this area. However, there are significant issues with current methods of proprioception assessment that currently preclude this. In Chapter 5, the cross sectional investigation showed that all but one upper limb position matching movement lacked correlation with any test of upper limb impairment. Chapter 5 provides preliminary evidence that even when a current clinical proprioception assessment is standardised and quantified, it has little relevance to upper limb co-ordination and function, similar to other published (but infrequently used in practice) clinical assessments of proprioception (Meyer, Karttunen et al. 2014).

Of all the seven different positions tested, only radial deviation correlated with an upper limb functional test, bimanual co-ordination. However, this correlation should be interpreted with caution in its application to clinical practice. Notably, there was a high variability of participant match accuracy within movements. A potential explanation of the single correlation is that the small anatomical range of radial deviation (~ 20 degrees in healthy individuals), limited variability in such a way that removed its impact on the correlation. Additionally, this was the only movement where the end-point of movement was the end of anatomical range.

Extra proprioceptive and sensory feedback is available at these joint ranges (Gandevia 2011), which could have increased match accuracy for this movement, also decreasing variability of performance and increasing the consistency of correlation. Additionally, radial deviation, while an important functional movement, is subject to multiple confounds beyond proprioception impairment (for example, anatomical restrictions due to wrist muscle spasticity or contracture, or difficulties with positioning in shoulder subluxation).

Taken together, these findings suggest that current clinical proprioception assessment is sensitive only to basic aspects of the sense and fails to account for aspects of proprioception that have higher relevance to upper limb coordination, and subsequently to function. Given that impairment of proprioception is associated with poor upper limb rehabilitation outcome after stroke (Rand 2018), it is essential that assessment tools are able to capture this association in order to provide insight into the impact of proprioception treatment on impairment level in a manner relevant to the rehabilitation goals of people with stroke. The preliminary findings presented in this chapter suggest that alternate assessments of the sense of position and movement relative to the moving parts *and* the space they are moving in should be developed. To incorporate a sense of movement in space, such tools should incorporate methods of assessing the body representation, a long implicated but frequently neglected component of proprioception (Proske and Gandevia 2018, Proske and Allen 2019). Additionally, the *variability* of performance error rather than average task error of a person with stroke in proprioceptive assessment may be an alternative, viable indicator of impairment level in novel assessment tools.

Clinical assessment of unilateral neglect

A further step in improving clinical assessment of the relationship between unilateral neglect and proprioception impairment is to increase a) the currently limited assessment frequency and, b) low functional relevance of unilateral neglect assessment in stroke rehabilitation. The mixed-methods investigation of clinician experiences in Chapter 6 identified barriers and facilitators to achieving both of these steps. First, the clinical utility of many unilateral neglect assessments is limited by their lack of suitability for people with post-stroke cognitive or language impairment. Importantly, people with unilateral neglect are more likely to present with these impairments as the condition is associated with larger, more severe strokes (Ringman, Saver et al. 2004). Second, many standardised unilateral neglect assessment tools are limited to a single presentation of the condition and have limited functional relevancy (Menon and Korner-Bitensky 2004). As with proprioception, presence of unilateral neglect is a prognostic factor for a poor functional rehabilitation outcome (Jehkonen, Laihosalo et al. 2006, Tarvonen-Schröder, Niemi et al. 2020). The fact that current clinical assessment does not give clinicians or people with stroke insight into the impact of the impairment on functional outcome is a significant point for practice change. Thus, it is essential that new, more appropriate assessments are developed and that they are adapted to be inclusive to the needs of people with post-stroke cognitive or language impairments.

Chapter 6 also highlighted the importance of the multidisciplinary team in implementing unilateral neglect assessment tools. The complex nature of unilateral neglect means that its associated impairments cross multiple scopes of practice, which has numerous implications. Chapter 6 presented a clear barrier to the uptake of a specific unilateral neglect assessment in multi-disciplinary settings if the assessment is perceived to fall within the responsibility of another profession's scope of practice. This barrier could be overcome by the co-ordinated implementation of tools within the traditional scopes of each profession, the results of which could then be communicated at team meetings to plan appropriate patient care. In settings where a multi-disciplinary team is unavailable (e.g., community-based rehabilitation organisations), any implementation strategy should be supported by the development of skills in areas considered outside the traditional scope of practice (e.g., language and cognitive impairment) and liaison with other professions in order to ensure clinicians feel confident enough in assessment use. Regardless of the setting, comprehensive unilateral neglect assessment needs to be formally introduced into standard assessment protocols to facilitate its implementation.

Finally, several facilitators to practice change in unilateral neglect assessment were identified in Chapter 6 that could inform future implementation work. The findings from the focus groups in this chapter showed that strong with- and between-profession communication and collaboration, and clear team goals to implement assessment tools increased the ease of implementation for clinicians which is in line with implementation research in stroke rehabilitation (Bayley, Hurdowar et al. 2012, Miao, Power et al. 2015, Moore, Marquez et al. 2018). Importantly, these goals were identified as more effective if developed in consultation with all team members, with a single site 'champion' to oversee their success. Thus, future implementation work in unilateral neglect should be collaboratively designed with the clinical contexts in which it occurs, and with flexibility to adapt to the unique needs of a particular site. Finally, this study also found that physical and structural cues to use unilateral neglect assessments including visibly displaying assessment equipment on the ward and incorporating the tool into standardised assessment forms also facilitated clinician use of assessment tools, similar to implementation work in stroke rehabilitation in general (Lisa A. Juckett 2020). These changes require the input of the management and oversight teams of rehabilitation organisations, who thus should also be consulted and involved in the design of practice change strategies.

7.4 Future directions – research

To understand proprioception impairment in unilateral neglect this thesis provides evidence that the gap between evidence-based and usual clinical practice is largely driven by a lack of research-based development of clinically feasible, functionally relevant assessments of proprioception and unilateral neglect. First, to expand our understanding of proprioception impairment in unilateral neglect, future work should include studies with larger populations, but also include more settings and professions (e.g., neuropsychologists and nursing staff). This would confirm the findings of the thesis and improve our understanding. Then, the focus should be on the development of assessments of both unilateral neglect and proprioception that take into account their complexity and functional relevance, the needs of complex patients, and the barriers and facilitators to implementation identified in this thesis. This will ensure that assessments are able to be widely implemented in clinical practice. Once assessments of unilateral neglect and proprioception of this nature are established, work can commence on incorporating proprioception assessment *into* clinical assessment of unilateral neglect to start to address their rarely considered interaction.

7.5 Future directions – clinical practice

Both proprioception and unilateral neglect both require accurate spatial and body perception, which has a complex underlying neuroanatomy and physiology. At present, neither proprioception nor unilateral neglect are clinically assessed in a method that captures this complexity. Instead, clinical assessment is targeted at the most obvious elements of each – visuospatial awareness in unilateral neglect, and position sense in proprioception. Due to this, we are unable to make accurate estimates of even their incidence in people with stroke, let alone judge their severity and their impact on rehabilitation. The research direction outlined above is essential to address these limitations, and to give clinicians the appropriate tools to support the people with stroke that they help rehabilitate.

It is clear that unilateral neglect and proprioception impairment are related, and thus, assessing proprioception impairment in people with unilateral neglect is an important component of their rehabilitation. The evidence from this thesis points to the need for widespread clinician education about the complex nature of unilateral neglect and proprioception and the limitations of current assessment tools. Indeed, such education would enable clinicians to select more appropriate assessment tools for their rehabilitation goals and increase the success of implementation of novel assessment tools. Once developed, implementation of novel assessment tools should be supplemented with practical skill training for clinicians in a wide variety of settings. Finally, such skill training will require an unequivocal multidisciplinary approach that is tailored to the diversity and methods of collaboration of professions at each site, to improve care for people with stroke.

7.6 Thesis limitations

Interpretation of the findings of the studies in this thesis is limited by a number of factors. First, the small sample sizes in Chapters 4, 5, and 6. While largely due to the SARS-COV19 pandemic, these negatively affect the statistical power and generalisation of results in the studies. Next, missing data. There was a large survey attrition in the survey in Chapter 4, which precluded analysis of all data for all participants. Additionally, the position matching data from a prototype IMU device used in the investigation in Chapter 5 was corrupted and thus unable to be used. Each of these additionally reduced the statistical power of the analyses conducted. Third, outcome measure bias. The Kessler Foundation Neglect Assessment Process (KF-NAP) used to assess unilateral neglect in the position matching study in Chapter 5 was conducted by myself for each study participant. While the measure is standardised and I am a trained neurological physiotherapist with adequate skill in its use, I am subject to bias of my involvement in the study which could have influenced the assessment outcome. This same bias is possible for the Upper Limb Physiological Profile (UL-PPA) in the same chapter which was conducted in most cases by Dr Kennedy, the primary supervisor in this thesis. Finally, participant bias. Participants in the survey and focus group studies in Chapters 4 and 6 self-elected to participate, which could have led to participant inherent bias by this group having different proprioception knowledge and practice patterns, and being both more motivated to implement unilateral neglect assessments than the general clinician population.

7.7 Final considerations

The studies of this thesis provided insights on the relationship between unilateral neglect and proprioception post-stroke and raise concerns about how they are assessed in usual clinical practice. These concerns likely contribute to the poor functional outcomes of patients with unilateral neglect or proprioception impairment as effective stroke rehabilitation is predicated on accurate definition, assessment, monitoring, and subsequent updating of clinician understanding of the rehabilitation needs of people after stroke. The studies of this thesis combined with previous work show that unilateral neglect and proprioception impairment are not assessed with enough accuracy to provide clinicians with the data needed to effectively design and plan treatments that will improve functional outcomes. This thesis identified a widespread lack of clinician knowledge about unilateral neglect and proprioception, multiple issues with current standardised assessments, and unique factors that limit the effectiveness of evidence implementation. Addressing these broader issues is an important next step in developing a clinical assessment tool for proprioception impairment in unilateral neglect that will ultimately improve clinician understanding of both impairments present in people with unilateral neglect after stroke. The findings of this thesis point to clear pathways to address this issue, build better tests that are inclusive to all people with stroke, advance the knowledge of health professionals about the impairments of the patients that they work with, and ultimately use this enhanced understanding to develop better treatments for both unilateral neglect and proprioception impairment that will improve the rehabilitation outcomes and thus quality of life of people with stroke.

Appendices

Appendix 1: Student perceptions of unilateral neglect and proprioception: A preliminary report

Unilateral neglect and proprioceptive deficit are two common (Connell, Lincoln et al. 2008, Demeyere and Gillebert 2019, Hammerbeck, Gittins et al. 2019) and related (Meyer, De Bruyn et al. 2016, Fisher, Quel de Oliveira et al. 2020) impairments affecting people after stroke that are associated with poor motor and functional recovery (Gorst, Rogers et al. 2019, Bosma, Nijboer et al. 2020). There is a large disparity between literature recommended best-practice and clinical practice (evidence-practice gap) in the clinical assessment of both proprioception and unilateral neglect in people with stroke (Pumpa, Cahill et al. 2015, Barrett and Houston 2019). In unilateral neglect, clinicians either use assessments limited to a certain aspect of unilateral neglect, or use non-standardised assessments that are subjective and do not measure the magnitude of the impairment (Plummer, Morris et al. 2006, Checketts, Mancuso et al. 2021). In proprioception, most clinicians either ‘eyeball’ position matching accuracy or ask patients to verbally determine the direction of passively imposed joint movement (see Chapter 3, and ref.Pumpa, Cahill et al. 2015). Assessment of this type is highly subjective, and does not quantify impairment instead acting as a screen for its presence. Additionally, there are no assessment tools that measure the severity of proprioception impairment specific to unilateral neglect.

The evidence-practice gaps in unilateral neglect and proprioception impairment are likely driven by clinical decision-making that is often based on past clinical experience and the knowledge of colleagues rather than institutional policy or based on available evidence (Doyle 2014, Pumpa, Cahill et al. 2015, Evald, Wilms et al. 2020, Checketts, Mancuso et al. 2021). Additionally, a previous study presented in this thesis (see Chapter 3) showed that clinicians reported their lack of knowledge and skills as primary limitations to evidence-based practice when assessing and managing somatosensory impairments after stroke (see Chapter 3 and Doyle, Bennett et al. 2013, Pumpa, Cahill et al. 2015, Evald, Wilms et al. 2020).

The absence of formal ongoing education identified in the previous studies in this thesis raised the question of how emerging evidence is translated into stroke rehabilitation clinical practice. A major contributor is likely pre-registration university education which, along with performance in examinations, are valid indicators of clinical practice (Terry, Hing et al. 2020). University education is charged with providing evidence-based content to prepare students to enter the workforce. The knowledge gained through coursework is integrated and shaped by the experience and knowledge pool in the workplace. Given the self-reported lack of knowledge in clinical practice regarding somatosensory impairment after stroke, university course content could be a viable target to increase the evidence-based knowledge in those topics, and, in turn, translate into improved clinical practice. Therefore, this data is the result of a survey with final year Australian physiotherapy and occupational therapy students to describe their knowledge about unilateral neglect and proprioception, and their confidence in assessing and interpreting assessment findings of unilateral neglect and proprioception.

Methods

This study consisted of a cross-sectional online survey. Study inclusion criteria were: a) students in their final year of study at an Australian University physiotherapy or occupational therapy program accredited by the Australian Health Practitioner Regulation Agency (AHPRA), b) the ability to give informed consent and c) the ability to read and understand written English. Exclusion criteria were students from the University of Technology Sydney, where the research was conducted, which was done to minimise bias from teaching exposure to the research team. The study was approved by the University of Technology Low Risk Research Ethics Committee, approval no. UTS-ETH20-4951. The survey was conducted via the online platform Qualtrics, and was of a similar layout to the survey presented in Chapter 3, except that questions about unilateral neglect were also asked.

Also similar to Chapter 3 was the use of a case vignette to assess student clinical knowledge and rationale for decision- making. Qualitative data was analysed using thematic analysis as described by Braun and Clarke (Braun and Clarke 2006), while quantitative data was analysed using descriptive statistics in Python software.

Study Survey

Case Vignette

This next section will ask you one question about a case study.

Mrs Jones is a 68-year-old female who was transferred to your rehabilitation ward yesterday evening. She suffered a (R) sided MCA territory infarct 7 days ago (NIHSS admission = 18). Her current function is 1x min A for bed mobility, stand by assist for sitting balance and 1x mod A for sit to stand. She currently mobilises ~30m with 1x mod A. However, she has a tendency to place her (L) foot in incorrect positions during gait – often creating a base of support on the (L) that is too narrow or too wide. Her strength MMT on the left side is as follows:

Shoulder: 4/5
Elbow: 3/5
Wrist: 3/5
Hand: 3/5
Hip: 4/5
Knee: 3/5
Ankle: 3/5
Foot: 3/5

Her sensitivity to fine touch is mildly reduced in the (L) hand only. She has difficulty finding items that she cannot directly see. When she is dressing herself, Mrs Jones often has difficulty remembering to put her (L) arm into her shirt, however she can do so once she is reminded. Mrs Jones' goal is to return home with her husband and eventually to work. However, she has acknowledged that this may not be possible.

1. Please list the key impairments that are present in the case above, and how you would assess each one if you were to see this patient TODAY. If you do not know the exact name of the assessment tool, please just describe it in your own words. You do not need to fill in all 10 spaces

Knowledge and Self-Rating Questions

The same questions were repeated specific first to unilateral neglect, then to proprioception. Thus, they are presented only once, and where IMPAIRMENT is written, the survey indicated unilateral neglect or proprioception respectively.

The next section of the survey is all about unilateral neglect / proprioception

2. IMPAIRMENT is an impairment that can occur after stroke. Please describe your understanding of IMPAIRMENT below.
3. How many hours would you estimate that you spent learning about IMPAIRMENT during your university course?
4. Please list any IMPAIRMENT assessments that you are aware of below. If you do not know the name of the assessment tool, you can simply describe the tool in your own words.
5. For ONE of the IMPAIRMENT assessments that you listed in the last question, please describe how an 'impaired' patient would present / score (If unsure -write unsure, save and move on)
6. How confident would you rate yourself in assessing IMPAIRMENT?
7. How confident would you rate yourself in interpreting the results of an IMPAIRMENT assessment?
8. Please indicate which of the following would impact your confidence in assessing IMPAIRMENT (tick all that apply)
    a) Unable to identify clinical indications for assessment
    b) Lack of knowledge of assessment tools
    c) Insufficient clinical experience with patients with the condition
    d) Insufficient knowledge of condition
    e) Other (please specify)
9. How well prepared do you feel to assess IMPAIRMENT in clinical practice?
10. How confident would you feel if you were required to treat IMPAIRMENT in a patient?

Results

A total of 294 surveys responses were registered online. Only 58 surveys contained complete self-rating question data sets, and of these 33 contained clinical reasoning and knowledge question datasets that were suitable for analysis. Table 1 illustrates the characteristics of the physiotherapy and occupational therapy students with complete responses to each survey section. All 33 clinical reasoning question datasets also contained complete self-rating question data.

Demographic characteristic	Self-rating questions		Clinical Reasoning and Knowledge Questions	
	n	%	n	%
Profession				
Physiotherapy	48	82	32	97
Occupational Therapy	10	17	1	3
Degree Type				
Undergraduate	49	84	29	87
Post-Graduate	9	15	4	12
State				
NSW	23	39	11	33
WA	13	22	11	33
VIC	10	17	6	18
QLD	5	8	2	6
SA	3	5	2	6
ACT	3	5	0	0
TAS	1	1	1	3
Geographic Location		0		
Metropolitan	42	72	24	72
Regional	16	27	9	27
Course Size (number of students)				
100-199	20	34	13	39
80-99	17	29	13	39
50-79	13	22	5	15
<49	8	13	2	6
Clinical Rehabilitation Experience				
Yes	38	65	32	97
No / Unsure	20	34	1	3

Table 1: Demographic characteristics of participating students for each question type

Case vignette interpretation

Proprioception impairment was identified by 51.1% (n = 17) of respondents, unilateral neglect by 21 (63.6%) of respondents, with 11 (33.3%) identifying both impairments. Proprioception impairment to the lower limb was frequently identified, while unilateral neglect was mostly described in general terms as ‘inattention’ or ‘unawareness’ with infrequent inclusion of specific modalities and hemi-spaces.

Unilateral neglect

Self-rating questions

Table 2 reports results from the VAS self-rating questions.

Question	Unilateral Neglect Mean +/- SD (95%CI)
Reported course hours	4.8 ± 2.7 (4.1 - 5.5)
Readiness to assess (/10)	6.5 ± 1.8 (6.0 - 7.0)
Confidence (/100) in:	
Assessing	65.1 ± 19.7 (59.8 - 70.3)
Interpreting assessment	68.5 ± 17.6 (63.8 - 73.1)
Treating	59.8 ± 21.4 (54.1 - 65.6)

Table 2: Results from unilateral neglect VAS survey questions.

Clinical Reasoning Questions

In the open-ended knowledge questions, the two most common definitions of unilateral neglect were a contralesional lack of awareness (n = 12, 36.3%) or an attentional deficit (n = 14, 42%). The majority of the students selected pen and paper tasks (n = 30, 90.1%) to assess unilateral neglect, with a smaller percentage including extinction to bilateral stimuli (n = 8, 24.2%) or observation of a functional task (n = 12, 36.3%) as part of their assessment.

Proprioception

Self-rating questions

Table 3 Reports results from the VAS self-rating questions.

Question	Proprioception Mean +/- SD (95%CI)
Reported course hours	6.5 ± 2.5 (5.8 - 7.1)
Readiness to assess (/10)	6.8 ± 2.1 (6.2 - 7.4)
Confidence (/100) in:	
Assessing	68.5 ± 22.2 (62.4 - 74.5)
Interpreting assessment	67.9 ± 22.0 (62.0 - 73.9)
Treating	65.8 ± 22.4 (59.6 - 71.9)

Table 3: Results from Proprioception VAS survey questions.

Clinical reasoning questions

The majority of respondents understood proprioception to be the sense of angular displacement of the joints of the body (n = 29, 87.9%) and recognised that this perception had a spatial component (n = 20, 67.0%). A smaller number recognised the contribution of proprioception to movement control (n = 8, 24.2%) and awareness of the body (n = 5, 15.1%). When describing their assessment of proprioception, most students described position (n = 23, 69.7%) or passive movement detection tests (n = 15, 45.4%). Almost half of all students also reported use of an assessment tool that is not specific to proprioception (n = 15, 45.4%).

Barriers

Students most commonly identified a lack of knowledge of assessment tools and insufficient clinical experience as barriers to the use of evidence-based assessments of proprioception and unilateral neglect (Figure A2).

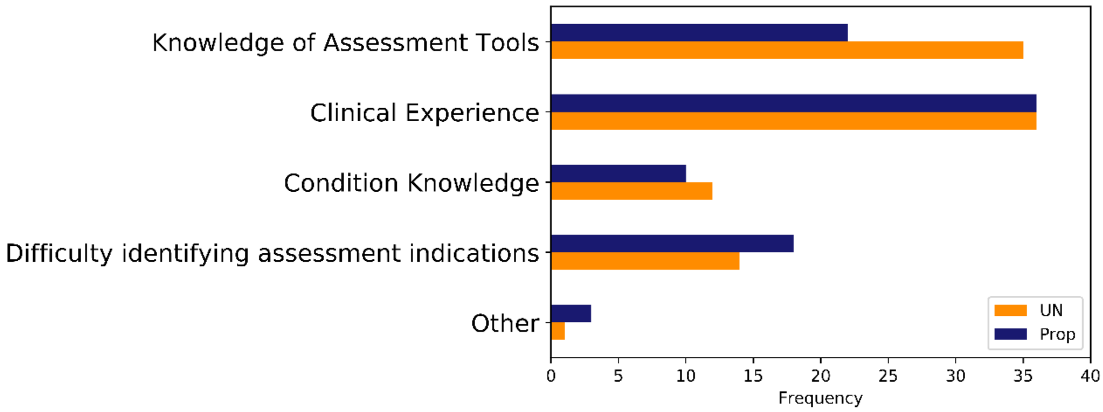


Fig 2: Raw counts of respondents (N = 58) to the identified barriers to assessment of unilateral neglect and Proprioception. Multiple answers were permitted, resulting in a total response count that is larger than the survey sample size.

Future directions

The consistency between student and clinician practice decisions in this and previous work in this thesis (see Chapter 3, and Pumpa, Cahill et al. 2015, Checketts, Mancuso et al. 2021) may be an indicator that university education is integral to informing practice in stroke rehabilitation. Thus, a change to pre-registration physiotherapy and occupational therapy education represents a viable method to improve practice in this area. Evidence-based practice underpins both physiotherapy and occupational therapy clinical frameworks, but the limited student understanding and assessment of unilateral neglect and proprioception identified in this study suggests that current evidence pertaining to unilateral neglect or proprioception impairment may not be communicated in depth in pre-registration education. The large variation in course content that is not specific to unilateral neglect and proprioception is a potential contributor (Sellar, Murray et al. 2018, Mistry, Yonezawa et al. 2019). Thus, potential solutions could include introduction of a standardised curriculum across universities and a nationwide pre-registration examination to enable standardised assessment and benchmarking of graduating therapists. Furthermore, stroke rehabilitation guidelines should include more specific information about sensorimotor impairment that could guide development of better university course content, improve the clinical practice in this area, and ultimately improve rehabilitation outcomes for people with stroke.

Conclusion

Two thirds of Australian physiotherapy and occupational therapy students in this sample were unable to identify the need to assess both impairments in a case study. Student understanding of unilateral neglect and proprioception was limited to visuospatial and basic joint position detection respectively, which was also reflected by their non-comprehensive assessment choices. Thus, the evidence-practice gaps that are present in assessment of unilateral neglect and proprioception after stroke could have their foundation in the lack of knowledge and skills developed in university education. However, the small sample size precludes the ability to assert this finding. Thus, this study should be replicated in a larger, more representative sample size.

Acknowledgements

I would like to thank Ms Victoria Keogh for her assistance in collecting and analysing the data for the above study.

Appendix 2

Appendix 2A: Upper Limb Physiological Profile Assessment test descriptions

Adapted with permission from: Ingram LA, Butler AA, Walsh LD, Brodie MA, Lord SR, et al. (2019) The upper limb Physiological Profile Assessment: Description, reliability, normative values and criterion validity. PLOS ONE 14(6): e0218553. https://doi.org/10.1371/journal.pone.0218553

Finger tapping. The test measured the number of times the participant could tap their dominant index finger up and down over a 10-second period. Each tap was recorded by a tapping sensor (Magic Trackpad, Apple Inc., USA), which was synced to a Samsung Galaxy Tab 3 (using a simple custom made Finger Tap Counter application). The participant placed the tip of their index finger lightly on top of the tapping sensor, with the thumb and remaining fingers resting either side of the sensor. Ensuring that each tap was isolated to the metacarpophalangeal joint (i.e. knuckle), the participant tapped their index finger as many times as possible for a trial time of 10-seconds. The 10-second countdown period commenced with the first tap of the sensor. The participant's test score was the number of taps completed in the 10-second trial, recorded and displayed on the Samsung Galaxy Tab 3 via the Finger Tap Counter application.

Loop and wire test. The custom made loop and wire test was designed to measure dexterity of the upper limb as the participant navigates a hand-held ring through a three-dimensional maze. The loop and wire apparatus was positioned approximately 25 cm from the edge of the table in front of the participant. Following an initial half-length practice trial, the participant held the handle attached to the ring and attempted to move the ring through the copper wire maze as fast *and* as accurately as possible, i.e. without touching the ring on the copper wire. An electronic timer was initiated once the participant commenced the test, stopping when the ring was placed in the holder at the opposite end of the maze. Two trials were performed, one in each direction. Right-handed participants moved right-to-left, then left-to-right. The order was reversed for left-handed participants. The total number of touches was recorded and displayed on an LCD screen at the completion of each trial. The total number of touches was averaged across both trials to give the participant's test score.

Bimanual pole test. The apparatus consisted of two cylindrical-shaped pieces of Perspex—one opaque and the other clear—with the 'former' fitted within the inner circumference of the latter. The inner opaque cylinder contained a maze (414 mm in length) in which a screw, fixed to the surface of the outer clear cylinder, was attached. The participant held the device with one hand at each end akin to holding the handles of a rolling pin, the opaque end held in the right hand. To complete the test, the participant moved the screw through the maze (which contained two dead ends) as fast as possible by flexing and extending their wrists in a coordinated manner while concurrently moving the cylinders apart on the way out, then moving them together on the return. The time taken (in seconds) to move the screw from right-to-left and return was recorded as the participant's test score.

Shirt task. The standing participant was instructed to pick up a folded unbuttoned long sleeve shirt placed on a table directly in front of them and put it on as fast as possible. The test was completed when all six buttons (not including the collar and sleeve buttons) were done-up in their corresponding holes. The sex of the participant determined whether a male or female shirt was used (as the buttons and holes are on opposite sides for each gender). The time taken to complete the task (seconds) was recorded as the participant's test score.

Appendix 3

Appendix 3A: Supplemental data 1: Search strategy

“stroke” OR “cerebrovascular accident”

AND

“neglect” OR “unilateral neglect” OR “hemispatial neglect” OR “visuospatial neglect” OR “personal neglect” OR “motor neglect” OR “peripersonal neglect” OR “extrapersonal neglect” OR “hemineglect”

AND

“propriocept*” OR “kinesth*” OR “position sense” OR “body image” OR “body schema” OR “body representation

Appendix 3B: Supplemental data 2: Reasons for full text exclusion

KEY: 1. Abstract only, 2. Insufficient data, 3. No UN- group, 4. No UN+ group, 5. No proprioception measure, 6. Participants with previous stroke, 7. Ineligible study design

Study	*Reasons for Exclusion*						
	1	2	3	4	5	6	7
Amesz, 2016		✓					
Anderson, 1993		✓					✓
Antoniello, 2013	✓						
Baier, 2008		✓					
Balslev, 2013					✓		
Beis, 2001					✓		
Beis, 2007				✓			
Carey, 2011				✓			
Chalsen, 1987		✓					
Castiello, 2004					✓		
Dohle, 2009		✓					
Duclos, 2014					✓		
Fotopolou, 2011			✓				
Frassinetti, 2001			✓				
Glocker, 2006		✓					
Hawe, 2017	✓						
Herter, 2011	✓						
Herter, 2012	✓						
Jackson, 2000							✓
Lafosse, 2005		✓					
Lafosse, 2017					✓		
Liefert-Fiebach, 2013			✓				
Mark, 1990			✓				
Mattingly, 1994					✓		
Neppi-Modona, 2007					✓		
Pascal, 2010	✓						
Pavani, 2005			✓				
Paysant, 2004		✓					
Reinhart, 2012			✓				
Suzuki, 2006					✓		
Smith, 1983		✓					
Tyryshkin, 2014					✓		
Tyson, 2008		✓					
Vocat, 2010		✓					
Watanabe, 2006	✓						
Welfringer, 2011			✓				
Welmer, 2007						✓	
Williams, 2015	✓						

Appendix 3C: Supplemental data 3: AXIS Quality assessment full results

Author / AXIS Item		1		2	3	4	5	6	7	8	9	10	11		12	13	14	15	16		17	18		19	20	RISK
Baas	INTRODUCTION	✓	METHODS	✓	×	✓	×	×	×	✓	✓	✓	✓	RESULTS	✓	×	NA	✓	✓	CONCLUSIONS	✓	×	OTHER	✓	×	MOD
Barra		✓		✓	✓	✓	×	✓	✓	✓	✓	✓	✓		✓	✓	×	✓	✓		✓	✓		✓	✓	LOW
Borde 1997		✓		✓	×	✓	✓	✓	✓	✓	×	✓	✓		✓	×	✓	✓	✓		✓	×		×	×	MOD
Borde 2006		✓		✓	×	✓	✓	✓	×	✓	×	✓	✓		✓	✓	NA	✓	✓		✓	×		✓	✓	MOD
Cocchini		×		×	×	✓	✓	×	×	×	×	×	×		✓	×	NA	✓	×		✓	×		×	×	HIGH
Coslett*		✓		✓	×	✓	✓	✓	×	✓	✓	×	✓		✓	✓	NA	✓	×		✓	×		×	×	MOD
Di Vita		✓		✓	×	✓	✓	✓	×	✓	✓	×	✓		✓	✓	NA	✓	×		✓	×		✓	✓	MOD
Heilman		✓		✓	×	✓	×	×	×	✓	✓	×	×		×	×	NA	✓	×		✓	×		✓	×	HIGH
Meyer		✓		✓	×	✓	✓	✓	×	✓	✓	✓	✓		✓	×	NA	✓	✓		✓	✓		✓	✓	MOD
Richard		✓		✓	×	✓	✓	✓	×	✓	✓	✓	✓		✓	×	NA	✓	×		✓	×		×	✓	MOD
Rosseaux		✓		✓	×	✓	✓	×	×	✓	×	✓	✓		×	×	NA	✓	✓		✓	×		×	✓	HIGH
Saj		✓		✓	×	✓	×	×	×	✓	✓	✓	✓		×	×	NA	✓	✓		✓	×		✓	✓	MOD
Schmidt		✓		✓	×	✓	×	×	×	✓	✓	✓	×		×	×	NA	✓	✓		✓	✓		✓	✓	MOD
Semrau 2015		✓		✓	×	✓	✓	×	×	✓	✓	✓	✓		✓	×	NA	✓	✓		✓	×		×	✓	MOD
Semrau 2018		✓		✓	×	×	✓	✓	×	✓	✓	✓	✓		✓	×	NA	✓	✓		✓	✓		×	✓	MOD
Tosi		✓		✓	×	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	×	✓	✓		✓	×		✓	✓	LOW
Van Stralen		✓		✓	×	✓	✓	×	×	✓	✓	✓	✓		×	✓	NA	✓	✓		✓	✓		✓	✓	MOD
Vromen		✓		✓	×	✓	✓	✓	×	✓	✓	✓	✓		×	✓	NA	✓	✓		✓	✓		✓	✓	MOD

KEY: Y = satisfied item, N = did not satisfy item, NA = item not applicable.

Appendix 3D: Supplemental data 4: AXIS assessment description

Introduction
Were the aims/objectives of the study clear?
Methods
Was the study design appropriate for the stated aim(s)?
Was the sample size justified?
Was the target/reference population clearly defined? (Is it clear who the research was about?)
Was the sample frame taken from an appropriate population base so that it closely represented the target/reference population under investigation?
Was the selection process likely to select subjects/participants that were representative of the target/reference population under investigation?
Were measures undertaken to address and categorise non-responders?
Were the risk factor and outcome variables measured appropriate to the aims of the study?
Were the risk factor and outcome variables measured correctly using instruments/ measurements that had been trialled, piloted or published previously?
Is it clear what was used to determined statistical significance and/or precision estimates? (e.g., p values, CIs)
Were the methods (including statistical methods) sufficiently described to enable them to be repeated?
Results
Were the basic data adequately described?
Does the response rate raise concerns about non-response bias?
If appropriate, was information about non-responders described?
Were the results internally consistent?
Were the results for the analyses described in the methods, presented?
Discussion
Were the authors' discussions and conclusions justified by the results?
Were the limitations of the study discussed?
Other
Were there any funding sources or conflicts of interest that may affect the authors' interpretation of the results?
Was ethical approval or consent of participants attained?

Appendix 4

Appendix 4A: Survey

Proprioception Clinical Assessment Survey
Section 1: Demographics

1. Please identify your profession:
a. Physiotherapist
b. Occupational Therapist
c. Both

2. What is your current primary workplace setting?
a. Inpatient Rehabilitation
b. In-home Rehabilitation
c. Inpatient Acute Care
d. Outpatient Care – Public Sector
e. Community Private Practice
f. Community Non-for-profit

3. What is your highest level of qualification?
a. Undergraduate
b. Post graduate – Masters Level
c. Post graduate – Doctorate Level
d. Masters by research
e. Doctor of Philosophy
f. Other

4. How would you classify the geographical area in which you work?
a. Metro
b. Regional
c. Rural

5. How many years of clinical experience do you have?
a. < 3 years
b. 3-5 years
c. 5-10 years
d. > 10 years

6. What is your employment status (in rehabilitation)?
a. Part-time
b. Full-time
c. Casual
d. Self-employed

7. How many stroke clients would you see in a typical day?
a. < 3
b. 3-5
c. 5-10

8. Is there a stroke unit or a multidisciplinary team present at your setting?
a. Yes
b. No

9. Is your workplace affiliated with a university?
a. Yes
b. No

10. Is stroke rehabilitation research conducted at your setting?
a. Yes
b. No

11. Are there student placements at your setting?
a. Yes
b. No

12. Do you have protected work time for continuing education?
a. Yes
b. No

Section 2: Vignettes

1. Imagine you are assessing this patient for the first time today. Please list the assessments that you would conduct in your initial clinical assessment to identify and quantify the relevant impairments of the patient in the vignette AND the

target of the assessment. An assessment is defined as any scale, measure, tool, equipment or procedure applied to a patient where the results are then recorded in written format. They can be published standardised measures (e.g. Motor Assessment Scale) or those that are not (e.g. gait analysis / observation). If you do not know the name of the assessment, please simply describe it to the best of your ability. The assessments do not have to be in order of priority, and you do not need to complete all boxes

2. Now, please list the additional assessments would you conduct on the patient during their entire admission AND what you would be aiming to assess with their use. If you do not know the name of the assessment, please simply describe it to the best of your ability. The assessments do not have to be in order of priority and you do not need to complete all boxes.

Section 3: Proprioception Knowledge

1. How would you best define proprioception?
2. How important to you believe it is to assess proprioception in patients after stroke? (VAS 0 - 100)
3. What are the components of an assessment of proprioception? Please list as many as you know, rather than only those that you commonly use in clinical practice.
4. In what percentage of your patients with stroke do you specifically assess proprioception in patients with stroke? (VAS 0 - 10)
5. Please list the assessments that you use in your clinical practice when assessing proprioception of a patient after a stroke?
6. How confident do you feel assessing and treating a patient when their main impairment is proprioception? (VAS, 0 - 10)
7. Please list 5 conditions or clinical presentations that are associated with impaired proprioception? E.g. ataxia
8. If you use a limb position match task as a clinical assessment of proprioception, please explain how you do this. E.g. (Passive/active) movement of patient limb with eyes (closed/open), patient (actively/passively) matches position with (other/same) limb, measured with (goniometer/eyeball/other) device
9. How confident do you feel treating a patient when their main impairment is proprioception? (VAS, 0 - 10)
10. Have you been involved in any professional development or education related to proprioception in the last twelve months (e.g. an in-service, a course)? If yes, please describe:

Appendix 4B: Vignettes

Inpatient

Mr Jones is a 68 year-old man who was transferred to your rehabilitation ward yesterday evening. He suffered a (R) sided MCA territory infarct 7 days ago (NIHSS admission = 18), for which he underwent endovascular clot retrieval (NIHSS post = 9). His only relevant past medical history is uncontrolled hypertension. Prior to his admission, Mr Jones was independent in all activities of daily living and was working as an IT manager. He lives in a single storey home with his supportive wife, with level access front and rear. His current function is 1 x min A for bed mobility, SBA for sitting balance, and 1 x mod A for STS. When Mr Jones reaches back to the arms of the chair to sit, he often has difficulty finding the (L) arm rest to guide himself down. He can currently mobilise ~30m with 1 x mod A, however has a tendency place his (L) foot in incorrect positions during gait – often creating a base of support on the (L) that is too narrow or too wide. His strength is intact on the (R) side, and on the (L) has the following MMT's:

Shoulder	**4/5**	**Wrist**	**3/5**	**Hip**	**4/5**	**Ankle**	**3/5**
Elbow	**3/5**	**Hand**	**3/5**	**Knee**	**3/5**	**Foot**	**3/5**

His sensitivity to fine touch is mildly reduced in the (L) hand only. Mr Jones' wife has reported to you that during feeding tasks he often grips items either too hard or too softly and has difficulty finding items that he cannot directly see. When he is dressing himself, Mr Jones often has difficulty remembering to put his (L) arm into his shirt however can do so once he is reminded. Mr Jones would like to return to his home with his wife and eventually to work, however he has acknowledged that this may not be possible.

Community

Ms Allen is a 60 year-old woman who was referred into your service for management of residual deficits associated with a (R) MCA infarct that occurred 12 months ago. After the stroke, Ms Allen had a 2-week acute inpatient admission followed by a 3-month inpatient rehabilitation admission. She was discharged home after this admission into the care of her supportive husband with the arrangement that he would provide support for activities of daily living. On discharge, she required stand by assistance to mobilise indoors, and 1 x min A to ambulate in the community. Ms Allen was referred for ongoing physiotherapy and occupational therapy, however there were issues with the original service provider chosen and minimal intervention was delivered. She is now presenting to your service for ongoing rehabilitation. Ms Allen is currently ambulating independently indoors, however requires stand by assistance to ambulate in the community. She has started to help her husband with domestic tasks including cooking and cleaning. However, she reports being clumsy and having trouble getting objects from cupboards that are above her head as she has difficulty with locating the objects in the cupboard, and once she has found them, appropriately grasping them. Ms Allen reports nil issues with strength in her upper or lower limb, a finding that her husband confirms. She occasionally loses her balance when ambulating in the community, as she sometimes has trouble placing her foot in the correct position. When Ms Allen first wakes in the morning, she has trouble finding her glasses and dentures on her bedside table before her husband turns on the light. Ms Allen has come to see you to improve her community ambulation and her upper limb function.

Appendix 4C: Code maps

Definition	Assessment

Sensory Processes
▪ Position / Location
▪ Movement / Motion
▪ Muscle Force
▪ Muscle Tone
▪ Effort
▪ Coordination
▪ Heaviness
▪ Stiffness (muscle / joint)
▪ Stiffness (material)
▪ Body Posture / Balance
▪ Body image / representation
▪ Location of Objects Relative to the Body
▪ Other
 	
Anatomy
▪ Peripheral
    ▪ Muscle Spindle
    ▪ Golgi Tendon Organ
    ▪ Joint Receptors
    ▪ Skin receptors
    ▪ Other
▪ Central
    ▪ Dorsal Columns
    ▪ Spinocerebellar Pathway
    ▪ Parietal Lobe
    ▪ Insula
    ▪ Cerebellum
    ▪ Other
▪ Neurophysiology
    ▪ Sensorimotor integration
    ▪ Spatial and/or temporal congruence
    ▪ Other
▪ Misc:
    ▪ Conscious
    ▪ Unconscious
    ▪ No vision / Vision
    ▪ Vestibular
	Low-level
	▪ Passive movement detection
	▪ Limb matching
	▪ Reaction time
	▪ Other
	
	High-level
	▪ Body Axis Judgement
	▪ Laterality
	▪ Joint Position Reproduction
	▪ Effort matching
	▪ Force matching
	▪ Body Part Localisation
	▪ Target based functional movements
	▪ Vibration
	▪ Discriminative (fine) touch
	▪ Other
	
	Non-specific Tests
	▪ Balance
	▪ Co-ordination
	▪ Gait
	▪ Reaching and manipulation
	▪ Vestibular Function
	▪ Stepping reaction
	▪ Other

Associated Conditions	Assessment Technique (matching / detection)
▪ Ataxia ▪ Unilateral Neglect ▪ Sensory deficit ▪ Memory Impairment ▪ Cerebellar atrophy ▪ Traumatic brain injury ▪ Multiple sclerosis ▪ Amyotrophic lateral sclerosis ▪ Myasthenia gravis ▪ Neuropathic conditions ▪ Cerebral palsy ▪ Charcot-Marie-Tooth Disease ▪ Dystonia ▪ Brain tumours ▪ Muscular dystrophies ▪ Vestibular impairments ▪ Other	Motor Involvement ▪ Active Indicator / active match ▪ Passive indicator / active match ▪ Passive indicator / passive match ▪ Active indicator / passive match ▪ Other Limb Involvement ▪ Between limbs ▪ Within limbs ▪ Other Thixotropy control ▪ Yes ▪ No Measurement Method ▪ Eyeball ▪ Goniometer ▪ Robotic assessment ▪ Other Other

Appendix 4D: Python analysis code

```
csv = 'clin_confidence.csv'
data = pd.read_csv(csv)

data.head()
names = list(data.columns)
alpha = 1e-3

for name in names:
    dropped = data[name].dropna()
    conf = sms.DescrStatsW(dropped).tconfint_mean()
    print('{}g CI : {}'.format(name, conf))

    skew = data[name].skew()
    print('{} skew = {}'.format(name, skew))

    dropped = data[name].dropna()
    stat, p = scp.normaltest(dropped)
    print('{} p: {}'.format(name, p))

    if p < alpha:
        print("Reject null - skewed data")
    else:
        print("Accept null - normal data")

    fig, assessment = plt.subplots()
    sns.kdeplot(data = data[name])
    sns.distplot(data[name])
```

Appendix 4E: Qualitative data codebook and frequencies

Survey Question **Primary Node** **Sub-Node**	**Count**	**% Respondents**
List the assessments that you would conduct in your *initial clinical Assessment* AND the target of the assessment.		
Proprioception Target, Proprioception Assessment	21	36.2
Proprioception Target, Non-proprioception Assessment	7	12.1
List the Assessments that you would conduct in your *subsequent clinical Assessment* AND the target of the assessment.		
Proprioception Target, Proprioception Assessment	5	8.6
Proprioception Target, Non-proprioception Assessment	2	3.4
How would you best define proprioception?		
Anatomy	8	13.5
sensation	5	8.6
joint	3	5.2
muscle	3	5.2
tendons	2	3.4
Components	55	94.8
position in space	43	74.1
joint or limb position	38	65.5
body position	27	46.6
body movement	14	24.1
position alone	13	22.4
force awareness / judgement	1	1.7
balance	1	1.7
other sensory process	1	1.7
What are the components of an assessment of proprioception? Please list as many as you know, rather than only those that you commonly use in clinical practice.		
High-level	3	5.2
body part naming	1	1.7
thumb finding test	1	1.7
vibration sense	1	1.7
Low-level	43	74.1
matching	33	56.9
movement direction judgement (passive)	26	44.8
mvmt detection (passive)	8	13.5
Romberg's test	4	6.9
other	3	5.2
Non-specific	28	48.3
functional task observation	13	22.4
co-ordination task observation	12	20.7
sensation	11	19.0
balance task observation	9	15.5
other	3	5.2
stereognosis	2	3.4
subjective history	2	3.4
Standardised battery	4	6.9

How do you assess the proprioception of a patient after a stroke in *your clinical practice*?		
Proprioception Assessment	41	70.7
matching task	31	53.4
movement direction judgement (passive)	23	39.7
movement detection (passive)	3	5.2
Romberg's test	2	3.4
Thumb finding test	2	3.4
Non-specific Assessment	32	55.2
functional observation	13	22.4
co-ordination task observation	12	20.7
other non-specific	12	20.7
balance observation	6	10.3
No Assessment	5	8.6
List 5 conditions or clinical presentations associated with impaired proprioception		
Other	42	72.4
Ataxia	30	51.7
Stroke	30	51.7
Multiple Sclerosis	19	32.8
Acquired brain injury	15	25.9
Neuropathy	13	22.4
Spinal cord injury	12	20.7
Sensory deficit	12	20.7
Parkinson's Disease	11	19.0
Unilateral neglect	5	8.6
Amyotrophic lateral sclerosis	4	6.9
Guillian Barre Syndrome	3	5.2
Pusher syndrome	2	3.4
Vestibular impairment	2	3.4
Cerebral palsy	1	1.7
Please explain how you use a limb position match task to assess of proprioception.		
Limb involvement		
between	39	67.2
within	15	25.9
unclear	3	5.2
Measurement method		
eyeball	27	46.6
unclear	16	27.6
gross direction	10	17.2
goniometer	5	8.6
other	1	1.7
Match type (reference, indicator)		
passive / active	37	63.8
passive / verbal	11	19.0
unclear	6	10.3
active / active	2	3.4
mimic examiner	2	3.4
active / verbal	1	1.7
passive / passive	1	1.7
Not used	5	8.6

Appendix 5

Appendix 5A: IMU analysis code

```
import pandas as pd
import numpy as np
import copy
import logging
import os
import glob
from collections import namedtuple
from plotly.subplots import make_subplots

from plot import plot_raw, finalise_figure, plot_processed_abs, plot_processed_rel,
plot_test_data_abs, plot_test_data_rel
from utils import get_labels

def norm(x):
    return (x - min(x)) / (max(x) - min(x))

def invnorm(x):
    return (max(x) - x) / (max(x) - min(x))

def integrate(x):
    return np.array([sum(x[:i]) for i in range(len(x))])

def to_angle(x):
    return np.arccos(x)

def match_acceleration_left_right_orientation(left, leom, right, reom):
    axes = ['rx', 'ry', 'rz']
    # Match the orientation of the right hand to the left one.
    for ax in axes:
        if leom is None:
            l = left[f"{ax}_combined_rel_mpers"]
        else:
            l = left[left.t < leom][f"{ax}_combined_rel_mpers"]
        if reom is None:
            r = right[f"{ax}_combined_rel_mpers"]
        else:
            r = right[right.t < reom][f"{ax}_combined_rel_mpers"]

        logging.info(f"  Left-Right Acceleration Matching:    Sign Left = {np.sign(np.mean(l))},
Sign Right = {np.sign(np.mean(r))}")
        if np.sign(np.mean(l)) != np.sign(np.mean(r)):
            logging.info(f"  Left-Right Matching:   Inverting Right")
            right[f"{ax}_combined_rel_mpers"] *= -1
            right[f"{ax}_acc_rel_mpers"] *= -1
            right[f"{ax}_gyro_rel_mpers"] *= -1

    return right

def match_angular_position_left_right_orientation(left, leom, right, reom):
```

```
    axes = ['ax', 'ay', 'az']
    # Match the orientation of the right hand to the left one.
    for ax in axes:
        if leom is None:
            l = left[f"{ax}_combined_rel_deg"]
        else:
            l = left[left.t < leom][f"{ax}_combined_rel_deg"]
        if reom is None:
            r = right[f"{ax}_combined_rel_deg"]
        else:
            r = right[right.t < reom][f"{ax}_combined_rel_deg"]

        logging.info(f"  Left-Right Angle Matching:    Sign Left = {np.sign(np.mean(l))}, Sign
Right = {np.sign(np.mean(r))}")
        if np.sign(np.mean(l)) != np.sign(np.mean(r)):
            logging.info(f"  Left-Right Matching:   Inverting Right")
            right[f"{ax}_combined_rel_deg"] *= -1
            right[f"{ax}_acc_rel_deg"] *= -1
            right[f"{ax}_gyro_rel_deg"] *= -1

    return right

def match_acc_gyro_orientation(data, eom = None):
    axes = [
        ('rx_acc_abs_mpers', 'rx_gyro_abs_mpers'),
        ('ry_acc_abs_mpers', 'ry_gyro_abs_mpers'),
        ('rz_acc_abs_mpers', 'rz_gyro_abs_mpers')
    ]
    if eom is not None:
        cut = data[data.t < eom]
    else:
        cut = data
    for acc, gyro in axes:
        # match the gyro the acc orientation by looking at their covariance matrix
        g = cut[gyro]
        go = g.iloc[:10].mean()
        a = cut[acc]
        logging.debug(f" Covariance of {gyro}          = {np.corrcoef(a, g)[0][1]}")
        logging.debug(f" Covariance of Inverted {gyro} = {np.corrcoef(a, (g * -1) + 2*go)[0][1]}")
        if np.corrcoef(a, (g * -1) + 2*go)[0][1] > np.corrcoef(a, g)[0][1]:
            data[gyro] *= -1
            data[gyro] += 2*go

    return data

def invert_data(data):
    """
    Perform an inversion of the timeseries which flip when we are
    considering the right hand vs the left hand.

    NOTE: Z axis flips because the planar surface of the IMU device is facing the
    the opposite direction (i.e. it is always medial).
    """
    data.az *= -1
    data.gy *= -1
```

```
    data.gz *= -1
    return data

def calc_normalised_acceleration_vectors(row):
    """
    Calculate the acceleration vector R and then normalise each of its component vectors
    along the X, Y and Z axes to the magnitude of the R vector. Return the normalised X, Y
and Z vectors.
    """
    x = row.ax
    y = row.ay
    z = row.az
    r = np.sqrt(x**2 + y**2 + z**2)
    x /= r
    y /= r
    z /= r
    return x, y, z

def calc_angle_from_acceleration(x, r):
    """
    Calculate the angle in degrees between vectors x and r.
    Note that the input acceleration is bounded between -1,1 before calculating the angle
    (because arccos is only defined between -1,1 radians). This will produce floor and ceiling
    effects in the output.
    """
    if x<0:
        a = max([-1, x/r])
    else:
        a = min([1, x/r])

    return np.arccos(a) * 180 / np.pi

def calc_starting_position(test):
    """
    Calculate the baseline output of the accelerometer at the start of the test.
    This will be used to determine the starting position of the IMU.
    """
    # Baseline accelerometer output
    x = test.iloc[1:10].ax.mean() # Take the mean of the first 10 samples.
    y = test.iloc[1:10].ay.mean()
    z = test.iloc[1:10].az.mean()
    r = np.sqrt(x**2 + y**2 + z**2)
    x /= r # Normalise to the magnitude of the force vector R
    y /= r
    z /= r

    # Starting position of the hand, relative to the reference axis, in degrees.
    ax = calc_angle_from_acceleration(x, r)
    ay = calc_angle_from_acceleration(y, r)
    az = calc_angle_from_acceleration(z, r)

    return x, y, z, ax, ay, az

def resolve_component_vectors_from_planar_position(axz, ayz, signz):
    """
```

```
    Convert the angular position in the xz and yz planes (i.e. rotation around the y and x axes,
respectively)
    into component position vectors along the X, Y and Z axes. Note that this conversion
assumes a
    magnitude for the R position vector of 1 (i.e. it produces component vectors which are
comparable
    to our accelerometer output so long as we have normlised).
    """
    axz = np.deg2rad(axz)
    ayz = np.deg2rad(ayz)
    # Calculate position (r) vectors according to the gyro
    x = np.sin(axz) / np.sqrt(1 + np.cos(axz)**2 * np.tan(ayz)**2)
    y = np.sin(ayz) / np.sqrt(1 + np.cos(ayz)**2 * np.tan(axz)**2)
    z = signz * np.sqrt(1 - x**2 - y**2)

    return x, y, z

def calc_combined_estimate(data):
    """
    Calculate combined estimates of acceleration and angular rotation.

    """
    w = 5
    # Acceleration
    axes = [
        ('rx_acc_abs_mpers', 'rx_gyro_abs_mpers'),
        ('ry_acc_abs_mpers', 'ry_gyro_abs_mpers'),
        ('rz_acc_abs_mpers', 'rz_gyro_abs_mpers')
    ]
    for acc, gyro in axes:
        ax = acc.split('_')[0]
        # Absolute combined estimate NOTE: This will have uncontrolled DC bias.
        newax = f"{ax}_combined_abs_mpers"
        a = data[acc]
        g = data[gyro]
        data[newax] = (a + w * g) / (1+w) # Combined Acceleration estimate

        # Relative combined estimate
        newax = f"{ax}_combined_rel_mpers"
        ao = data[acc].iloc[1:10].mean()
        a = copy.deepcopy(data[acc]) - ao
        data[f"{ax}_acc_rel_mpers"] = a
        go = data[gyro].iloc[1:10].mean()
        g = copy.deepcopy(data[gyro]) - go
        data[f"{ax}_gyro_rel_mpers"] = g
        data[newax] = (a + w * g) / (1+w) # Combined Acceleration estimate

    # Angles
    data = calc_absolute_angles(data)
    axes = [
        ('ax_acc_abs_deg', 'ax_gyro_abs_deg'),
        ('ay_acc_abs_deg', 'ay_gyro_abs_deg'),
        ('az_acc_abs_deg', 'az_gyro_abs_deg')
    ]
    for acc, gyro in axes:
```

```
        ax = acc.split('_')[0]
        # Absolute combined estimate. NOTE: This will have uncontrolled DC bias.
        newax = f"{ax}_combined_abs_deg"
        a = data[acc]
        g = data[gyro]
        data[newax] = (a + w * g) / (1+w) # Combined Angular estimate

        # Relative combined estimate
        newax = f"{ax}_combined_rel_deg"
        ao = data[acc].iloc[1:10].mean()
        a = copy.deepcopy(data[acc]) - ao
        data[f"{ax}_acc_rel_deg"] = a
        go = data[gyro].iloc[1:10].mean()
        g = copy.deepcopy(data[gyro]) - go
        data[f"{ax}_gyro_rel_deg"] = g
        data[newax] = (a + w * g) / (1+w) # Combined Angular estimate

    return data

def calc_absolute_angles(data):
    """
    Calculate the angular rotation for each axis in absolute terms.

    NOTE: The angular rotation cannot be accurately calculated from relative (i.e. normalised)
          acceleration data because we cannot determine absolute magnitude of the
acceleration vector
          from the normalised acceleration. So, it is necessary to calculate angular rotation
directly
          from the acceration data and then normalise the result.
    """
    axes = [ 'acc', 'gyro’ ]
    for ax in axes:
        x = f'rx_{ax}_abs_mpers'
        y = f'ry_{ax}_abs_mpers'
        z = f'rz_{ax}_abs_mpers'
        r = f'r_{ax}_abs_mpers'
        x_a = f'ax_{ax}_abs_deg'
        y_a = f'ay_{ax}_abs_deg'
        z_a = f'az_{ax}_abs_deg'
        data[x_a] = [calc_angle_from_acceleration(row[x], row[r]) for idx, row in data.iterrows()]
        data[y_a] = [calc_angle_from_acceleration(row[y], row[r]) for idx, row in data.iterrows()]
        data[z_a] = [calc_angle_from_acceleration(row[z], row[r]) for idx, row in data.iterrows()]
    return data

if __name__ == "__main__":
    logging.basicConfig(level=logging.INFO)
    # This bit of python magic tells us the path to the directory of the current file.
    # This is useful because now we can reference where everything is relative to this
    # file.
    this_dir = os.path.realpath(os.path.dirname(__file__))
    raw_data_path = os.path.join(this_dir, 'rawdata')
    Trial = namedtuple('Trial', ['movement', 'l', 'r'])
    Processed = namedtuple('Processed', ['movement', 'l', 'lsom', 'leom', 'r', 'rsom', 'reom'])
    for datafile in glob.glob(os.path.join(raw_data_path, '*csv')):
        # Create a dedicated folder to save the processed data for this patient.
```

```
patient = datafile.split(os.sep)[-1].split('.')[0]
if patient == 'pn18':
    continue
logging.info(f"Processing data file:     {datafile}")
df = pd.read_csv(datafile) # Import into a dataframe.
# df = relabel_acceleration_axes(df)
counter = 0
w = 5
for trial, trialdata in df.groupby('trial'):
    logging.info(f"      Trial : {trial}")
    savepath = os.path.join(this_dir, 'processed', patient, f'trial_{trial}')
    if not os.path.exists(savepath):
        os.makedirs(savepath)


    for (movement, hand), test in trialdata.groupby(['movement','hand']):
        if hand == 'R':
            right = copy.deepcopy(test)
        else:
            left = copy.deepcopy(test)

    t = Trial(movement, left, right)
    fig = make_subplots(rows=1, cols=2)
    for hand, test in [('L', t.l), ('R', t.r)]:
        logging.info(f"     Movement No. {t.movement}, (Higgins JPT) Hand")
        result = pd.DataFrame()
        mw = pd.DataFrame()
        if hand == 'R':
            col = 2 # The right plot.
        else:
            col = 1 # The left plot.
        logging.info("      Calcualting IMU starting position...")
        xref, yref, zref, axref, ayref, azref = calc_starting_position(test)
        axzref = np.arctan2(xref,zref)
        ayzref = np.arctan2(yref,zref)
        rref = np.sqrt(xref**2 + yref**2 + zref**2)

        for idx, row in test.iterrows():
            if idx == test.index[0]:

                dt = 0
                rx, ry, rz = calc_normalised_acceleration_vectors(row)
                r = np.sqrt(rx**2 + ry**2 + rz**2)
                z = row.az

                estaxz = np.arctan2(xref, zref)
                estayz = np.arctan2(yref, zref)

                rxgref, rygref, rzgref =
resolve_component_vectors_from_planar_position(estaxz, estayz,
        np.sign(z))
                rg = np.sqrt(rxgref**2 + rygref**2 + rzgref**2)
                axgref = calc_angle_from_acceleration(rxgref, rg)
                aygref = calc_angle_from_acceleration(rygref, rg)
                azgref = calc_angle_from_acceleration(rzgref, rg)
```

```
            result_row = {
                't' : row.t,
                'dt_ms' : dt, # The timestep between this measurement and the previous
measurement, in ms
                'rx_acc_abs_mpers' : xref,
                'ry_acc_abs_mpers' : yref,
                'rz_acc_abs_mpers' : zref,
                'r_acc_abs_mpers' : r,
                'rx_gyro_abs_mpers' : rxgref,
                'ry_gyro_abs_mpers' : rygref,
                'rz_gyro_abs_mpers' : rzgref,
                'r_gyro_abs_mpers' : rg,
                'ax_acc_abs_deg' : axref,
                'ay_acc_abs_deg' : ayref,
                'az_acc_abs_deg' : azref,
                'ax_gyro_abs_deg' : axgref,
                'ay_gyro_abs_deg' : aygref,
                'az_gyro_abs_deg' : azgref,
                'axz_est_abs_deg' : estaxz,
                'ayz_est_abs_deg' : estayz
            }
            result = result.append(result_row, ignore_index=True)

        else:
            dt = (row.t - test.loc[idx-1].t) * 1e-3 # in seconds
            if dt == 0:
                dt = 0.001

            rx, ry, rz = calc_normalised_acceleration_vectors(row)
            r = np.sqrt(rx**2 + ry**2 + rz**2)

            signz = np.sign(z) # Get the polarity of the z axis acceleration from the
previous time step
            signz = 1
            estaxz += row.gy * dt
            estayz += row.gx * dt
            rxg, ryg, rzg = resolve_component_vectors_from_planar_position(estaxz,
estayz, signz)
            rg = np.sqrt(rxg**2 + ryg**2 + rzg**2)

            z = row.az # Update z for the next time step

            result_row = {
                't' : row.t,
                'dt_ms' : dt,
                'rx_acc_abs_mpers' : rx,
                'ry_acc_abs_mpers' : ry,
                'rz_acc_abs_mpers' : rz,
                'r_acc_abs_mpers' : r,
                'rx_gyro_abs_mpers' : rxg,
                'ry_gyro_abs_mpers' : ryg,
                'rz_gyro_abs_mpers' : rzg,
                'r_gyro_abs_mpers' : r,
                'ax_acc_abs_deg' : calc_angle_from_acceleration(rx, r),
```

```
            'ay_acc_abs_deg' : calc_angle_from_acceleration(ry, r),
            'az_acc_abs_deg' : calc_angle_from_acceleration(rz, r),
            'ax_gyro_abs_deg' : calc_angle_from_acceleration(rxg, rg),
            'ay_gyro_abs_deg' : calc_angle_from_acceleration(ryg, rg),
            'az_gyro_abs_deg' : calc_angle_from_acceleration(rzg, rg),
            'axz_est_abs_deg' : estaxz,
            'ayz_est_abs_deg' : estayz
        }
        result = result.append(result_row, ignore_index = True)
    som, eom = get_labels(patient, trial, t.movement, hand)
    result = match_acc_gyro_orientation(result, eom)
    result = calc_combined_estimate(result)
    if hand == 'L':
        left_result = result
        left_eom = eom
        left_som = som
    elif hand == 'R':
        right_result = result
        right_eom = eom
        right_som = som

right_result = match_acceleration_left_right_orientation(left_result, left_eom,
right_result, right_eom)
right_result = match_angular_position_left_right_orientation(left_result, left_eom,
right_result, right_eom)
savefile = os.path.join(savepath, f'R_movement{t.movement}.csv')
right_result.to_csv(savefile)
savefile = os.path.join(savepath, f'L_movement{t.movement}.csv')
left_result.to_csv(savefile)
```

Appendix 5B: Statistical analysis python code

```
import pandas as pd
import scipy.stats as scp
from sklearn import linear_model
import statsmodels.api as sm
from pearson import pearsonr_ci
import numpy as np
from scipy import stats

def pearsonr_ci(x,y,alpha=0.05):
    r, p = stats.spearmanr(x,y)
    r_z = np.arctanh(r)
    se = 1/np.sqrt(x.size-3)
    z = stats.norm.ppf(1-alpha/2)
    lo_z, hi_z = r_z-z*se, r_z+z*se
    lo, hi = np.tanh((lo_z, hi_z))
    return r, p, lo, hi

# read in dataframe of means of match errors
df_2 = pd.read_csv("means_match_error.csv")

# Store individual dataframes of each movement
mvmt_1 = df_2.loc[df_2['movement']==1]
mvmt_2 = df_2.loc[df_2['movement']==2]
mvmt_3 = df_2.loc[df_2['movement']==3]
mvmt_4 = df_2.loc[df_2['movement']==4]
mvmt_5 = df_2.loc[df_2['movement']==5]
mvmt_6 = df_2.loc[df_2['movement']==6]
mvmt_7 = df_2.loc[df_2['movement']==7]
# combine dataframes for analysis
movement_list = [mvmt_1, mvmt_2, mvmt_3, mvmt_4, mvmt_5, mvmt_6, mvmt_7]
col_list = df_2.columns
col_list = [col_list[5:-1]]

# Run Spearman's correlations on each UL-PPA test - Example of one only
for movement in movement_list:
    pearsonr_ci(movement['error_mean'], movement['shirt'])
```

Appendix 6

Appendix 6A: COREQ items

Developed from:
Tong A, Sainsbury P, Craig J. Consolidated criteria for reporting qualitative research (COREQ): a 32-item checklist for interviews and focus groups. *International Journal for Quality in Health Care*. 2007. Volume 19, Number 6: pp. 349 – 357

No. Item	**Guide questions/description**	**Reported on Page #**
Domain 1: Research team and reflexivity		
Personal Characteristics		
1. Inter viewer/facilitator	Which author/s conducted the inter view or focus group?	Chapter 6, P118
2. Credentials	What were the researcher's credentials? E.g. PhD, MD	Chapter 6, P118
3. Occupation	What was their occupation at the time of the study?	Chapter 6, P118
4. Gender	Was the researcher male or female?	N/A
5. Experience and training	What experience or training did the researcher have?	Chapter 6, P118
Relationship with participants		
6. Relationship established	Was a relationship established prior to study commencement?	N/A
7. Participant knowledge of the interviewer	What did the participants know about the researcher? e.g. personal goals, reasons for doing the research	Chapter 6, P118
8. Interviewer characteristics	What characteristics were reported about the inter viewer/facilitator? e.g. Bias, assumptions, reasons and interests in the research topic	Chapter 6, P118
Domain 2: study design		
Theoretical framework		
9. Methodological orientation and Theory	What methodological orientation was stated to underpin the study? e.g. grounded theory, discourse analysis, ethnography, phenomenology, content analysis	Chapter 6, P115
Participant selection		
10. Sampling	How were participants selected? e.g. purposive, convenience, consecutive, snowball	Chapter 6, P115
11. Method of approach	How were participants approached? e.g. face-to-face, telephone, mail, email	Chapter 6, P116
12. Sample size	How many participants were in the study?	Chapter 6, P120-121
13. Non-participation	How many people refused to participate or dropped out? Reasons?	Chapter 6, P121
Setting		
14. Setting of data collection	Where was the data collected? e.g. home, clinic, workplace	Chapter 6, P115
15. Presence of non-participants	Was anyone else present besides the participants and researchers?	N/A
16. Description of sample	What are the important characteristics of the sample? e.g. demographic data, date	Chapter 6, P120, P121
Data collection		
17. Interview guide	Were questions, prompts, guides provided by the authors? Was it pilot tested?	Chapter 6, P118
18. Repeat interviews	Were repeat inter views carried out? If yes, how many?	N/A
19. Audio/visual recording	Did the research use audio or visual recording	Chapter 6, P118

	to collect the data?	
20. Field notes	Were field notes made during and/or after the inter view or focus group?	Chapter 6, P118
21. Duration	What was the duration of the inter views or focus group?	Chapter 6, P118
22. Data saturation	Was data saturation discussed?	N/A
23. Transcripts returned	Were transcripts returned to participants for comment and/or correction?	Chapter 6, P118
Domain 3: analysis and findings		
Data analysis		
24. Number of data coders	How many data coders coded the data?	Chapter 6, P119
25. Description of the coding tree	Did authors provide a description of the coding tree?	Appendix 6D
26. Derivation of themes	Were themes identified in advance or derived from the data?	Chapter 6, P119-120
27. Software	What software, if applicable, was used to manage the data?	Chapter 6, P120
28. Participant checking	Did participants provide feedback on the findings?	N/A
Reporting		
29. Quotations presented	Were participant quotations presented to illustrate the themes/findings? Was each quotation identified? e.g. participant number	Chapter 6, P125, 126
30. Data and findings consistent	Was there consistency between the data presented and the findings?	Chapter 6, P124-126
31. Clarity of major themes	Were major themes clearly presented in the findings?	Chapter 6, P125, 126
32. Clarity of minor themes	Is there a description of diverse cases or discussion of minor themes?	N/A

Appendix 6B: Education slides

- Unilateral neglect (UN) is an umbrella term for a range of clinical presentations
- Characterised by a failure to respond or orient to stimuli presented on the side opposite to a brain lesion (Wee and Hopman 2008)
- Estimated to affect 23.5% to 67.8% of people after stroke (Ringman, Saver et al. 2004, Chen, Chen et al. 2015)

3

linked to:

- greater length of hospital stay
- higher incidence of falls
- reduced likelihood of home as a discharge destination (Di Monaco, Schintu et al. 2011, Chen, Chen et al. 2015, Bosma, Nijboer et al. 2019)

Symptoms persist at one-year post stroke in 30-60% of patients (Cherney and Halper 2001, Karnath, Rennig et al. 2011, Nijboer, Kollen et al. 2013)

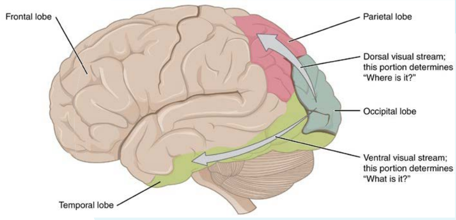
4

UN is not the result of lesions in a single location

Instead, it is due to impaired functional connectivity between brain regions associated with:

- attention
- sensorimotor and visual processing

(Doricchi and Tomaiuolo 2003, He, Snyder et al. 2007, Smith, Clithero et al. 2013).



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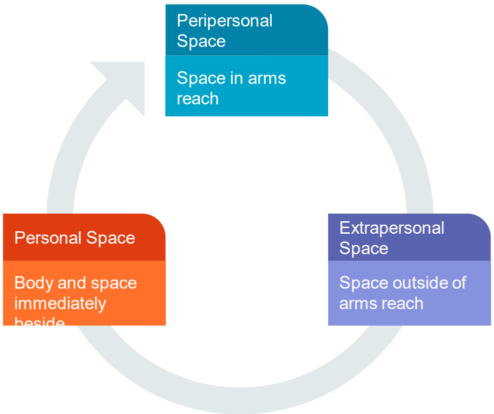
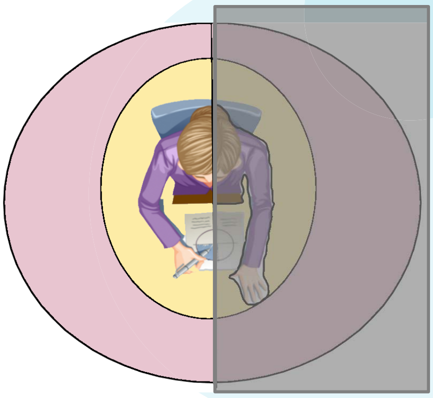
Because of this, unilateral neglect can affect multiple spaces:





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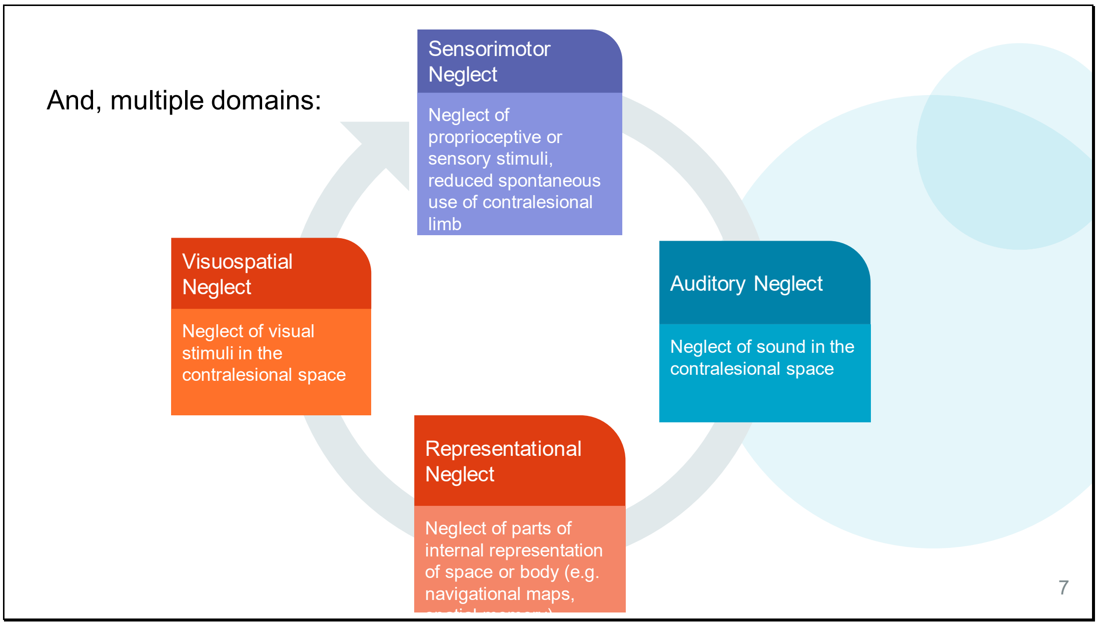
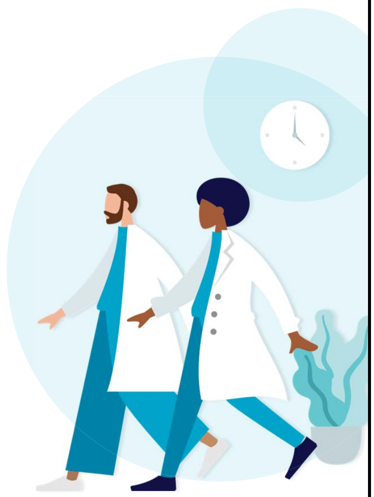

And, multiple domains:
Sensorimotor Neglect
Neglect of proprioceptive or sensory stimuli, reduced spontaneous use of contralesional limb
Visuospatial Neglect
Neglect of visual stimuli in the contralesional space
Auditory Neglect
Neglect of sound in the contralesional space
Representational Neglect
Neglect of parts of internal representation of space or body (e.g. navigational maps,
7


So, to assess unilateral neglect comprehensively it is important to assess in as many domains and spaces as possible
8

2 Unilateral Neglect

Assessment Options



- Stroke Foundation Guidelines recommend "***assessment of UN using a standardized outcome measure***" – however do not specify which
- A recent review found 62 published Ax tools for UN, of which 28 are standardized (11)
- Of the 28 standardised Ax tools:
  - 20 Ax near extra-personal space in isolation
  - 2 Ax personal neglect in isolation,
  - 5 tools combine Ax of two separate hemi-spaces
  - 1 attempts to assess UN in all domains and hemispaces

10

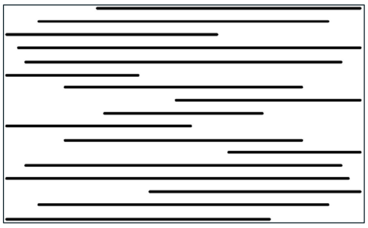
- Lots of non-comprehensive assessment tools -> clinicians recommended to use multiple Ax tools
- However, in clinical practice this is often not feasible
- The remainder of the presentation will give an ***overview of the different options*** available to clinicians to allow you to ***choose the ones that best suit your clinical practice***

11

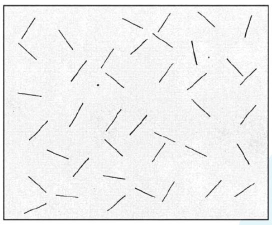
Tests for Peripersonal UN

- Most commonly used assessments in the literature = pen and paper tasks or BIT
- Examples:
  - Star Cancellation
  - Line Cancellation (Albert's Test)
  - Line Bisection
  - Bell's Test
  - Behavioural Inattention Test (BIT)
- Patients are required to cancel out a certain type of stimulus in a page with a combination of stimulus + distractors

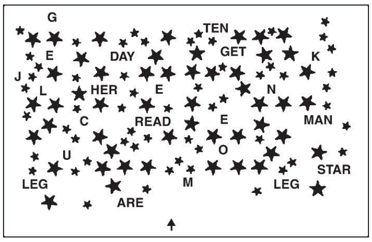
12



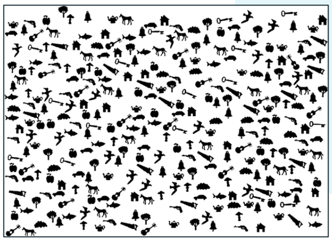
Line Bisection



Line Cancellation



Star Cancellation



Bells Test

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Pen + Paper Tasks

- Pros:
  - Quick and simple to administer
  - Good test – retest reliability
  - Minimal equipment
- Cons:
  - Not functional + poor correlation with functional outcomes (Nijboer and Van Der Stigchel 2019)
  - Shown to allow for compensation (Bonato 2012)
  - Results have been shown to be influenced by non-spatial factors (Huygelier H, Gillebert CR, 2020)
  - Assess only peripersonal and visuospatial aspects of UN (Menon, 2008)

14

Behavioural Inattention Test (BIT)

Conventional subtests (6): Line crossing, letter and star cancellation, figure and shape copying, line bisection, and representational drawing

Behavioral subtests (9): Picture scanning, telephone dialling, menu reading, article reading, telling and setting time, coin sorting, address and sentence copying, map navigation, card sorting

Scoring: Max. and cut-off scores to indicate USN:
- Conventional subtests: 129 out of 146;
- Behavioral subtests: 67 out of 81
- Total test: 196 out of 22

15

Behavioural Inattention Test (BIT)

- Pros:
  - Multiple tests have higher chance of capturing UN
  - Includes functional tasks
  - Inter-rater + test-retest reliability = 99% agreement
- Cons:
  - Only upper limb tasks, all seated
  - 40 mins to administer
  - Licenced -> Test needs to be purchased ($729)
  - Only peripersonal UN assessed

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Tests for Personal Neglect

- Personal and extra / peri - personal neglect frequently co-occur
  - recent study: 85% of people with UN showed personal neglect associated with extrapersonal neglect
- Examples:
  - Comb and Razor Test
  - Vest Test / Fluff Test

17

Comb + Razor:

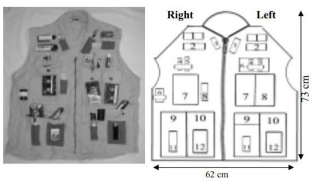
Patient is asked to demonstrate the use of two common objects for 30 seconds each: comb, razor, and powder compact. Each object is placed at the patient's midline.

Scoring: The number of strokes with the razor, comb, or powder compact that are performed on the left, right, or ambiguously is recorded to calculate a mean percentage score for the three categories. A score less than 0.35 indicates USN.

Vest Test

The blindfolded patient wears a vest and is instructed to pick up all objects from the 24 pockets of the vest (12 on each side) as quickly as possible using the ipsilesional, nonparetic hand.

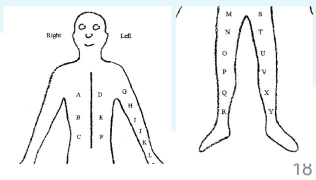
Scoring: < 9 objects on the contralesional side of the vest in 210 seconds indicates UN.



Fluff Test

24 identical circles (2 cm in diameter) attached to clothes with Velcro. Patients asked to remove all the targets attached to the front of their clothes

Scoring: <13 stickers detached out of 15 indicates UN



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Tests of Personal Neglect

- Pros:
  - More functional than pen and paper
  - Quick and easy to administer
- Cons:
  - Assess only personal aspects of UN (Menon, 2008)
  - Significantly different %'s of patients show UN on Vest and Fluff Tests -> ? Issues with validity (Caggiano, 2018)
  - Comb and Razor Test only includes facial region, which may not be as affected by the symptoms of UN as other body regions (Caggiano, 2018)

19

Tests for Extrapersonal Neglect

- Specific tests only recently starting to be developed
- Examples:
  - Dublin Extrapersonal Neglect Assessment (DENA) (Cunningham, 2017)
  - Virtual Lateralised Attention Test

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DENA

- 30m long corridor with 20 red diamonds spaced on right and left side
- patient asked to walk / wheel down corridor and ID diamonds

- **Scoring:**
  - count of number of omitted diamonds on contralateral (affected) and ipsilateral (unaffected) sides
  - omission of ≥ 2 indicates the presence of extrapersonal neglect

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DENA

- Pros:
  - Quick and simple to administer
  - Functional + rehab relevant
  - Inter-rater reliability = almost perfect agreement.

- Cons:
  - Only extrapersonal neglect assessed
  - 90% of patients who showed extrapersonal +ve on CBS-E (discussed later in presentation) were identified by DENA as having UN -> ? Additional value

22

Virtual Lateralised Attention Task

- Patients travel along a virtual, non-branching path, either:
  - via computer joystick or,
  - passively viewing the environment while the examiner is navigating
- Asked to name + avoid collisions with virtual objects in 3 conditions:
  - simple (20 target objects)
  - complex (20 additional common outdoor objects)
  - enhanced (8 additional auditory distractors)

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Virtual Lateralised Attention Task

- Pros:
  - significant correlations with personal neglect measure (r = .41), Bells Test cancel left (r = .43)
  - 5 – 10 mins to administer
  - Functional real world relevant task accessible to patients who are non-ambulant
- Cons:
  - equally likely to categorise patients with and without visual deficits as having neglect
  - Joystick and computer required
  - Extrapersonal + representational neglect only assessed

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Tests for Multiple Aspects of UN

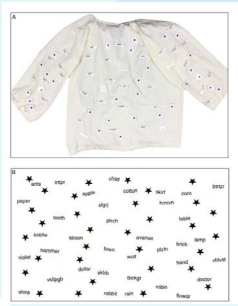
- In response to the acknowledgement of the difficulty conducting multiple tests in clinical practice, tests aiming to assess multiple aspects of UN have started to be developed
- Examples:
  - Halifax Visual Scanning Test
  - Catherine Bergego Scale / Kessler Neglect Assessment

Halifax Visual Scanning Test

Aims to capture visuospatial neglect in all three hemi-spaces, 2 min time limit

Patients are instructed to “look all over the [shirt, table, or wall] and read aloud as many real words as you can find” in a 2-min time limit.

Stimuli presented in 3 ways
1) similar to vest test, stimuli on shirt
2) similar to star cancellation, stimuli on paper
3) on wall in front of patient



Halifax Visual Scanning Test

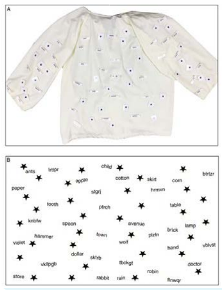
Scoring: < 14 items correctly identified for shirt subtest and < 22 for paper and wall subtests indicates UN

Pros:

- Assesses in all 3 hemi-spaces
- Quick and simple to administer
- identified more stroke patients as exhibiting symptoms of UN than pen and paper tests

Cons:

- Non functional assessment
- Only assesses visuospatial aspects



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Catherine Bergego Scale

Observation of the patient in 10 everyday activities:

- Knowledge of left limbs
- Dressing
- Safe mobility
- Grooming
- Eating
- Personal belongings
- Gaze orientation
- Auditory attention
- Spatial orientation
- Mouth cleaning

Scoring: Each item is on a 4-point scale where 0 is no presence of neglect; 1 is mild neglect, 2 is moderate neglect, and 4 is severe neglect. Specific criteria for each score are given.

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Catherine Bergego Scale

- Has been further structured into the Kessler Foundation Neglect Assessment Process (KF-NAP)

KF-NAP™ Scoring Sheet

Date:_____________ Name of Examinee:_________________________

Time:_________ am/pm Examiner(s):_____________________________

Kessler Foundation Neglect Assessment Process (KF-NAP™)

How to use the Catherine Bergego Scale to assess spatial neglect

	Category	0 no neglect	1 mild neglect	2 moderate neglect	3 severe neglect	NA (provide reasons)
1	Gaze orientation					
2	Limb awareness					
3	Auditory attention					
4	Personal belongings					
5	Dressing					
6	Grooming					
7	Navigation					
8	Collisions					
9	Meals					
10	Cleaning after meals					

Neglected side (circle one): ***left-sided*** spatial neglect ***right-sided*** spatial neglect

Sum of assigned scores: _______________ / Number of scored categories: × 10 = **Final score** __________

Score Assignment

Score = 3 The patient is easily able to direct his gaze toward the right side of space but does not attempt to orient the eyes toward the left side.

Score = 2 There are constant and clear asymmetries in the gaze direction toward the left and right sides of space. The patient explores the environment by looking toward the right first, and after a long delay, slowly looks toward the left. During the entire session, the patient spends much more time looking to his right side.

Score = 1 There are inconsistent but observable asymmetries in the gaze direction toward the left and right sides of space. The patient explores an environment by looking toward the right first, and then slowly toward the left with some hesitation. During the entire session, the patient looks toward the right more often than the left.

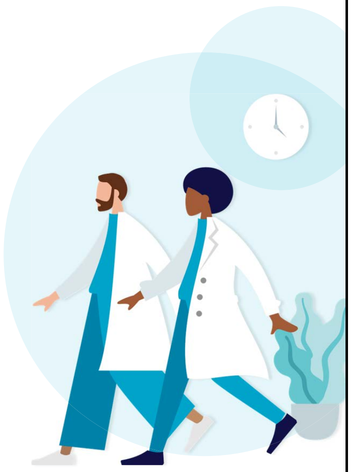
Score = 0 The patient spontaneously directs his/her gaze toward the right and left sides of space without hesitation and without any prompting.

KF-NAP

- Pros:
  - Functional tasks of upper and lower limbs
  - Attempts to measure of all aspects of UN (Menon, 2008)
  - Items are all commonly performed in PT / OT assessments / sessions
  - Includes motor, auditory, visuospatial UN
  - Shown to be responsive to patient improvement (Samuel, Louis-Dreyfus, & Kaschel, 2000)
  - Can predict lower FIM discharge scores (Chen, 2015)
- Cons:
  - Higher degree of subjectivity than other measures

3 Unilateral Neglect

Other Issues / Research



JOURNAL OF CLINICAL AND EXPERIMENTAL NEUROPSYCHOLOGY
https://doi.org/10.1080/13803395.2020.1798881

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Increasing cognitive demand in assessments of visuo-spatial neglect: Testing the concepts of static and dynamic tests

Lauriane A. Spreij[a], Antonia F. Ten Brink[a,b,c], Johanna M.A. Visser-Meily[a,d] and Tanja C.W. Nijboer[a,e]

- Static = shape cancellation, line bisection, letter cancellation
- Dynamic = CBS / KF-NAP, Mobility Assessment Course, Simulated Driving
- Dissociations between patients between test types
  - 54% showed VSN on tests within both clusters
  - 33% only on tests within the dynamic cluster
  - 13% only on tests within the static cluster
- Confirmatory factor analyses showed distinction between static and dynamic tests

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Do Neglect Assessments Detect Neglect Differently?

Emily S. Grattan, Michelle L. Woodbury

OBJECTIVE. We determined whether various assessment tools detect neglect differently by administering a battery of assessments to people with stroke.

METHOD. We conducted a case series study and administered five neglect assessments (paper-and-pencil, functional, virtual reality) to participants poststroke.

RESULTS. Twelve participants (6 men, 6 women) with stroke completed the assessment battery, which required approximately 2 hr to administer (over one to two sessions). All participants demonstrated neglect on three or more assessments. Functional assessments and the virtual reality assessment detected neglect more frequently than the paper-and-pencil assessments. Participants performed differently on the paper-and-pencil assessments and functional assessments.

CONCLUSION. Because neglect is complex, detection may depend largely on the assessment administered.

Grattan, E. S., & Woodbury, M. L. (2017). Do neglect assessments detect neglect differently? *American Journal of Occupational Therapy, 71*, 7103190050. https://doi.org/10.5014/ajot.2017.025015

Table 4. Classification of Neglect by Assessment

ID	Paper-and-Pencil: BIT–cs	Functional: BIT–bs	Functional: CBS & NAT	Virtual Reality: VRLAT
01		X	X	X
02	X	X	X	X
03	X	X	X	X
04			X	X
05	X		X	X
06			X	X
07			X	X
08	X	X	X	X
09			X	X
10	X	X	X[a]	X
11			X	X
12	X	X	X	X
Total % of participants classified as having neglect	50.0	50.0	100.0	100.0

Note. An *X* indicates that assessment classified the participant as having neglect. BIT–bs = Behavioral Inattention Test behavioral subtests; BIT–cs = Behavioral Inattention Test conventional subtests; CBS = Catherine Bergego Scale; NAT = Naturalistic Action Test; VRLAT = Virtual Reality Lateralized Attention Test.
[a]Missing data for NAT but impaired on CBS.

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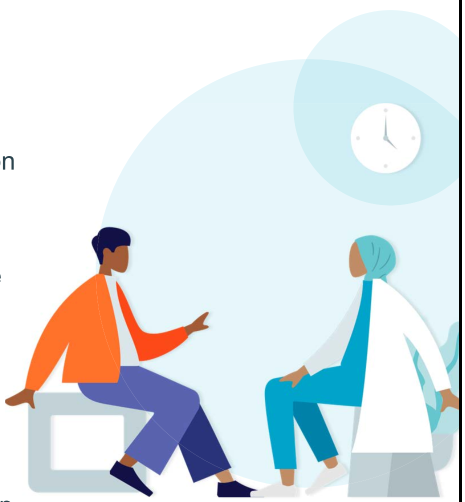
NEXT STEPS

- You will have access to this presentation and a resource pack of associated articles
- For the next three months, you are able to choose any of the assessments presented here in your clinical practice with stroke patients
- You can change assessment types at any time
- If you are participating in the study, keep a record of ones that you use and some



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Appendix 6C: Focus group question guide

Question	Probes	TDF Number
1. What are your initial thoughts on implementing standardised unilateral neglect assessment tools during the last two months?	- Did you feel that you knew how to implement standardised unilateral neglect assessment? - How difficult or easy was it for you to use? - What emotions or feelings do you have about standardised unilateral neglect assessment?	- Knowledge (1) vvv - Beliefs about capability (8) - Emotion (14)
2. Of the assessments available, which did you use in the study period?	- Was there an assessment tool that you preferred? - What made you choose the assessment tool that you used the most?	- Memory, attention, decision (3)
3. How well do you feel that standardised unilateral neglect assessment fits into your daily clinical practice?	- What do you think about the feasibility of its use in community / inpatient settings? - How likely are you to use a standardised unilateral neglect assessment in future? - What would prompt you to use a standardised unilateral neglect assessment? - Should standardised unilateral neglect assessment be part of your job?	- Optimism (9) - Intentions (11) - Memory, attention, decision (3) - Professional role (7)
4. What did you feel hindered the implementation of standardised unilateral neglect assessment?	- Did you feel that you had the clinical skills to use a standardised unilateral neglect assessment? - Did you feel like a lack of time in your clinical schedule limited your ability to use a standardised unilateral neglect assessment? - To what extent did physical factors associated with your workplace hinder your use of a standardised unilateral neglect assessment? For example, equipment available	- Skills (2) - Environmental context (5)
5. If you were to design a program to implement a standardised unilateral	- How would you monitor whether you are using a standardised unilateral neglect assessment with all new stroke admissions?	- Behavioural regulation (4) - Behavioural regulation (4)

neglect assessment in your workplace, which would you pick and what would this look like?	- What prompts would you put in place to remind clinicians to use a standardised tool? - What would motivate you to use a standardised unilateral neglect assessment? - Are there advantages/disadvantages to sharing the assessment components between disciplines?	- Reinforcement (13) - Professional role (7)
6. What can we do to increase the use of standardised unilateral neglect assessment in your setting?	- Is there anything that you would add or remove from the standardised unilateral neglect assessments that you used in the study period? - What additional skills / training would you require? - What is the role of other healthcare professionals in using standardised unilateral neglect assessments?	- Knowledge, skills (1, 2) - Social Influences (6)
7. Would you like to continue using a standardised unilateral neglect assessment in your clinical practice?	- How do you think you will continue to use it? - In an ideal world, how would you implement standardised unilateral neglect assessment in your practice? - What would be the consequences of not using it?	- Goals (12) - Goals (12) - Reinforcement (13)
8. The CBS / KF-NAP is the current 'gold standard' of clinical unilateral neglect assessment. What are your thoughts on it as an assessment tool?	- Did you trial the CBS / KF-NAP? - If you did, is there anything that you would add or take out to improve it? - What additional skills or training would you require? - Will you continue to use the CBS / KF-NAP in your clinical practice?	- Memory, attention, decision (3) - Goals (12) - Knowledge, skills (1, 2) - Goals (12)
9. Is there anything else that you would like to add about your experience of using standardised unilateral neglect assessments?		

Appendix 6D: Initial coding nodes

TDF Determinant	Sub-node(s)
Knowledge	▪ Lack of previous formal education ▪ Experiential knowledge ▪ Knowledge of assessment tools / condition
Skills	▪ Increased skill in assessing unilateral neglect ▪ Previous skill in assessing unilateral neglect
Social / professional role or identity	▪ Perception of assessment as own scope of practice ▪ Perception of assessment as other professions scope of practice
Beliefs about capabilities	▪ Capabilities of other colleagues ▪ Lack of confidence in own ability
Optimism	▪ General optimism about assessment tool
Beliefs about Consequences	▪ Positive consequences for patients ▪ Negative consequences for patients ▪ Positive consequences for practice
Reinforcement	▪ Positive experience with assessment tool
Intentions	▪ Intent to implement ▪ Unfulfilled intentions
Goals	▪ Team goals to use tool
Memory, attention and decision processes	▪ Perception of patient benefit ▪ Perception of assessment versatility ▪ Perceived ease of use ▪ Published validity and reliability
Environmental context / resources	▪ Caseload suitability ▪ Equipment / training / resources ▪ Infection control ▪ Setting infrastructure ▪ Standardised assessment forms ▪ Staffing ▪ Unforeseen circumstances ▪ Workload ▪ Limitations of assessment with complex patients
Social influences	▪ Team dynamics
Emotion	
Behavioural regulation	▪ Prompts and reminders
Other	▪ Recommendations for assessment tool ▪ Recommendations for future implementation

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